Summary

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This thesis focuses on improvements and development of analytical models and artificial intelligence (AI) implementation for optical network design, planning and controlling based on the physical-layer-aware quality of transmission (QoT) estimation.

In general, with the increasing demand for capacity and traffic, network operators have started to look toward innovative solutions that can maximize transmission speeds and capacities. In this perspective, open and disaggregated optical network infrastructures have been considered as they offer more flexibility and allow for a multi-vendor approach to be realized. In such frameworks, software-defined networking (SDN) can be used to implement optical network control and management with lightpaths (LPs) being assigned dynamically. A partially disaggregated optical network with a SDN approach to control and management, is composed of disaggregated re-configurable optical add-drop multiplexers (ROADMs) connected by independent optical line systems (OLSs) that include the degrees of the ROADM multiplexer/de-multiplexer, fibers, and amplifiers (booster, in-line and pre-amp). These OLSs transport colored wavelength division multiplexing (WDM) optical tributary signals from ROADM to ROADM upon transparent LPs, with each OLS independently orchestrated using the SDN controller. To achieve this, a quality of transmission estimator (QoT-E) is required to compute the generalized signal-to-noise ratio (GSNR) of transparent LPs to assess network performance before, after and during deployment. Operating under the assumption that LPs are additive white Gaussian noise (AWGN) channels, the GSNR includes the accumulations of both the amplified spontaneous emission (ASE) noise that arises from the amplifiers, and the nonlinear interference (NLI) noise that is induced by the fiber propagation, with the interaction between these two contributions being negligible in terrestrial networks. This approach has been extensively validated and can be refined including system margins that take into account additional impairments as the intrinsic transceiver SNR, the polarization mode dispersion, the polarization dependent loss (PDL) and filtering penalties. By means of this assumption, any LP can be separated into the OLSs and switching nodes that are traversed during signal propagation; crucially, the total QoT may be calculated as the proper cumulative function of each QoT contribution arising from these subdomains.

In this framework, the open-source library for design and lightpath computation in real-world mesh optical networks, GNPy, has been implemented by the Physical Simulation Environment (PSE) group, within the Telecom Infra

Project, which includes the major operators and vendors in the optical networking field. As a matter of fact, GNPy has gained an increasing interest for both academia and industry, representing an accurate, vendor-agnostic QoT-E used for network design and standards definition and for lightpath computation, paving the way towards a SDN planning and controlling. This broad interest in GNPy is due to the rising request in optical network communities of a reliable and efficient digital twin of the optical systems. As a stand alone software, GNPy is a digital model where information exchange with the real system is performed through structured input/output data in a manual manner. By mean of further improvements, an advanced software framework based on an enhanced digital model has been implemented, including a more precise and efficient physical layer signal propagation model, along with a faster and more flexible structure, to enable the simulation of new transmission technologies, dynamic application of automated AI, and heuristic methods for optimization and margin management in SDN environments. This software framework, has been validated on several experimental setups including cutting-edge transmission scenarios.

Additionally, the enhanced transmission modeling has been employed for investigating wideband optical systems as future looking network innovation that provides significant capacity gain on already installed network infrastructures, with limited and cost-effective system upgrades.