Cognitive and Autonomous Software-Defined Open Optical Networks

Giacomo Borraccini

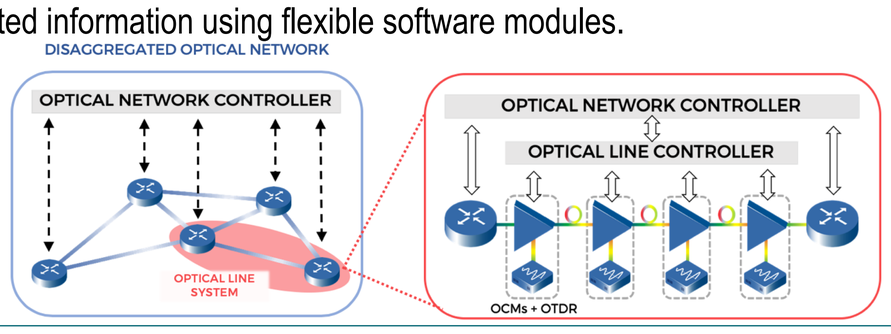
Supervisor: Prof. Vittorio Curri

ScuDo
Scuola di Dottorato ~ Doctoral School
WHAT YOU ARE, TAKES YOU FAR

XXXV Cycle

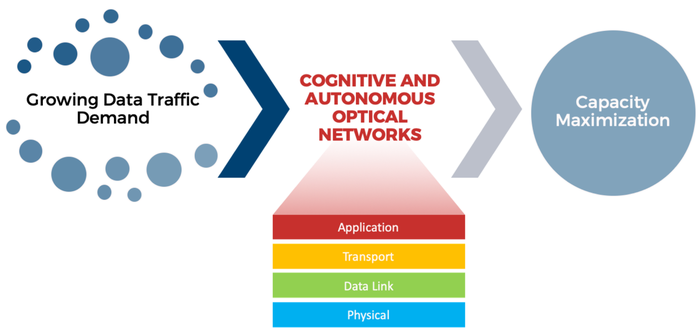
Research context and motivation

- Driven by the **increasing** and **greedy Internet data traffic request**, optical network operators are working to satisfy this need, improving the already installed resources, or updating them thanks to the introduction of new technological discoveries. In this context, the most relevant support for service capacity increase and system management is conferred by optical network automation, due to standardization and the consequent implementation of software-defined (SD) networks.
- Another important characteristic for an efficient usage of optical networks is the capability of the **infrastructure** to be **agnostic with respect to the adopted vendor equipment**.
- Starting from the last decade, **cognition** has been introduced and theorized as an emerging feature of the **next generation of optical networks**, implying the autonomous and prompt control of a network at each abstraction layer operating decisions and strategies based on the processing of information related to the status of the system.
- The response to the increasing complexity of the infrastructure is given by the possibility to **probe the condition of the network** through monitoring devices and to efficiently analyze the extracted information using flexible software modules.

