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Routing, WA, Planning and Transmission Nonlinear Effects in Wideband Optical Networks

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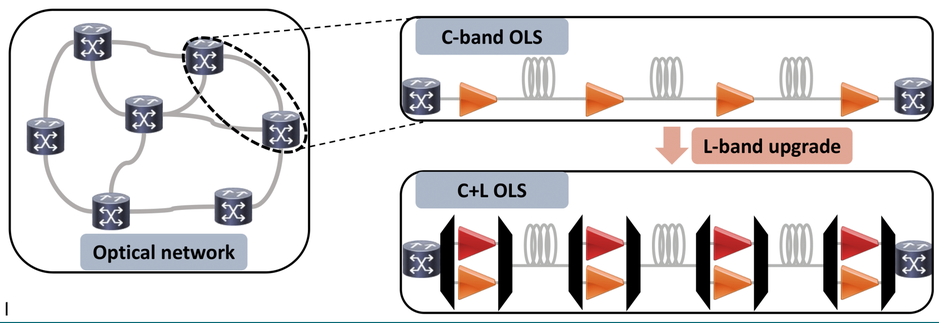
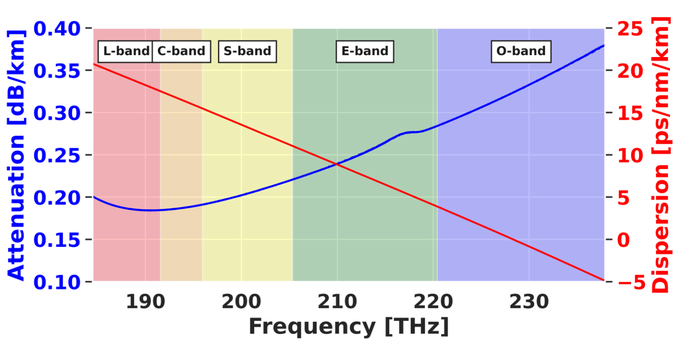
Research context and motivation

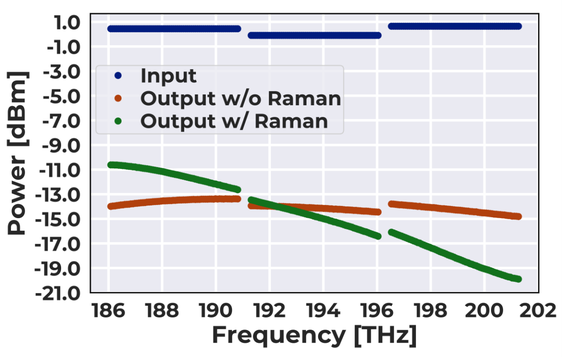
- The capacity increase of optical networks is a topic of high importance in the scientific community and industry. This topic has become relevant due to the challenges that have arisen from growing transport network traffic demands, which include imminent deployment of 5G services and the constant growth of IP traffic, cloud computing, and interconnections between data centers;
- In order to cope with the continuous increase in traffic demand required from backbone optical network, multi-band transmission (MBT) systems emerges as a viable short/mid-term solution to deal with this demand, relying on increasing the used fiber bandwidth, which nowadays are based on C-band transmission using around 4.8 THz, which can be extended to more than 50 THz from L- to O-band;
- This solution is based on upgrading the optical line systems (OLS) in an optical network, such as amplifiers and ROADMs, capable to deal with this higher bandwidth usage, without the deployment of new fiber infrastructure.



