ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

XXXIII Cycle

# Physical Layer Aware Networking

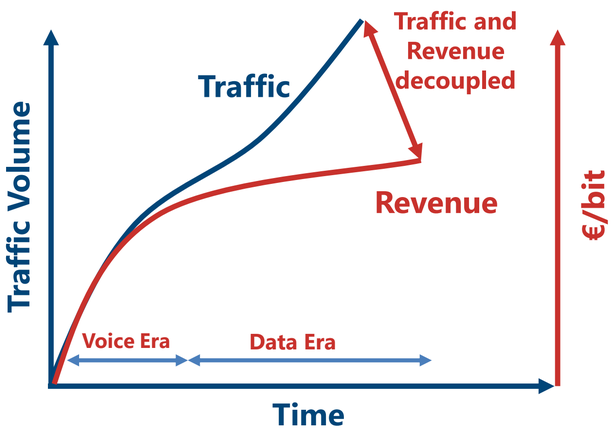

## Alessio Ferrari

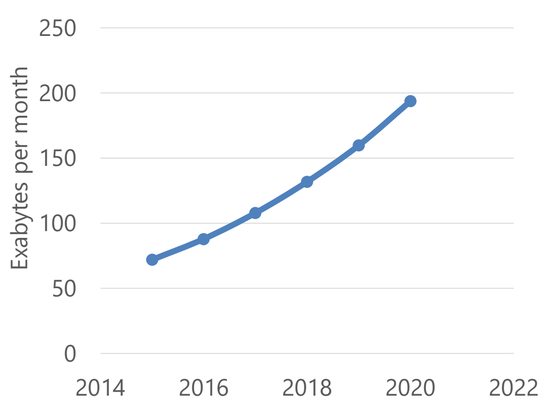
## Supervisor: Prof. Vittorio Curri


## Research context and motivation

- In the next **5 years**, global IP traffic over internet will grow **3 times**, mostly driven by internet video, which is expected to grow 4 times in 5 years.

- At the same time **operators revenues are not following the same path**, and since the beginning of the so-called data-era we are assisting to a decoupling of revenues from carried traffic.



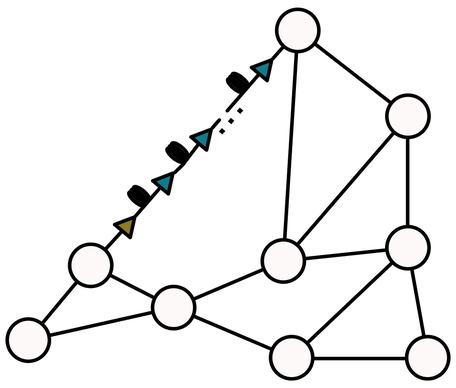



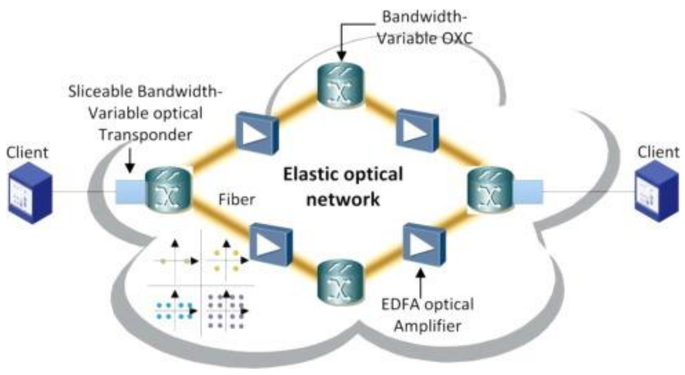

- Physical layer technologies evolved towards **coherent transmission** over **dispersion uncompensated links,** where, dispersion is digitally recovered through **DSP techniques**. This the node transparency **transparent in optical networks**.

- As a consequence, the physical layer awareness has to be taken included in the **network planning, management and optimization processes.**

## Addressed research questions/problems

- In this holistic scenario, the **planning**, the **design** and the **upgrade** strategies **must be consciously addressed** in order to face the growth of the traffic and to maximize the return over the investment over the installed equipment.



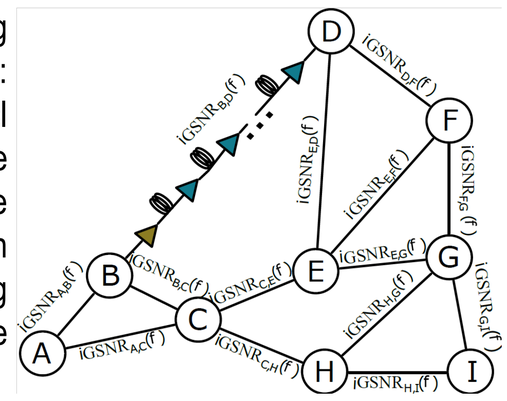



- To do so, given an optical network and the set of physical layer technologies (fibers, amplifiers, transceivers, etc.) that already installed or are going to be installed in it, **telecom operators must** be able to **answer** to question like:
  - **Which are** the most **critical sections** of the network?
  - **What section** of the network should be **upgraded**?
  - **Which physical layer technology** better fits with the be used?

