Ph.D. in Information Technology
Thesis Defense

December 16th, 2025
at 1:45 p.m.
Alpha Room – Building 24

Franci GJEÇI – XXXVI Cycle

Programmable Self-Organizing Radio Access Networks

Supervisor: Prof. Antonio Capone

Abstract:

The evolution of mobile radio networks has been consistently driven by the need to increase data rates to satisfy the demands of an increasingly connected society. With the advent of 5th generation (5G), the focus has shifted from merely enhancing throughput to enabling a diverse range of advanced communication services, including mission-critical applications, high-bandwidth services, and Ultra Reliable and Low Latency Communications (URLLC) communications. Among these, Vehicle-to-Everything (V2X) communication stands out, supporting essential applications such as collision avoidance, cooperative driving, and traffic optimization. These services impose stringent requirements on latency, reliability, and service continuity, exceeding the capabilities of traditional mobile networks. Meeting these demands requires a fundamental rethinking of network management paradigms. In this context, Self-Organizing Network (SON) has emerged as a key technology, providing autonomous configuration, optimization, and self-healing functionalities. The SON framework reduces operational complexity and enables real-time adaptation to dynamic network conditions. Its optimization and healing functions are particularly critical in 5G and V2X networks. When integrated with intelligent control frameworks such as Open RAN (O-RAN), SON unlocks unprecedented programmability and visibility, enabling tailored solutions for the unique challenges of 5G and V2X. This dissertation investigates the synergy between 5G, V2X, and SON running on top of O-RAN, laying the foundation for highly responsive and resilient mobile networks capable of supporting the most demanding use cases of the connected world. On this premise, we first highlight the characteristics of O-RAN, a Radio Access Network (RAN) architecture overhaul that offers unprecedented data collection and control capabilities, in line with the SON requirements, making it a primer for the widespread dissemination of the SON paradigm. In the initial phase of this disseration, we advanced the functions of SON-O-RAN within 5G networks by proposing a novel self-optimizing SON framework aimed at enhancing the Quality of Service (QoS) of user

services exhibiting conflicting performance requirements. As a case study, we focused on the coexistence of two challenging services, namely bandwidth-intensive Heavy-Hitterss (HHs) and low-latency Multicast/Broadcast Services (MBS) services. In such a challenging use case, it is impossible to devise a single SON solution that entirely addresses the complexity of this situation; thus, the synergy of different SON functions is essential. In this context, we propose seamlessly using load-balancing and Resource Allocation (RA) SON functions to tackle the problem. Specifically, the proposed RA algorithm is based on Multilevel Queue Scheduling (MLQ) and is capable of guaranteeing the QoS of low-latency MBS services while simultaneously maintaining a high QoS for high-bandwidth HHs. An additional novelty of this solution lies in the use of the X2 interface to broadcast MBS data to neighboring cells, thereby minimizing inter-cell dissemination latency. Furthermore, a Deep-Neural Network (DNN)-based detection mechanism is tailored for HHs within a disaggregated 5G network architecture, and a heuristic load-balancing SON function is proposed, leveraging HH-guided handovers to further enhance the QoS of HHs services. Building on the substantial benefits of SON applications within 5G networks, the second phase of this doctoral dissertation was devoted to extending SON to V2X networks and developing advanced SON functions for this domain. Our contributions are both theoretical and experimental. Specifically, we examine the architectural extensions required to integrate V2X network into O-RAN, thereby enabling O-RAN to deploy SON functions over them, eventually highlighting the extensive opportunities that arise from this integration. Initially, nodes' —Connected and Autonomous Vehicles (CAVs)— mobility as an unexplored aspect in the O-RAN architecture is identified and analyzed. Subsequently, the use of the cellular infrastructure, along with the ubiquitous Below 6GHz (sub-6GHz) frequencies, is proposed as a feasible solution to relay O-RAN control messages to the CAVs and backwards. To foster practical experimentation, we present a simulation framework based on Network Simulator 3 (ns-3) and O-RAN that allows testing the V2X integration in a realistic environment. It is the first open-source V2X-O-RAN testbed. Using this framework, we addressed two open issues in V2X networks. The first involves the application of SON to mitigate link blockages through a self-healing Traffic Relaying solution, a critical mechanism for ensuring reliable communication in high-mobility scenarios. We provide a theoretical formulation of the problem and present extensive simulation results demonstrating the effectiveness of this approach. The second focuses on using self-optimization paradigm of SON to develop a novel RA scheme for V2X networks implemented on top of O-RAN. The theoretical model of the problem is outlined, and comprehensive simulation results illustrate the performance gains achieved by our solution.

PhD Committee

Prof. Alessandro Enrico Cesare Redondi, **Politecnico di Milano**

Dr. Andrea Pimpinella, **Università degli Studi di Bergamo**

Prof. Pierpaolo Loreti, **Università degli Studi di Roma “Tor Vergata”**