technische universität
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Faculty EE/IT
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05.08.2025

Master Thesis

Analyzing Scalability and Reliability of Mobile Networks for Mass Teleoperation Deployments

Motivation and Problem Statement

The deployment of Intelligent Transportation Systems (ITS) poses significant challenges to mobile networks, particularly for demanding applications such as teleoperation, which require low latency, high reliability, and stable uplink data rates for real-time video transmission. As teleoperated vehicles rely entirely on mobile connectivity for safe operation, any degradation in network performance can pose critical safety risks. While current mobile networks can cope with the deployment of single teleoperation systems, their ability to support large-scale ITS applications under real-world conditions remains uncertain.

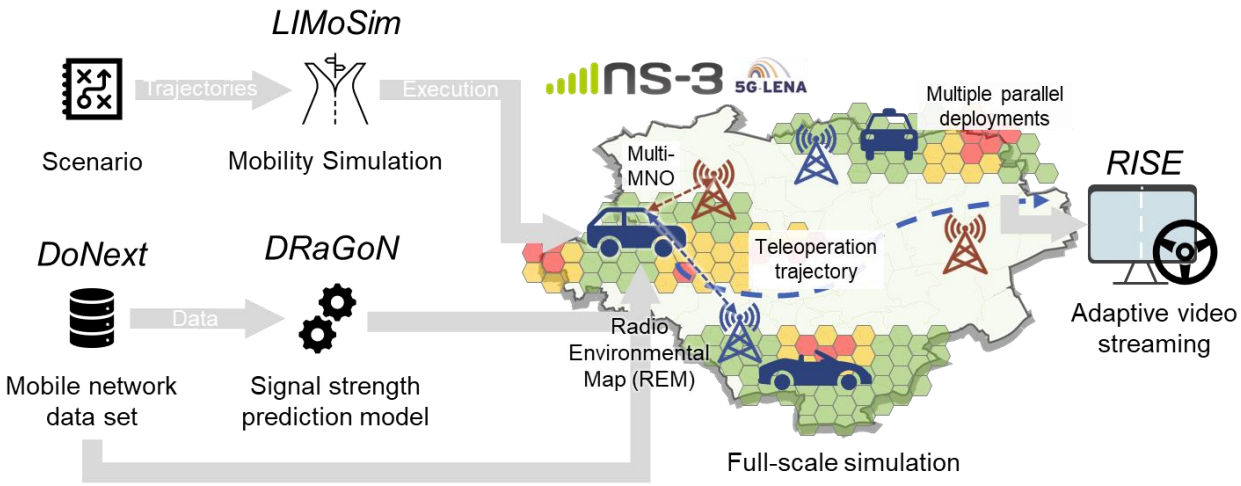

Figure 1: Overview of the simulation setup for analysis of teleoperation deployments at scale.

As dedicated measurements can hardly verify this, simulation methods are a promising enabler for analyzing future transportation systems. However, simulations must accurately model the real word and need to be parameterized correctly. For this purpose, the existing measurement database *DoNext*, which contains data from multiple Mobile Network Operators (MNOs), shall be utilized [1]. DoNext covers vast areas of Dortmund and provides both low-level parameters such as signal strength, and high-level indicators, including the available data rate. As DoNext is only available in Dortmund and smaller areas, where data may still be missing, the signal strength prediction model DRaGoN shall be used to impute gapless Radio Environmental Maps (REMs) [2].

A discrete event network simulator like ns-3 is then to be adapted to use these REMs to accurately simulate the mobile network connectivity depending on the location of the vehicles. As the mobility of the vehicles is dependent on exact trajectories, other vehicles and speed limits, a mobility

simulation with LIMoSim is planned [3]. Depending on the exact mobility and location, path-loss and fading are affected resulting in different achievable data rates. Thus, the applications may need to adapt to the channel characteristics using Reliable Intelligent Stream Encoding (RISE) [4]. RISE adapts the data rate of the teleoperation video stream according to the current connectivity and utilizes multi-MNO networking with the help of the SEAMLESS multi-link protocol [5]. This approach extends the feasibility of teleoperation to areas with weaker connectivity and improves reliability significantly.

Potential work steps of the master thesis:

- Surveying related work on the topics of map-based mobile network performance estimation and teleoperation applications
- Familiarization with ns-3 and the 5G-LENA module for mobile network simulations as well as with LIMoSim for mobility simulation
- Implementation of a limited evaluation scenario as a baseline
- Extension of the simulation to the area of Dortmund and

Requirements

- Interest in mobile communications and 5G technology
- Participation in the *MFN/MRN* lecture (Grade: E*xcellent/Good*) and the OMNeT++ practicum is highly desirable; participation in other CNI lectures is a plus.
- Excellent English skills; highly desirable: Willingness to write thesis in English
- Advanced C/C++ and basic LaTeX/TikZ skills

References

[1] H. Schippers, M. Geis, S. Böcker, C. Wietfeld, "DoNext: An Open-Access Measurement Dataset for Machine Learning-Driven 5G Mobile Network Analysis," IEEE Transactions on Machine Learning in Communications and Networking, vol. 3, pp. 585-604, April 2025. DOI: 10.1109/TMLCN.2025.3564239.

[2] M. Geis, B. Sliwa, C. Bektas, C. Wietfeld, "TinyDRaGon: Lightweight Radio Channel Estimation for 6G Pervasive Intelligence", In 2022 IEEE Future Networks World Forum (FNWF), Montreal, Canada, October 2022. (Best Paper Award).

[3] B. Sliwa, C. Wietfeld, "LIMoSim: A framework for lightweight simulation of vehicular mobility in intelligent transportation systems", Chapter in Recent Advances in Network Simulation - The OMNeT++ Environment and its Ecosystem (A. Virdis, M. Kirsche, eds.), Springer International Publishing, May 2019.

[4] H. Schippers, T. Gebauer, K. Heimann, C. Wietfeld, "RISE: Multi-Link Proactive Low-Latency Video Streaming for Teleoperation in Fading Channels," in IEEE 101st Vehicular Technology Conference (VTC-Spring), Oslo, Norway, June 2025.

[5] T. Gebauer, M. Patchou, C. Wietfeld, "SEAMLESS: Radio Metric Aware Multi-Link Transmission for Resilient Rescue Robotics", In 2023 IEEE International Conference on Safety, Security, and Rescue Robotics (SSRR), Fukushima, Japan, November 2023. (Best Paper Award).