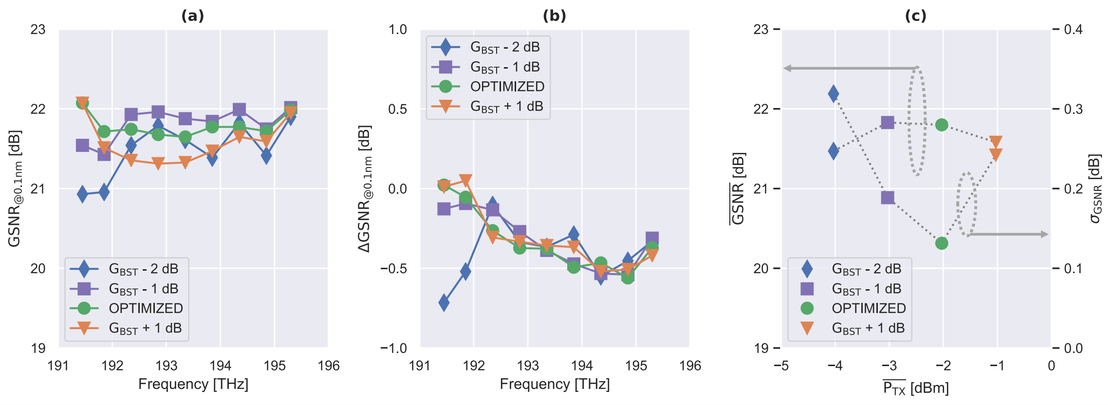


Addressed research questions/problems

- Our investigation has the purpose to deepen **cognition** and **automation in optical networks at the physical layer**, defining vendor agnostic control procedures and architectures capable of autonomously maximize the capacity of the optical infrastructure. The latter implies a larger exploitation of the installed resources, even in case of lack of knowledge about equipment specifications.



- In particular, it has been proved that the performance of a ROADM-to-ROADM optical link can be optimized **maximizing** and **flattening the quality of transmission over all the channels** propagating through the link.

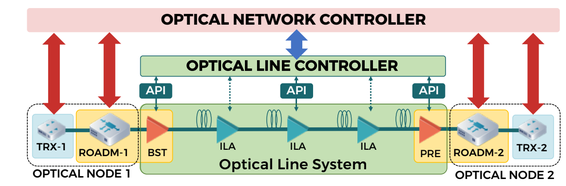


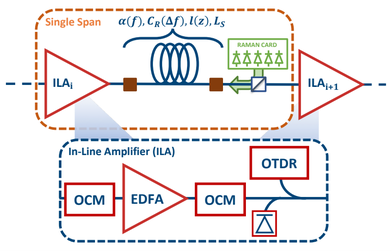
Published works

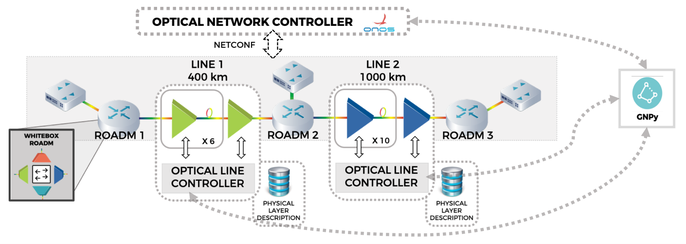
- D'Amico, Andrea, et al. "Scalable and disaggregated GGN approximation applied to a C+ L+ S optical network." JLT 40.11 (2022): 3499-3511
- Borraccini, Giacomo, et al. "QoT-Driven Optical Control and Data Plane in Multi-Vendor Disaggregated Networks." 2022 OFC
- Borraccini, Giacomo, et al. "Cognitive Raman Amplifier Control Using an Evolutionary Optimization Strategy." IEEE PTL 34.4 (2022): 223-226
- Borraccini, Giacomo, et al. "Statistical Analysis of GSNR Fluctuations Due to Physical Layer Uncertainties." 2021 ONDM
- Borraccini, Giacomo, et al. "Autonomous Raman amplifiers in multi-band software-defined optical transport networks." JOCN 13.10 (2021): E53-E62
- Borraccini, Giacomo, et al. "Cognitive and autonomous QoT-driven optical line controller." JOCN 13.10 (2021): E23-E31
- Borraccini, Giacomo, et al. "Autonomous physical layer characterization in cognitive optical line systems." 2021 OFC
- Borraccini, Giacomo, et al. "QoT-E driven optimized amplifier control in disaggregated optical networks." 2021 OFC
- Borraccini, Giacomo, et al. "Autonomous Raman amplifiers using standard integrated network equipment." IEEE PTL 33.16 (2021): 868-871
- D'Amico, Andrea, et al. "Enhancing lightpath QoT computation with machine learning in partially disaggregated optical networks." IEEE Open Journal of the Communications Society 2 (2021): 564-574
- Borraccini, Giacomo, et al. "Autonomous Raman amplifiers in software-defined optical transport networks." GLOBECOM 2020
- Borraccini, Giacomo, et al. "Using QoT-E for open line controlling and modulation format deployment: an experimental proof of concept." 2020 ECOC
- Borraccini, Giacomo, et al. "Softwarized and autonomous Raman amplifiers in multi-band open optical networks." 2020 ONDM
- Virgillito, Emanuele, et al. "Network performance assessment of C+ L upgrades vs. fiber doubling SDM solutions." 2020 OFC
- Borraccini, Giacomo, et al. "Flexible and autonomous multi-band Raman amplifiers." 2020 IPC