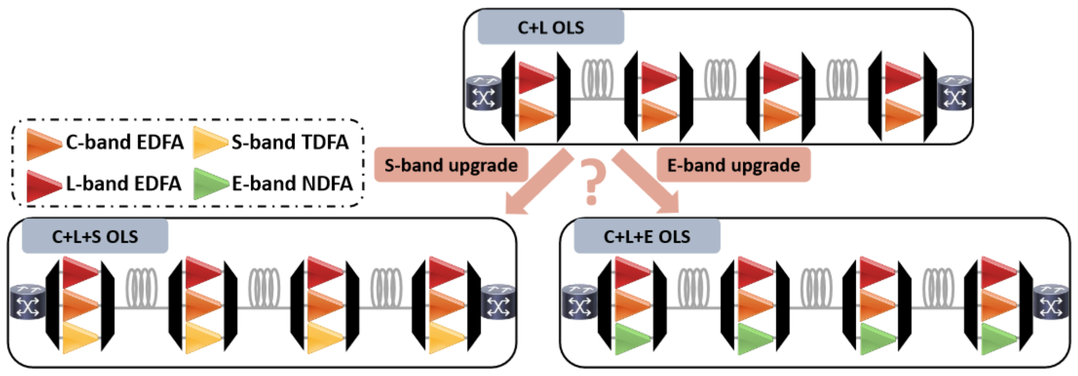
Addressed research questions/problems

- In order to properly model a MBT system, several aspects need to be considered, which can be neglected in a C-band only transmission;
- The first consideration is the fiber parameters, which vary significantly when the used bandwidth is extended, such as attenuation, chromatic dispersion, and nonlinear coefficient;
- Secondly, we need to consider the stimulated Raman scattering (SRS), a nonlinear transmission affect that induces a power transfer from higher to lower frequencies;



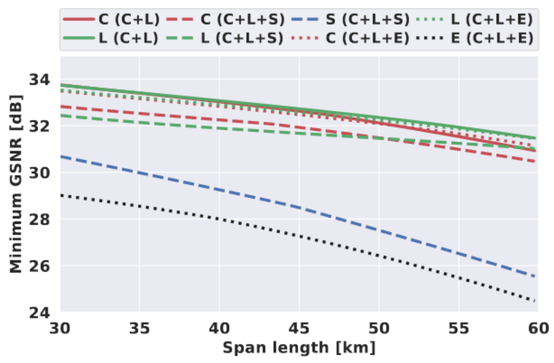


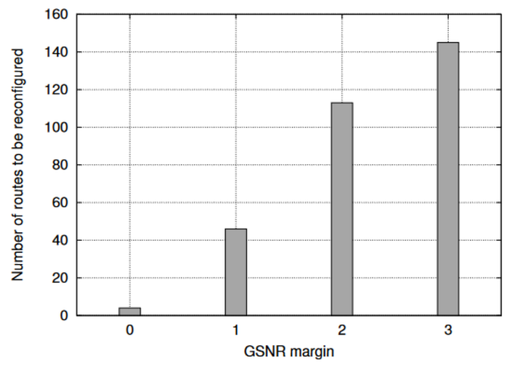
- Lastly, the amplifiers characteristics, mainly the noise-figure, needs to be considered per band/frequency, as each technology which the devices are made presents aspects which change its performance;
- Considering all these aspects, an important question raise: How the MBT upgrade can be made in order to maximize the delivered traffic increase? How can we minimize the impact in already running C+L systems? How can we minimize the costs of such upgrades?



