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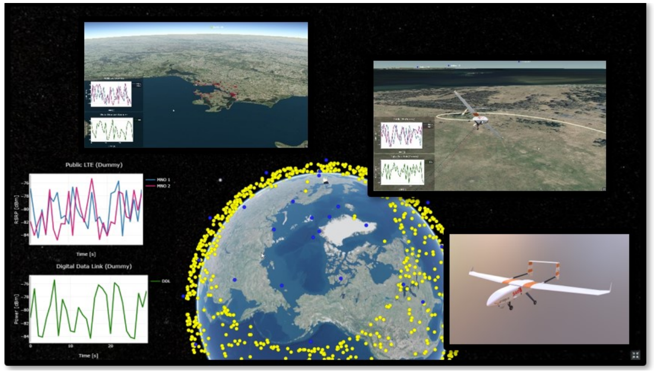
Digital Twin based Coverage Prediction of 6G Non-Terrestrial Networks

Satellite-based connectivity is on the rise. Projects like Starlink, OneWeb and Kuiper announce their development of satellite constellations for commercial and private internet access. Hence, these orbital platforms are emerging as considerable alternatives to terrestrial internet access. Furthermore, the development of 6G aims to extend terrestrial radio networks with non-terrestrial components.



Besides the straightforward use as a broadband alternative for private users, particularly in remote locations, satellite or non-terrestrial networks (NTN) offer considerable potential for providing fast and ubiquitous connectivity during disaster response and critical search and rescue missions. Especially in the latter category of scenarios, the use of autonomous systems becomes increasingly important. These systems allow a more resilient and faster rescue of the missing person and ensure the rescue forces' safety. To enable the reliable teleoperation of these systems, robust connectivity is critical for which digital twins are increasingly used as a way of preprediction.

Moreover, satellite and terrestrial networks do not have to only coexist but can be used to extend each other's capabilities with a so-called Multi-Link approach. With this, reliable and resilient communication can be established by intelligently switching between technologies.

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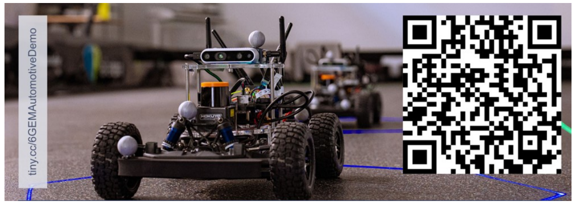
Digital Twin-based Performance Evaluation of Multi-Link Routing for Remote Operation

In the fields of rescue robotics, remote operation allows rescue forces to explore hazardous areas without endangering human personnel. On the vehicular site, the subclass of teleoperated driving is considered a legal requirement in the development towards fully autonomous driving. Within ongoing 6G development, some approaches indicate to match the requirements, which are ultra-low latency, high data rate in the uplink direction, but also a very high reliability in the downlink for accurate control commands. Such approaches are already in development at the Communication Networks Institute and need further integration and evaluation to be done for a variety of testing scenarios.



The AI-based routing protocol PARRoT is able to find reliable alternative routes for highly dynamic use cases and can react to disrupted network nodes. In further research this will converge with multi-link approaches to address the diversity of link requirements. In a digital twin, the combination of mobility and channel prediction enables outage estimation and strategic placement of aerial nodes for 3D networking.

On the methodical site, the digital twin can utilize the vSTING approach to imprint end-to-end network behavior in near-realistic simulative, hardware-in-the-loop, and real robot testbeds. Thus, comprehensive evaluations under the variation of channel conditions and scenario scaling can be performed to benchmark approaches.

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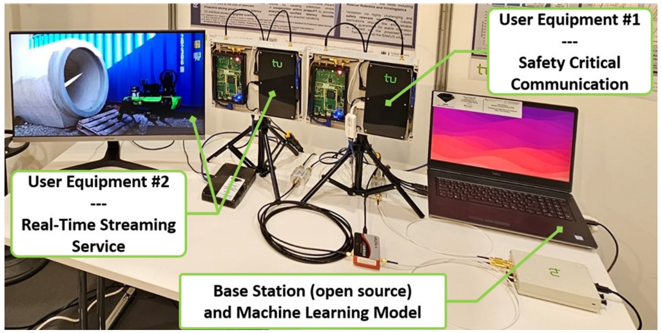
Machine Learning-driven 5G and Beyond Network Slicing Solutions

With focus on the next generation of mobile radio networks (6G), efficient and sustainable communication diverges for different use cases. The technology of network slicing acts as key enabler, providing resources for each network slice virtually, while being placed within a physical shared infrastructure. While the virtualization within the core network has already gone into production, the Radio Access Network (RAN) slicing offers a wide range of research possibilities here at the Communication Networks Institute (CNI).