- To answer to these questions, we focused **our research** in **understanding the merit of physical layer technologies on network performance.**

## Adopted methodologies

The network physical layer is abstracted according to the waveplane model~\cite{dai2015exp: resources are mapped in a number of parallel waveplanes equal to the SDM cardinality times the number of wavelengths; each waveplane is one spatial and spectral resource in the network. Each waveplane contains a weighted graph abstracting the physical layer as depicted. The graph nodes are the ROADM nodes and each graph edge is a



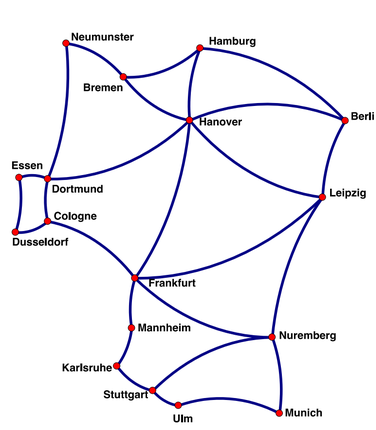

transmission line connecting two ROADM nodes including pre-amp and booster amplifiers. Each edge is characterized by a value of GSNR degradation (iGSNR(f,i)$_{l,m}$) representing the QoT degradation introduced by each transmission line between node $l$ and node *m* for the *i*-th channel at the frequency $f_i$. iGSNR(f,i)$_{l,m}$ does not depend on the deployed spatial resource, but only on the spectral one, being a function of $f_i$. The iGSNR(f,i)$_{l,m}$ of a transmission line is determined by the SNR degradation introduced by each element as:

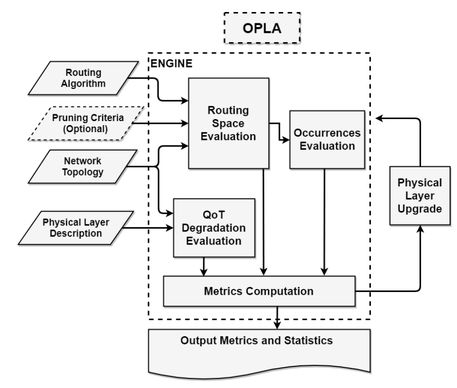
$$\mathrm{iGSNR}(f_i)_{l,m} = \mathrm{iOSNR}_{\mathrm{BST}}(f_i) + \sum_{n=1}^{N_s} \left(\mathrm{iSNR}_{\mathrm{NL}n}(f_i) + \mathrm{iOSNR}_n(f_i)\right)$$

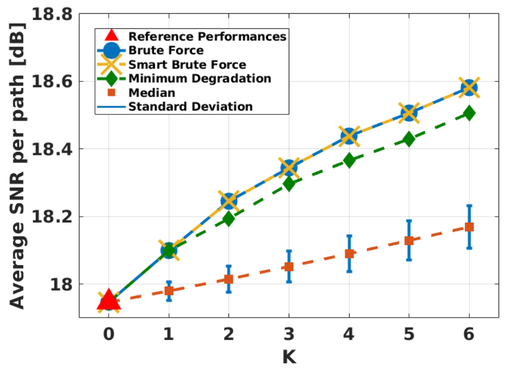
## Novel contributions

- We propose and compare strategies addressed by quality of transmission and quality of service to address the upgrades of amplification sites. We perform an offline physical layer assessment to deliver traffic independent results.

- In this work, we rely on OPLA to find the optimal placement of k OLAs maximizing the average SNR for the path in the RS. To this purpose, we compare the brute force (BF), a smart brute force (SBF) and a semi-analytical approach called minimum SNR degradation (MD). BF is the simplest approach: all the possible combinations of the k ASs are investigated, then the best solution is chosen. The complexity of this algorithm is binomial, i.e., it is the most complex of the three and required an affordable computation time only on small network topologies. The SBF is like the BF, but incrementally reduces the optimization space with the OLA placement. In general, it leads to a suboptimum solution, but the complexity is lower than BF: O(n·k). The MD method is based on the minimization of the average inverse SNR for each path in the RS Note that it is not equivalent to the maximization of the average SNR. It can be shown that minimizing the average inverse SNR drive the placement on the mostly used OLS and on the mostly degrading OLS span.




