XXXV Cycle

Transparent vs Translucent multi-band optical networking: capacity and energy analyses

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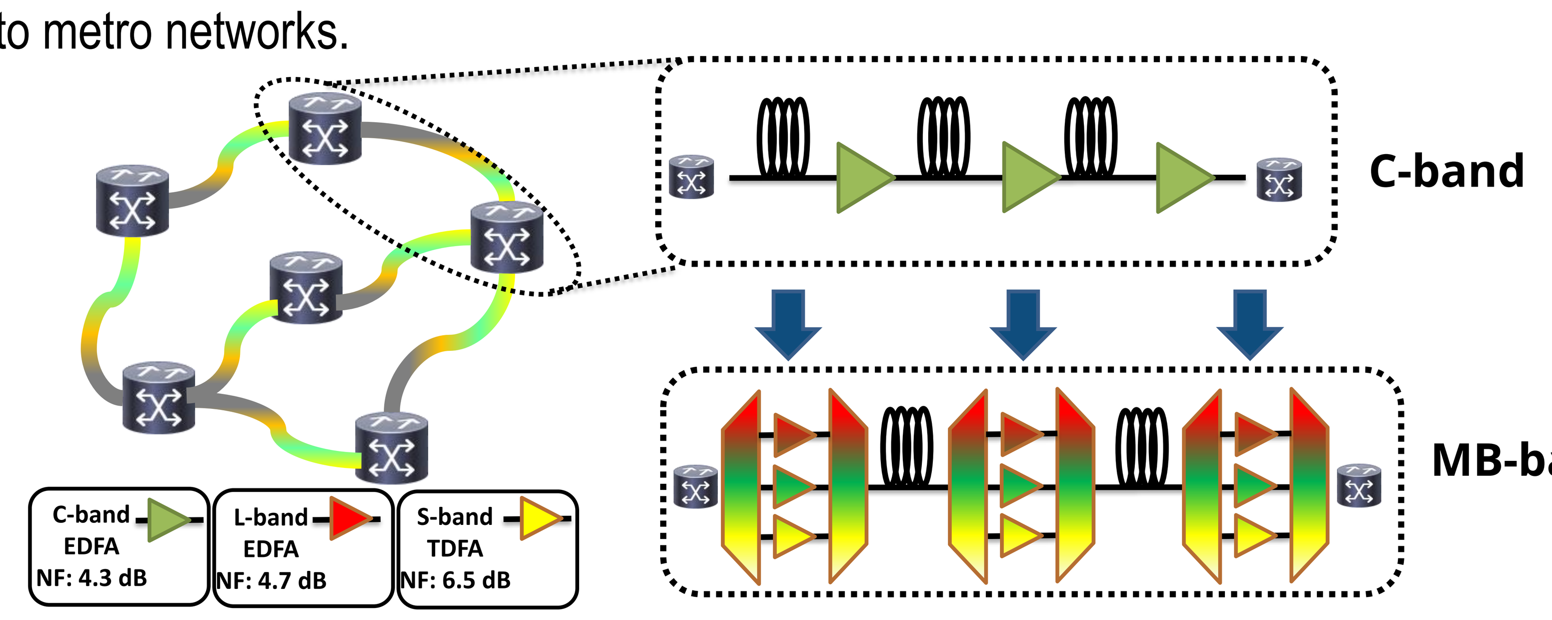
Research context and motivation

- The reliance of our modern society on the Internet has only grown stronger over the years. Wavelength division multiplexing (WDM) that exploits only the C-band with a bandwidth of ≅ 4.8 THz is currently the most commonly deployed and cost-effective solution for transmitting the required data in optical networks, ranging from very long-haul/submarine to metro networks.



- Multi-band optical fiber transmission (MBT) is a natural solution to cope with the increasing request of capacity, as it requires fewer changes to existing optical fiber infrastructures. This solution implements transmission over a wider spectral range within the low-loss region of the widely deployed single-mode optical fibers, namely the ITU-T G.652.D type, exceeding a total transmission bandwidth of ≈ 50 THz.