Novel contributions

- The developed methodologies have been applied to different use-cases, properly defining each architecture of the corresponding controller: **Raman amplifier** -- single span system; **Optical line system** (OLS) -- multi-span EDFA-amplified; **Complete optical network** with linear topology.

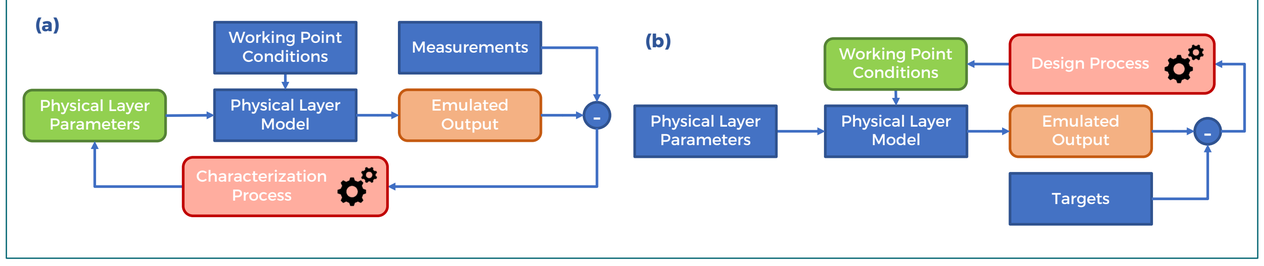






Adopted methodologies

- The adopted methodology that brings the considered system to maximize the its capacity can be summarized with a two-step optimization process applied during the provisioning phase of an optical network. The core of this approach is the use of a physical layer model able to simulate the behavior of the system.
- Firstly, the **physical layer** is completely **characterized** (Fig. a) retrieving in-field the needed features through the available telemetry in order to estimate the corresponding physical layer parameters. Then, on the basis of the tuned physical layer model, the **working point** of the system is properly **designed** (Fig. b).
- During the first step, the system is set under defined conditions and the physical layer model is tuned in order to match the optical transmission behavior reported by the telemetry, then according to the network controller targets, the working point of the system is optimized manipulating the softwarized representation of the optical system.



Future work

- As a continuation of the research activity, the **orchestration** and the **management** of the **optical network** within the **control system** will be **completed and improved** in terms of flexibility and adaptability with respect to several scenarios.
- Also, the **use of artificial intelligence techniques** will be implemented and investigated within the described frameworks in order to face soft/hard network failures, providing counteractions in real time.

List of attended classes

- 01REKRV – Coherent detection: a revolution in optical communication (29/9/2020, 6 CFU)
- 01QSAIU – Heuristics and metaheuristics for problem solving: new trends and software tools (10/7/2020, 4 CFU)
- 01TRLRV – Optical Transport Networks (16/7/2021, 6 CFU)
- 01RGBRV – Optimization methods for engineering problems (15/6/2020, 6 CFU)
- 02LWHRV – Communication (28/05/2020, 1 CFU)
- 01SHMRV – Entrepreneurial Finance (15/06/2020, 1 CFU)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (06/11/2020, 1 CFU)
- 08IXTRV – Project management (01/06/2020, 1 CFU)
- 01RISRV – Public speaking (27/01/2020, 1 CFU)
- 01SYBRV – Research integrity (02/06/2020, 1 CFU)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (03/06/2020, 1 CFU)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (16/06/2020, 1 CFU)
- 01SWPRV – Time management (29/05/2020, 2 CFU)

Politecnico di Torino
1859

PhD program in
Electrical, Electronics and Communications Engineering