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Simulating Hybrid Aerial- and Ground-based Vehicular Networks with ns-3 and LIMoSim

Benjamin Sliwa, Manuel Patchou, Karsten Heimann, Christian Wietfeld
Communication Networks Institute
TU Dortmund University, Germany
firstname.lastname@tu-dortmund.de

ABSTRACT

Integrating Unmanned Aerial Vehicles (UAVs) into future Intelligent Transportation Systems (ITSs) allows to exploit their unique mobility potentials for improving the performance of services such as near-field parcel delivery, dynamic network provisioning, and aerial sensing. In order to provide a controllable environment for the methodological performance analysis, simulation frameworks need to support ground- and aerial-based mobility as well as the involved communication technologies. In this paper, we present the open source Lightweight ICT-centric Mobility Simulation (LIMoSim) framework for simulating hybrid vehicular networks within Network Simulator 3 (ns-3). LIMoSim implements a shared codebase coupling approach which integrates all required components in a single simulation process. The low-level mobility behaviors rely on well-known analytical models. Different case studies discussing cutting-edge communication technologies such as Cellular Vehicle-to-Everything (C-V2X) and millimeter Wave (mmWave) are presented in order to illustrate how the proposed framework can be integrated into ns-3-based network simulation setups.

CCS CONCEPTS

• Networks → Network simulations; **Network performance analysis**; **• Computing methodologies → Discrete-event simulation**;

1 INTRODUCTION

The integration of UAVs into smart city-based ITSs [19] will allow to exploit the third physical dimension in order to overcome the limitations of purely ground-based traffic systems [30]. Novel applications for hybrid vehicular networks such as drone-enabled parcel pickup and delivery [21], dynamic aerial-based network provisioning [7] as well as aerial sensing [10] have been demonstrated in first feasibility studies. For the further development of these novel systems, the availability of reliable and efficient communication technologies is a basic requirement. This fact manifests in ongoing standardization initiatives such as 3GPP TR 36.777 [1] which aim to investigate the requirements for integrating aerial vehicles into cellular networks. The ongoing developments show that there is a *convergence of mobility and communication*.

Anticipatory communication [5] has emerged as a novel paradigm for wireless communication systems which aims to actively exploit measurable context information in order to improve decision processes such as data transmission scheduling [29], routing, and handover. UAV networks – as a sub-category of mobile robotic networks – implement a form of *controlled mobility*. Hereby, control routines are applied to execute a certain desired behavior (e.g., hovering over a centroid of ground users). Since knowledge about the planned mobility is inherently present within the mobile agents, those networks form a perfect match with anticipatory mobile networking mechanisms for proactive system optimization [28].

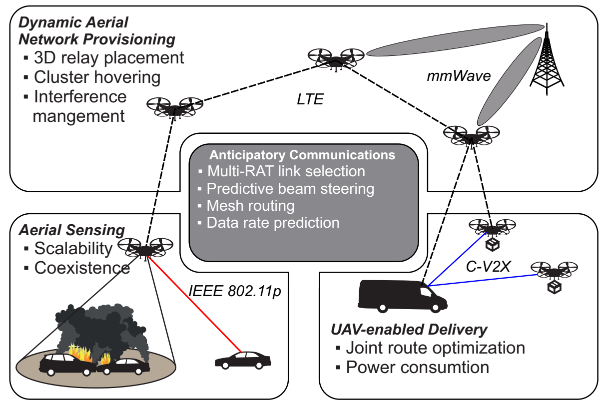


Figure 1: Overview of applications, challenges, and communication technologies for hybrid vehicular networks.

An overview of different applications for hybrid vehicular networks as well as challenges and research topics for the communication systems is illustrated in Fig. 1.

The proposed simulation framework LIMoSim aims to bring together ground- and aerial vehicular systems with anticipatory mobile networking. In previous work, we have presented an initial feasibility study for co-simulating ground-based and aerial vehicles [31]. In this paper, we focus on describing the interplay of LIMoSim and ns-3. In particular, LIMoSim[1] makes the following contributions to the ns-3 ecosystem:

- An **integrated** approach for joint simulation of hybrid ground-based an aerial communication networks based on well-known analytical mobility models.
- Focus on **anticipatory** mobile networking through native integration of enablers for prediction models (e.g., mobility prediction, network quality maps).
- Online **3D visualization** based on Open Graphics Library (OpenGL).