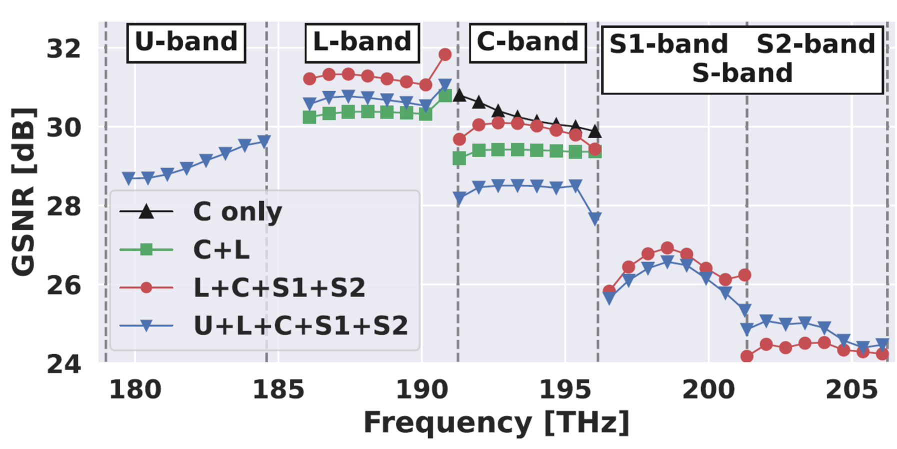
Addressed research questions/problems

- Two main solutions for increasing the network capacity proposed and compared in terms of capacity, energy consumption, costs, and link congestions: (i) using MBT systems in the C-, C+L-, C+L+S, and C+L+S+U-band , (ii) using signal regeneration in the intermediate nodes (translucent network design).
- The accurate modeling of signal propagation along an optical fiber, especially in MBT scenarios the QoT at the end of each fiber span for the i_{th} channel is computed using the generalized signal-to-noise ratio (GSNR):

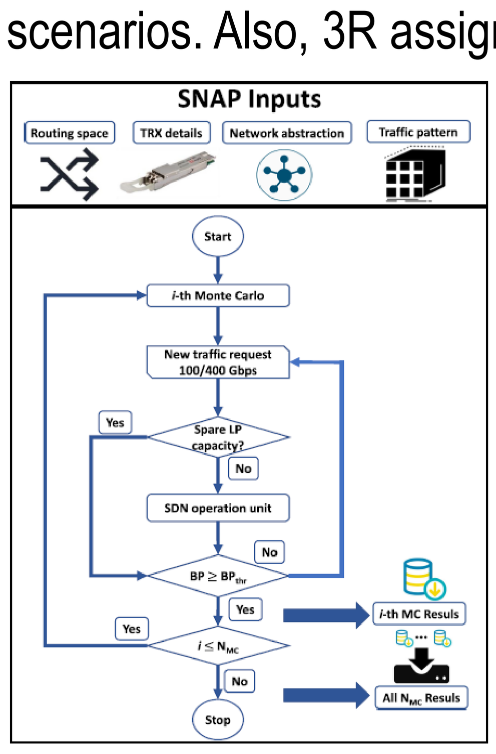
$$\mathrm{GSNR}_i = \frac{P_{S,i}}{P_{\mathrm{ASE},i} + P_{\mathrm{NLI},i}} = \left(\mathrm{OSNR}_i^{-1} + \mathrm{SNR}_{\mathrm{NL},i}^{-1}\right)^{-1}$$