Beside the traditional approach of allocating resources based on requests from the user equipment, machine learning (ML) algorithms can be utilized, for example, to provide them proactively, thus enabling precise and latency-free allocations. Therefore, innovative schedulers are to be designed and tested within prototypical testbed setups or within scalable simulation environments (OMNeT++/ns-3). As 6G networks are envisioned to be highly automated, sophisticated ML algorithms are necessary to reduce the trade-off between mission -critical and best effort network slices.



The associated radio resource orchestration also encompasses the Open RAN concept. This is where so-called xApps are proposed as microservices to provide greater control over the underlying future networks. The research focuses on leveraging the open interfaces for ML-based efficient and dynamic resource allocation. The aim is to optimize this allocation and thus improve overall network performance.

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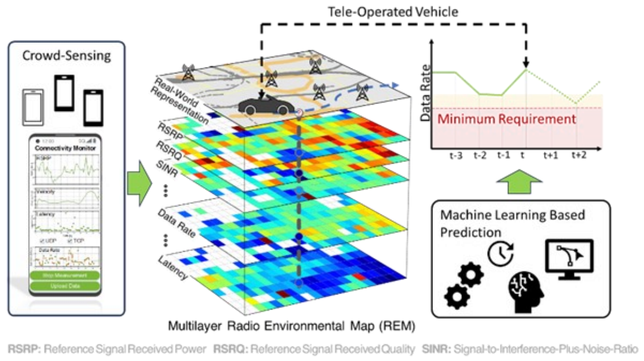
Machine Learning Based 6G Real-World Performance Prediction

Future 6G networks are envisioned to provide even higher data rates and thus enable new use cases like tele-operated driving. Tele-operated driving depends on strict compliance with set Key Performance Indicator (KPI) requirements to allow for uninterrupted service and represents a significant challenge to mobile networks.

Due to the shared nature of mobile networks, this is not always possible. However, dedicated machine learning models can predict compliance with KPI requirements. These models can be trained on multi-dimensional Radio Environmental Maps (REM). REMs consist of spatially aggregated passive (e.g. signal strength, quality) and active (e.g. data rate, latency) measurement data.



Based on a massive database of mobile network measurements created by crowd sensing and dedicated measurement campaigns, novel machine learning algorithms are evaluated.

Currently, REM-based and instantaneous predictions are analyzed. In the future, also time-series models could be utilized for KPI prediction. Furthermore, federated learning principles could be evaluated. Federated learning spreads the training process of machine learning models to multiple users and helps to keep privacy while specializing models.

Finally, green networking and power consumption aspects are a main concern of our research. Especially the energy consumption of user devices in different scenarios is the focus. For this, we operate sophisticated measurement equipment to evaluate power consumption in varying scenarios.

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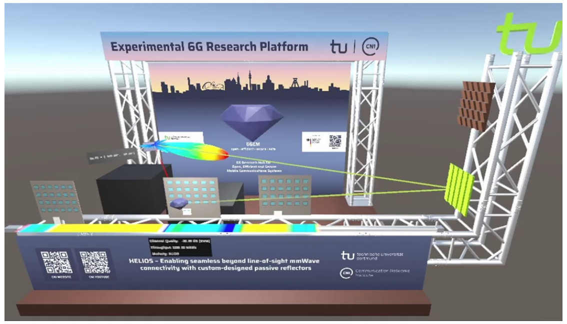
High-Performance mmWave Communications for Beyond 5G and 6G Networks

The continuously increasing penetration and utilization of mobile networks require the development of new frequency bands. The millimeter wavelength range (mmWave), i.e. frequencies greater than 24 GHz, offers a large number of currently unused spectral resources that can thus be exploited to meet the high data transmission demands of mobile networks.

However, more challenging propagation characteristics of radio signals prevail in the mmWave spectrum, requiring the use of advanced technologies such as phased array antennas and beamforming. Directional transmissions will finally overcome the challenging radio channel characteristics, for which, nevertheless, novel beamsteering protocols for link establishment and maintenance have to be researched, tested and optimized.



In this context, the CNI addresses efficient beam management methods enabling robust mobile mmWave connectivity for the subscribers. Further, as part of our activities towards the next mobile communication standard 6G, innovative technology solutions such as reconfigurable intelligent surfaces (RISs) are investigated in simulations and experiments. We are actively looking for students interested in hybrid network planning aiming to use as few base stations by intelligently incorporating such active surfaces or passive solutions such our HELIOS reflectors. As a result, usability of mmWave spectrum for high-performance mobile communication shall be attained with 6G.

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Topics for Final Theses (Bachelor/Master) 2023/2024

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