The remainder of this paper is structured as follows. After discussing related research work in Sec. 2, we provide an

[1]The source code is available at https://github.com/BenSliwa/LIMoSim_ns3

overview about the LIMoSim framework in Sec. 3 and discuss its integration into ns-3 in details. Afterwards, the considered research methodology and the application of LIMoSim is shown in different case studies in Sec. 4.

2 RELATED WORK

Aerial and ground-based networks: A comprehensive summary that approaches a large variety of recent and future research topics related to UAV communications is provided by Zeng et al in [38]. While the existence of a dominant Line-of-sight (LOS) link is often a valid assumption for *air-to-air* links, *air-to-ground* communication is massively impacted by the dynamics between LOS and Non-line-of-sight (NLOS) situations related to obstacle shadowing. Effects of the terrain profiles are further investigated by [13]. Zhou et al. introduce an architecture model for enabling cooperative vehicular networking between cars and UAVs in [41]. A variety of communication technologies is applied for interconnecting the different vehicle types. While IEEE 802.11-based multi-hop networks [40] have been in the research focus for several years, the integration of aerial vehicles into cellular communication networks is now actively being discussed [1].

Apart from only using single technologies for interconnecting the different vehicles, multi-Radio Access Technology (RAT) optimization [26] has become an emerging research field. Choi et al. [8] propose a Dedicated Short-range Communication (DSRC)-based exchange of position information in order to improve reduce the overhead of dynamic beam alignment for vehicular mmWave networks.

Due to the different mobility characteristics and the inherent resource constraints for aerial vehicles, many applications develop novel approaches for joint mobility optimization and cooperative routing [16]. Two-echelon vehicle trajectory optimization methods for battery usage improvement are analyzed by the authors of [39]. Shang et al. [27] use the flexibility of the UAV mobility to enhance the physical layer security for Vehicle-to-Everything (V2X) communications. In order to avoid eavesdropping, data transmissions between ground vehicles are forwarded by an intermediate aerial relay that establishes a virtually unobstructed LOS between the users. A communication-aware mobility model for UAV-supported V2X is proposed by [14]. Based on an attraction model, the UAV automatically approaches the car which the lowest measured signal quality in order to avoid link loss within the served cluster of ground users.

For the case studies presented in Sec. 4, we apply existing ns-3 implementations for mmWave extension [12, 20], C-V2X mode 4 [9] and Wireless Access for Vehicular Environment (WAVE)-based IEEE 802.11p.

System-level network simulation is the dominant performance analysis method for mobile and vehicular communication networks with the wireless research community [6]. While ground-based mobility simulation – often carried out with the Simulation of Urban Mobility (SUMO) traffic simulator [17] – has already reached a highly mature state, UAV mobility simulation is still in its infancy which has led to a variety of specialized simulation frameworks that target different use-cases and research topics. *FlyNetSim* [2] applies a middleware-based approach to couple ns-3 with Ardupilot and focuses on hardware-in-the-loop simulations. *CommUnicationS-Control distribUted Simulator (CUSCUS)* [37] provides a limited – e.g., Long Term Evolution (LTE) simulation is currently not supported – interconnection of ns-3 and Framework libre AIR (FL-AIR) based on Linux containers. *OpenUAV* [25] is an open source test bed for UAV research featuring rich visualization capabilities and cloud-based simulation support. However, it focuses on individual mobility control and does not provide capabilities for simulating actual communication technologies. *Corner-3D* [11] focuses on providing a realistic representation of typical UAV obstacle-related channel dynamics without actually simulating the UAV mobility itself. Within the ns-3 ecosystem, generic random-based obstacle-aware UAV mobility models have been introduced by the authors of [22]. However, these approaches focus on high-level mobility and lack of a realistic representation of the acceleration dynamics. In comparison to these approaches, LIMoSim combines high-level mobility modeling with validated low-level acceleration models. This method is comparable to the common approach used used in the car simulation domain.