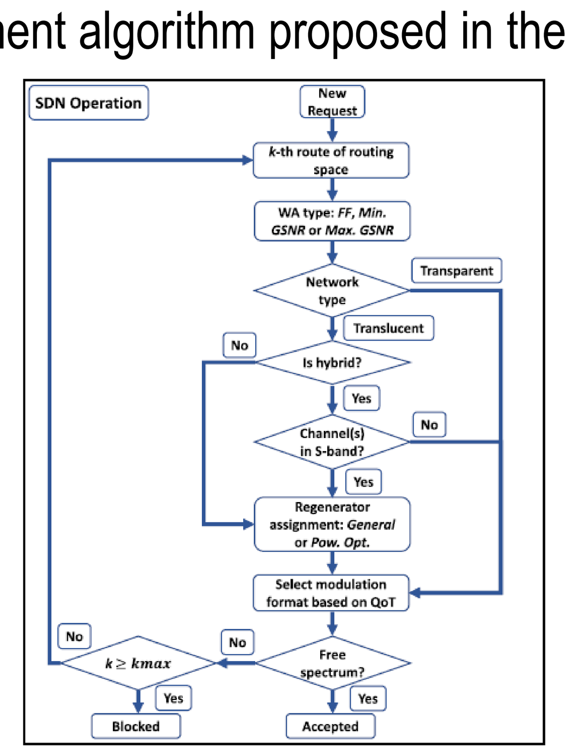
$$P_{\mathrm{ASE},i} = h f_i \mathrm{NF}(f_i) G(f_i) B_{\mathrm{ref}},$$

band	U	L	C	S1	S2
GSNR	–	–	30.25	–	–
	–	30.37	29.38	–	–
	–	31.28	29.94	26.48	24.38
	29.08	30.69	28.42	26.13	24.79



- Above figure depicts the GSNR profile after transmission of 64 channels with symbol rate of 64 GBaud in the 75 GHz WDM grid along a single 75 km ITU-T G.652D optical fiber span. The network evaluation is performed using the statistical network assessment process (SNAP) framework, which uses the GSNR as the QoT metric. The SNAP framework has been customized to cover both transparent and translucent network design scenarios. Also, 3R assignment algorithm proposed in the below (General Algorithm).





Algorithm 1: General Translucent Algorithm.

Input: Channel (ch), source / destination route path ($path_{tot}$), list of RGSNR for all modulation formats (RGSNR_{list})

Output: LP regeneration paths ($path_{reg}$)

