Ph.D. in Information Technology
Thesis Defense

February 2nd, 2026
At 11:00 a.m.
Room Seminari Alessandra Alario - Building 21

Alessandro GAGLIANO – XXXVIII Cycle

INTEGRATION OF QUANTUM COMMUNICATIONS IN PASSIVE OPTICAL NETWORKS

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Abstract:

The transition of global telecommunication networks toward quantum-secure communications represents one of the most critical challenges in modern information technology. The ongoing developments of quantum computers poses an unprecedented threat to classical cryptographic systems, which are based on mathematical functions vulnerable to already-known quantum algorithms. In this context, Quantum Key Distribution (QKD) provides an information-theoretic secure protocol for key exchange, independent of the adversary computational power and based instead on the fundamental principles of quantum mechanics. However, an end-to-end QKD adoption requires its integration in the already deployed optical infrastructures, where the Passive Optical Network (PON) represents the end point architecture. This work investigates this integration challenge by analysing, modelling and experimentally validating the coexistence of quantum and classical signals in shared optical access networks, and proposes innovative architectures that enable highly-secure PONs. A comprehensive characterization of Spontaneous Raman Scattering (SpRS) noise, recognised as the most detrimental optical effect for this integration, is performed in standard single-mode fibres across an extensive spectral range, exceeding the estimated regions currently available in literature. This characterization is validated with commercial devices and combined with a novel analytical model to estimate the SpRS generation in different PON infrastructures. This analysis demonstrates that the backscattered SpRS noise generated in the counter-propagation configuration strongly depends on the splitter position and network architecture. Based on the theoretical model and experimental measurements, this work defines design rules for integrating Discrete-Variable (DV) and Continuous-Variable (CV) QKD systems in legacy single-fibre, dual-feeder, and dual-fibre PON architectures. It reveals that the coexistence in single-fibre PON faces severe limitation due to cumulative Raman noise, while architectures with additional fibre availability offer substantial improvements in Secret Key Rate (SKR) and user reach. Comparative investigations between DV-QKD and CV-QKD show that no single protocol is universally superior: CV-QKD achieves higher rates in small-scale networks or high-noise scenarios, whereas DV-QKD maintains longer secure distances and better scalability. This highlights the importance of flexible deployment strategies, where the optimal protocol is selected according to network configurations and service requirements. A further analysis on the finite-key regime identifies the critical dependence of integrated Quantum Passive Optical Network (QPON) performance on the number of detected states and the need for an asynchronous mechanism for key generation and key request. Finally, the concept of highly-secure access network is extended by integrating Fiber Optic Sensing (FOS) and QKD technologies, achieving simultaneous data protection and infrastructure integrity. Performance investigations confirm that DV-QKD system, Michelson interferometric sensor and standardised PON channels can coexist in the same optical access network. A preliminary experimental demonstration focuses on business-user scenarios, where dedicated spare fibres and higher security demands support the early adoption of integrated quantum-sensing solutions. In summary, this thesis offers comprehensive guidelines for integrating quantum communications in passive optical networks, including the access segment in the transition towards quantum-safe optical networks. The presented models, measurements and innovative approaches represent a significant step in the deployment of highly-secure PONs, leading the way for next-generation access networks that offer real-time physical monitoring and quantum-secure data communications.

PhD Committee

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