In order to interconnect the mobility simulation with a network simulator, the majority of existing approaches applies a High Level Architecture (HLA)-based method. Popular examples are *iTETRIS* [24] which integrates SUMO [17] and ns-3 via the Traffic Control Interface (TraCI) protocol. A similar workflow is implemented by *Vehicles in Network Simulation (Veins)* [34] for *Objective Modular Network Testbed in C++ (OMNeT++)*. Although HLA has a long tradition in the performance analysis of wireless communication networks, as it allows to derive highly accurate simulation setups based on specialized tools, it has a number of disadvantages:

- **Complexity**: Although hybrid vehicular networks can be simulated with a combination of existing tools, this approach is not very practical. It requires to execute and synchronize at least three different system processes (network simulator, car mobility simulator, UAV mobility simulator) which results in a highly complex simulation setup.
- **Performance**: As a consequence of the setup complexity, computation and memory resources are wasted on the required coordination within the simulation setup itself. This aspect is further analyzed by the authors of [15] which analyze the scalability of integrated and HLA-based co-simulation approaches.
- **Maintenance**: Since the different frameworks are developed further independently from each other, compatibility issues might occur when new framework versions are introduced.
- **Usability**: For anticipatory mobile networking, the protocol-based synchronization is a non-intuitive way of data exchange between the mobility and communication domains which requires dedicated serialization and parsing for each newly integrated method.

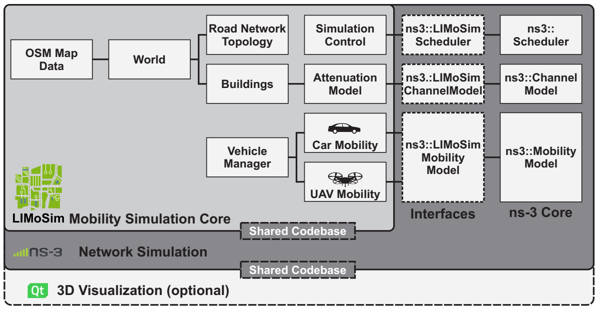


Figure 2: Simplified class diagrams for the integration of LIMoSim into ns-3.

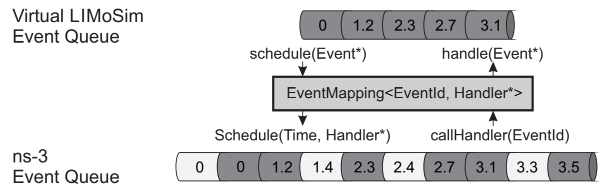


Figure 3: Mechanism for the event synchronization between LIMoSim and ns-3.

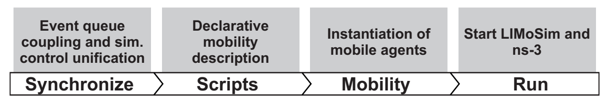


Figure 4: Logical steps that establish a joint simulation setup.

Instead, the integrated simulation approach of LIMoSim provides a more lightweight alternative as it brings together the different logical domains in a single system process. In addition, the shared-codebase coupling – mobility and communication interact based on C++ pointers – explicitly targets the development of novel anticipatory communication methods that exploit synergies between the different logical domains.

3 SIMULATING HYBRID VEHICULAR NETWORKS WITH LIMOSIM AND NS-3

Although the regular operation mode is the joint simulation of LIMoSim with a coupled ns-3 instance, LIMoSim does not have any code dependencies to the latter or any other external library. Objects of the LIMoSim core are not aware of their ns-3 execution environment. This design approach allows to execute *standalone* simulations focusing only on the mobility behavior of the vehicles. The interplay between LIMoSim and ns-3 as well as the most important modules is shown in the system architecture model in Fig. 2. Optionally, the mobility behavior of the vehicles and their 3D environment is visualized online based in an OpenGL-based User Interface (UI) which is implemented in `Qt C++` (see Fig. 6). In addition to the online visualization capabilities, LIMoSim features a native rendering engine for exporting screenshots of the 3D environment in a vector graphics format. In the following paragraphs, we give an overview about simulation control, mobility handling and obstacle-aware channel modeling.