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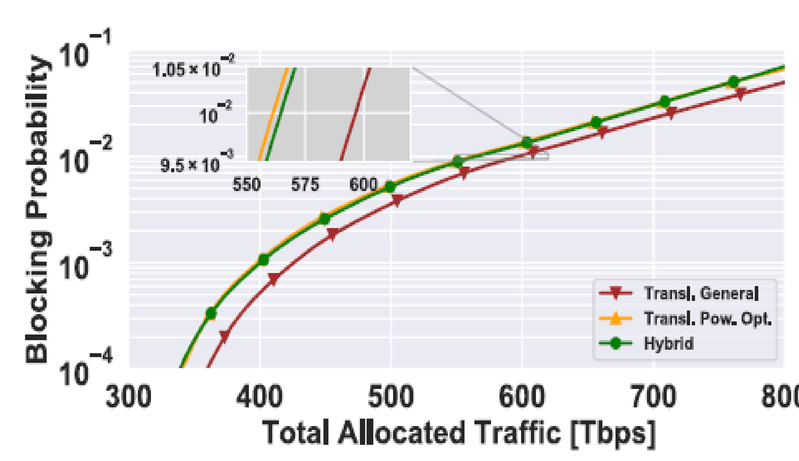
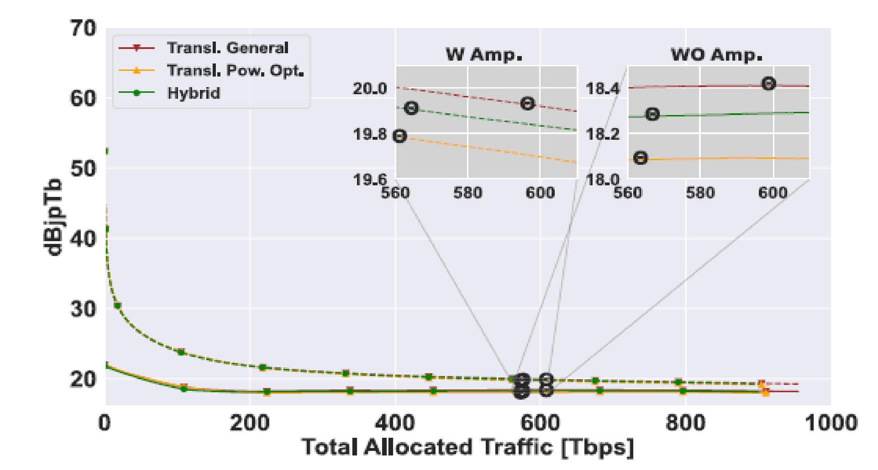
RGSNR_aux ← 0
path_temp, path_pre, path_reg ← ∅
while RGSNR_list ≠ ∅ AND LP not allocated do
  RGSNR_aux ← Highest RGSNR of RGSNR_list
  RGSNR_list ← RGSNR_list \ RGSNR_aux
  for all links (l) in path_tot do
    path_temp ← path_temp ∪ l
    if GSNR(path_temp, ch) ≥ RGSNR_aux then
      path_pre ← path_temp
    else
      if GSNR(path_pre, ch) ≥ RGSNR_aux then
        path_reg ← path_reg + path_pre ▷ New added transparent segment
        path_temp, path_pre ← l
      else
        break ▷ Not enough QoT for single link
    if l is the last link then
      path_reg ← path_reg + path_temp ▷ New added transparent segment
```

Novel contributions

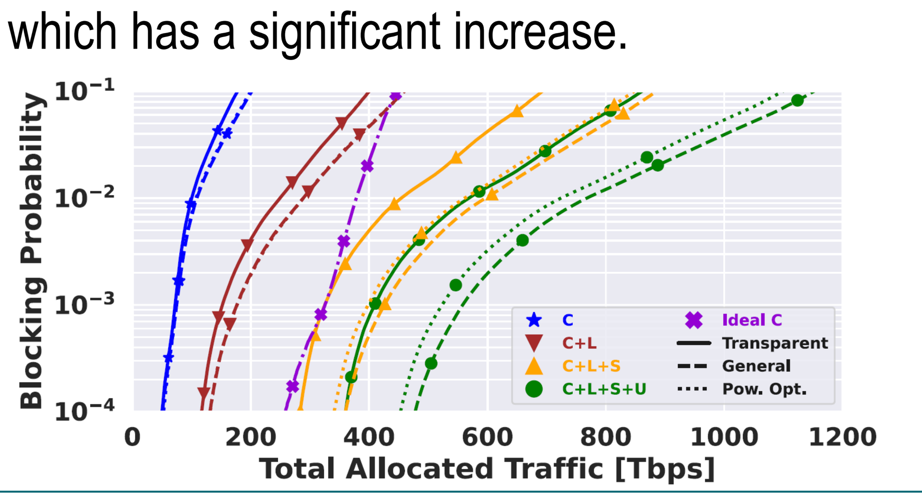
- Three different 3R regenerator placement algorithms are considered. Two of them can be used to assign 3R regenerators in any band whereas the last one focuses on placing 3R regenerators in the S-band only, since this band presents the lowest QoT in comparison to the other bands. The efficiency of the three different algorithms is compared in terms of total allocated traffic, consumed energy per Terabit, interface count as a cost, and allocated LPs.

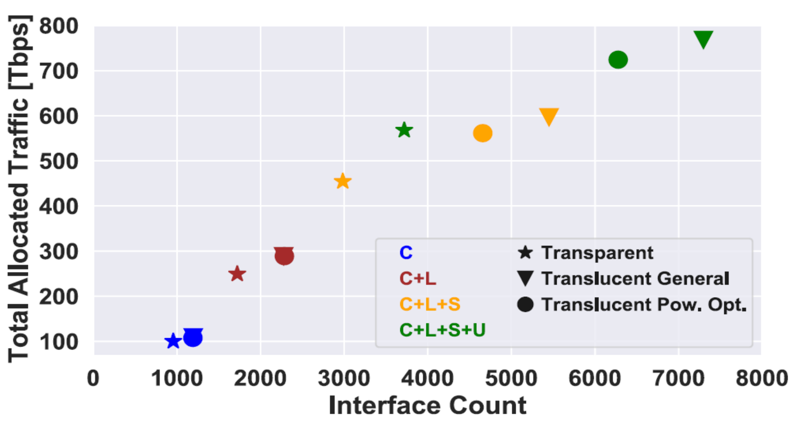




Adopted methodologies

- It can be observed that increasing the network capacity by exploiting more bands is more effective than deploying 3R regenerators in the C-band only scenario. Indeed, enabling the L-band in a transparent network design leads to more than twice the capacity, but performing signal regeneration only increases the network capacity by ×1.09 and × 1.07 times with the General and Pow. Opt. algorithms, respectively.
- a transparent network in the C+L+S+U-band scenario uses about 3719 interfaces to give a capacity of 570 Tbps; however, a translucent network design with one band less (C+L+S) needs about 5450 interfaces to reach the same capacity at the BP of 1%. Overall, by exploiting more bands progressively the allocated traffic increases in both the transparent and translucent network designs. On the contrary, the number of interfaces in the transparent network increases slightly in comparison to the translucent network type, which has a significant increase.





Future work

- Another possibility to augment fiber capacity is to extend the used bandwidth of traditional bands (C and L) from 4.8 to approximately 6 THz in each band, without needing new amplifiers.