## Submitted and published works


•A. Ferrari, et. al. “Observing the generalized SNR statistics induced by gain/loss uncertainties” 2019
•A. Ferrari, et. al. “Band-division vs. Space-division multiplexing: a Network Performance Statistical Assessment” 2019 JLT
•A. Ferrari, et. al. “The Achievable Capacity of Multi-band Transmission Systems Using ITU-T G.652.D Optical Fibers” 2019 JLT
•A. Ferrari, et. al. “Power Control Strategies in C+L Optical Line Systems”
•A. Ferrari, et. al. “Selection of Amplifier Upgrades Addressed by Quality of Transmission and Routing Space” 2019
•Zibar, D., Ferrari, A., Curri, V., Carena, A. “Machine learning-based Raman amplifier design” 2019 OFC conference
•A. Ferrari, et. al. “Multi-Band Optical Systems to Enable Ultra-High Speed Transmissions” 2019 CLEO Europe conference
•M. Cantono, A. Ferrari, D. Pilori, E. Virgillito, , J. L. Augé, V. Curri “Physical Layer Performance of Multi-Band Optical Line Systems ..” 2019 JOCN
•T. Zhang, A. Samadian, A. Shakeri, B. Mirkhanzadeh, C. Shao, M. Razo, M. Tacca, A. Ferrari, M. Cantono, V. Curri, G. Martinelli, G. Galimberti, Xia, G. Wellbrock, A. Fumagalli,”A WDM Network Controller with Real-time Updates of the Physical Layer Abstraction” 2019 JLT
•Virgillito, E., Ferrari, A., D'Amico A., Curri, V. “Statistical assessment of open optical networks” 2018 MDPI
•Filer, M., Cantono, A. Ferrari, Grammel, Gert, Galimberti, Gabriele, V. Curri “Multi-vendor Experimental Validation of an Open Source QoT…” 2018 JLT
•M. Cantono, Pilori, Dario, A. Ferrari, Catanese, Clara, Thouras, Jordane, Auge, Jean-Luc, V. Curri “On the Interplay of Nonlinear Interference …” 2018 JLT
•Ghillino, Enrico et al“The Synopsys Software Environment to Design and Simulate Photonic Integrated Circuits: A Case Study for 400G Transmission” 2018 ICTON conference
•A. Ferrari, et. al. “A Two-Layer Network Solution for Reliable and Efficient Host-to-Host Transfer of Big Data” 2018
•A. Ferrari, et. al. “Coupled vs. Uncoupled SDM Solutions: A Physical Layer Aware Networking Comparison” 2018
•A. Ferrari, et. al. “Physical Layer Strategies to Save Lightpath Regenerators” 2018 JOCN
•M. Cantono, Pilori, Dario, A. Ferrari, Carena, Andrea, V. Curri “Observing the interaction of PMD with generation of NLI in uncompensated amplified optical links” OFC 2018
•B. Mirkhanzadeh, A. Ferrari, Lu, Zhen, Shakeri, Ali, Shao, Chencheng, Tacca, Marco, Razo, Miguel, M. Cantono, V. Curri, Martinelli, Giovanni, Galimberti, Gabriele Maria, Fumagalli, Andrea “Two-Layer Network Solution for Reliable and Efficient Host-to-Host Transfer of Big Data” 2018 Conference
•A. Ferrari, et. al. “A Networking Comparison between Multicore Fiber and Fiber Ribbon in WDM-SDM Optical Networks” 2018 presented at ICTON conference
•Ali, Hina, Ahmad, Arsalan, A. Ferrari, V. Curri “Impact of Fiber Type on Regenerator Placement in Reconfigurable DWDM Transparent Optical Networks” 2018 Conference
•A. Ferrari, et. al. “Networking Benefits of Advanced DSP Techniques and Hybrid Fiber Amplification” 2017, presented at ICTON conference
•A. Ferrari, et. al. “Networking Benefits of Advanced DSP Techniques” 2017
•A. Ferrari, et. al. “Routing Space Size Estimation for Reconfigurable Optical Networks” 2017
•M. Cantono, A. Ferrari, V. Curri - Politecnico di Torino “SNAP-Driven Updates of Physical Layer to Improve Performances of Photonic Networks” 2017
•M. Cantono, A. Ferrari, U. Waheed, A. Ahmad, S. M. Hassan Zaidi, A. Bianco, V. Curri. “Networking Benefit of Hybrid Fiber Amplification for Lightpath Regenerators Saving" OFC 2017, W4F.7


## Future work

- We want to expand the investigations OPLA to include many phyisical layer upgrades (different types of FEC, transceiver and fiber, introduce space division multiplexing solutions, ecc.. )

## List of attended classes

- 02LWHRV – Communication (15/02/2018, 1)
- 01SIKRV – Optical components for Telecom (didattica di eccellenza vp) (17/05/2018, 4)
- 01MNFIU – Parallel and distributed computing (26/06/2018, 5)
- 08IXTRV – Project management (15/06/2018, 1)
- 01RISRV – Public speaking (15/02/2018, 1)
- 01SHCRV – Unsupervised neural networks (didattica di eccellenza) (09/04/2018, 6)
- 02LWHRV – Advanced iterative techniques for digital receivers (25/06/2019, 4)
- 01SIKRV –Coherent detection: a revolution in optical communication (07/02/2019, 6)
- 01MNFIU –Entrepreneurial Finance (26/06/2018, 1)
- 08IXTRV – Research integrity (15/06/2018, 1)
- 01RISRV – Responsible research and innovation, the impact on social challenge (15/02/2018, 1)
- 01SHCRV - The new Internet Society: entering the black-box of digital innovation (09/04/2018, 1)

POLITECNICO DI TORINO

PhD program in

**Electrical, Electronics and Communications Engineering**