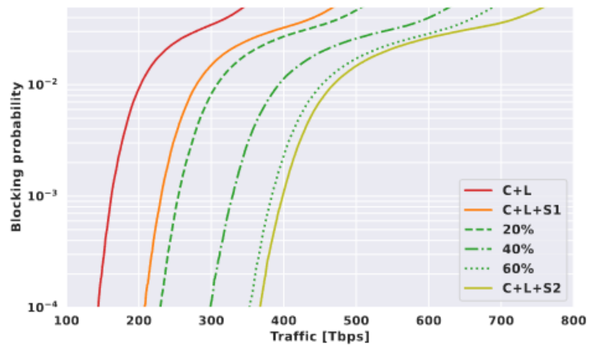
Methodologies and novel contributions

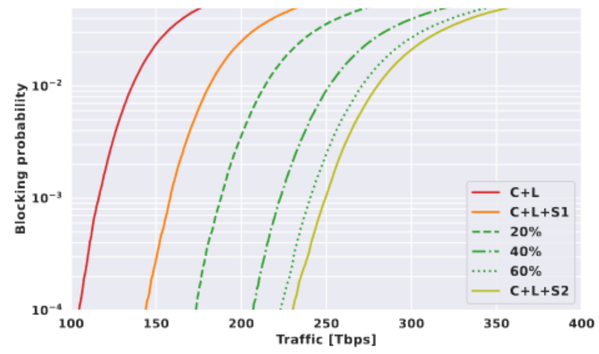
- Our analysis were performed using the open-source GNPy in order to compute the OLS quality of trasmission (QoT) using the generalized Gausian-noise model (GGN), which considers the fundamental interaction between the nonlinear interference (NLI) generation and SRS, and the generalized signal-to-noise ratio (GSNR) as metric;
- Starting from a C- and L-bands scenarios with 54 and 92 channels, respectively, following a 75 GHz WDM grid and symbol rate of 64 GBaud, we compared two MBT upgrades: add the S-band or the E-band with 125 and 146 channels, respectively. Our results shows that add the E-band with 14 THz of spacing from the already up-and-running C+L system has a minimal impact on it and, even with lower GSNR, can provide a compareble capacity, due to the larger bandwidth which can support more channels.
- We also show the number of lightpaths that needs reconfiguration (Change to less efficient modulation formats due to the GSNR threshold value) for the Spanish backbone network topology if we use the S-band upgrade.

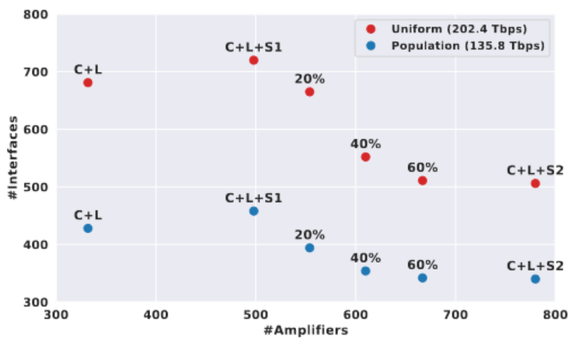




- We performed another network analysis regarding the deployment of new amplification sites (allocation based on the network route space to prioritize the deployment) in order to increase the QoT levels of lower performance bands (In our case S-band of a C+L+S scenario) for the Italian topology.







Future work

- Continue the investigation for the MBT upgrade strategies regarding capacity increase and costs for other network topologies, adding the possibility to upgrade only part of the networks with different number of channels/bands;
- Investigate the usage of machine learning in network design/operation for MBT systems;
- Development of a heuristic to optimize the input power profile (first/second year results) for MBT considering the SRS, presenting a tradeoff between computational effort and accurancy.

Submitted and published works

- Correia, B. et al., C., "*Power control strategies and network performance assessment for C+L+S multiband optical transport,* J. Opt. Commun. Netw., vol. 13, no. 7, 2021, pp. 147-157
- Sambo, N. et al., C., "*Network upgrade exploiting multi band: S- or E-band?*", J. Opt. Commun. Netw., vol. 14, no. 9, 2022, pp. 749-756
- Sadeghi, R. et al., "*Transparent vs Translucent Multi-Band Optical Networking: Capacity and Energy Analyses*", J. Lightwave Technol., vol. 40, no. 11, 2022, pp. 3486-3498
- D'Amico, A. et al., "*Scalable and Disaggregated GGN Approximation Applied to a C+L+S Optical Network*", J. Lightwave Technol., vol. 40, no. 11, 2022, pp. 3499—3511
- Conferences publications including OFC, GLOBECOM, ECOC, SUM, ONDM, IPC and others, between 2020 and 2022.

List of attended classes

- 01REKRV – Coherent detection: a revolution in optical communication (2020, 50)
- 01UJARV – Data science for networks (2020, 26.67)
- 01QSAIU – Heuristics and metaheuristics for problem solving: new trends and software tools (2020, 26.67)
- 01QFFRV – Tecniche innovative per l'ottimizzazione (2020, 33.33)
- 01TRLRV – Optical Transport Networks (2022, 30)
- Soft skill courses: Entrepreneurial Finance (01SHMRV), Project management (08IXTRV), Public speaking (01RISRV), Research integrity (01SYBRV), Responsible research and innovation, the impact on social challenges (01SWQRV), Time management (01SWPRV).

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