- we compared the network capacity as well as the number of interfaces between regular and extended bandwidth bands in transparent and translucent network designs. We showed that super bands lead to an increase in network capacity in comparison to the regular bands for the same number of bands. Importantly, super C+L-band translucent network design provides the same delivered traffic compared with regular C+L+S1-band transparent network design, with both solutions featuring a trade-off between extra interfaces and extra amplifiers.
- Additionally, using machine learning (ML) / Reinforcement Learning (RL) would help to increase the network capacity. This topic currently is the topic that I am working on it. And good results have been achieved by PLANET team.

Submitted and published works

- R. Sadeghi, B. Correia, A. Souza, N.Costa, J. Pedro, A. Napoli, V. Curri, "Transparent vs Translucent Multi-band Optical Networking: Capacity and Energy Analyses", Journal of Lightwave Technology, 2022
- R. Sadeghi, B. Correia, E. Virgillito, A. Napoli, N. Costa, J. Pedro, V. Curri, "Optimal Spectral Usage and Energy Efficient S-to-U Multiband Optical Networking", OFC, 2022
- R. Sadeghi, B. Correia, N.Costa, J. Pedro, A. Napoli, V. Curri, "Extending the C+L System Bandwidth versus Exploiting Part of the S-band: Network Capacity and Interface Count Comparison", ECOC, 2022
- R. Sadeghi, B. Correia, N.Costa, J. Pedro, A. Napoli, V. Curri, "Capacity and Energy Usage of Translucent and Multi-Band Transparent Optical Networks", Advance Photonic Congress (APC), 2022
- R. Sadeghi, B. Correia, E Virgilito, E London, N. Costa, J. Pedro, A. Napoli, V. Curri, "Optimized Translucent S-band Transmission in Multi-Band Optical Networks", ECOC, 2021
- R. Sadeghi, B. Correia, E. Virgillito, A. Napoli, N. Costa, J. Pedro, V. Curri, "Performance comparison of translucent C-band and transparent C+ L-band network", Optical Fiber Communication Conference (OFC), 2021
- R. Sadeghi, B. Correia, A. Napoli, N. Costa, J. Pedro, V. Curri, "Capacity and Energy Consumption Comparison in Translucent Versus Transparent Multi-Band Designs", International Conference on Optical Network Design and

List of attended classes

- 01REKRV – Coherent detection: a revolution in optical communication (2021, credits)
- 01QSAIU – Heuristics and metaheuristics for problem solving new trends and software tools (2021, credits)
- 01TRLRV – Optical Transport Networks (2021, credits)
- 01RGBRV – Optimization methods for engineering problems(2021, credits)
- 01SFURV – Advanced scientific programming in matlab (2021, credits)
- 02LWHRV – Communication (2021, credits)
- 01SYBRV – Research integrity (2021, credits)
- 08IXTRV – Project management (2021, credits)

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