Abstract

From the invention of the wheel to the dominance of internal combustion engines and now the advent of electric vehicles (EVs), technology has consistently shaped transportation. In recent decades, mobility innovation has expanded its focus beyond individual vehicles toward system-level intelligence powered by advancements in communication technologies, onboard sensors, and edge computing. At the core of this evolution lies the concept of Cooperative Intelligent Transport Systems (C-ITS), which enables seamless data exchange between vehicles and infrastructure to enhance cooperation and safety. Building on this foundation, the paradigm of Cooperative, Connected, and Automated Mobility (CCAM) has emerged to integrate connectivity, automation, and collaboration into modern transportation systems, improving safety, optimizing traffic flow, and reducing environmental impact.

However, this vision brings its own challenges, particularly in ensuring real-time communication and computation for safety-critical applications like collision avoidance and coordinated maneuvers. When hosting such vehicular application services on traditional cloud computing architectures, challenges arise due to latency, bandwidth constraints, and operation costs. Recognizing these limitations, the Multi-access Edge Computing (MEC) paradigm has emerged as a pivotal enabler, relocating computational resources closer to vehicles at the edge of the network. Nevertheless, the growth of data generated by modern perception systems and the highly dynamic nature of vehicles may still pose challenges for MEC-based services needing to serve vehicles roaming under changing network operators or travelling under limited network coverage.

This thesis explores vehicular micro-clouds as a transformative approach to address these challenges. By leveraging vehicle-to-vehicle (V2V) communication, vehicles may form dynamic, localized clusters capable of aggregating, caching, and processing data at the edge. Acting as virtual edge servers, these clusters can

reduce dependency on centralized resources while enhancing system-wide scalability, responsiveness, and cost efficiency. The work presented in this dissertation explores the architectures, protocols, and applications enabled by vehicular micro-clouds, with a particular emphasis on their potential to support CCAM use cases.

The base methodology of this research lies, first, in the development of innovative simulation tools like the ms-van3t framework and its integration with the CARLA simulator. This co-simulation framework allows for high-fidelity modeling of vehicular scenarios, including the transmission and processing of Cooperative Perception Messages (CPMs) and the validation of architectures and applications designed for vehicular micro-clouds.

Two key contributions then anchor this research. The first is the design and validation of the Server Local Dynamic Map (S-LDM), a MEC-based middleware service that integrates real-time data from vehicles and infrastructure to maintain a centralized yet localized map of the road environment. This service, evaluated for its scalability and cross-border performance, demonstrates how MEC can bridge gaps in latency-sensitive applications. The second contribution is the development of the Platoon-Local Dynamic Map (P-LDM), a vehicular micro-cloud service tailored for cooperative perception among platooning vehicles. By synchronizing data from multiple platoon members, P-LDM enhances situational awareness and ensures robust performance in dynamic environments. Through extensive simulations, this work demonstrates the benefits of vehicular micro-clouds in reducing latency, optimizing resource utilization, and improving safety-critical applications like automated platooning maneuvers.

Finally, this thesis aims to contribute to a scalable, efficient, and reliable framework for future mobility systems. Vehicular micro-clouds, as envisioned here, represent a significant step toward realizing C-ITS providing an additional underlying layer of virtualized resources for the reliable and efficient execution of CCAM applications.