3.1 Coupling of LIMoSim and ns-3

While the vast majority of existing approach relies on Interprocess Communication (IPC)-based coupling (see Sec. 2), LIMoSim implements a fundamentally different method to interconnect the logical domains. Instead, its mobility simulation core is directly embedded into ns-3 using a *shared codebase* coupling method. In order to support the explicit focus on the development of anticipatory vehicular communication systems, LIMoSim allows intuitive pointer-based direct interactions between C++ objects of the two domains.

LIMoSim uses its own logical event handling system in order to be agnostic to and independent from the coupled network simulator. However, if LIMoSim is coupled to ns-3, the event scheduler of the latter takes over control about the event handling mechanisms. Fig. 3 illustrates the involved event synchronization process. Mobility related events issued by LIMoSim are seamlessly integrated in the ns-3 event queue and transparently handled through a mediator class which transforms the events between the different simulation domains and invokes the corresponding event handlers.

For the establishment of a joint simulation setup, different steps are processed sequentially. Fig. 4 provides an overview about the resulting processing pipeline. The first step synchronizes both event queues and unifies the simulation control. This allows both frameworks to manipulate the event scheduling mechanisms of the active simulation – e.g., for pausing the simulation with the LIMoSim UI. Next, the ns-3 simulation script is processed. A dedicated helper extension is used to define LIMoSim mobility is associated to ns-3 nodes in a declarative fashion.

The mobility definitions are then used in the next step by the helper extension to automatically instantiate the mobile agents in LIMoSim and configure them to be linked to their ns-3 counterparts. The linker installs an `ns3::LIMoSimMobilityModel` that is derived from the ns-3 base class `ns3::MobilityModel` on the ns-3 nodes. In addition, mobile agents which do not belong to the LIMoSim domain – e.g., purely ns-3-based entities – can be registered in LIMoSim for visualization purposes

3.2 Hierarchical Mobility Modeling

Within ns-3, agent-based vehicular mobility simulation is performed based on `ns3::LIMoSimMobilityModel` which acts as an interface between the two framework domains. It is derived as a subclass of `ns3::MobilityModel` class of ns-3 and supports `ns3::MobilityHelper`-based simplified installation on ns-3 nodes. All LIMoSim vehicles are derived from the abstract `LIMoSim::Vehicle` class and are automatically registered to the event handling system upon instantiation. Further details about the analytical foundations of the vehicular mobility models are described in [31] and [32]. Fig. 5 summarizes core components of the hierarchical mobility models for both agent types which are further described in the following paragraphs.

Ground vehicle mobility models are implemented within the `LIMoSim::Car` class. It consists of two main submodels:

- High-level behaviors are represented by a **strategic model** which is responsible for target definition and routing processes and supports random as well as deterministic path planning methods.
- Cruise control and velocity dynamics are handled by a **follower model** which updates the current acceleration of a vehicle with respect to the velocities of nearby traffic participants and the traffic rules. For this purpose, the well-known Intelligent Driver Model (IDM) is implemented according to [35].

Aerial mobility relies on the hierarchical model proposed by [23] which consists of three logical layers that are brought together in the `LIMoSim::UAV` class:

- **Action selection** specifies the general behavior characteristics of the UAV and allows to implement *role*-based primitives (e.g., *aerial sensors* aim to stay close to defined ground vehicles, *aerial relays* maintain LOS to a cellular base station).
- **Steerings** are high-level mobility routines for a well-defined task that are executed in parallel. They are used for following a defined trajectory, for avoiding collisions with buildings and other vehicles, and for maintenance of a swarm coherence which ensures a certain level of connectivity. Within each update iteration, the result of each steering is a *steering* vector which represents the desired movement in the next step. The final steering vector is computed as a weighted average of all individual vectors.
- **Locomotion** represents the physical motion and separates the logical vehicle control from the actual execution platform. Within LIMoSim, these low-level mobility functions based on analytical 3D acceleration and orientation models according to [18]. On this layer, also the propulsion-related power consumption is computed based on the model of [36] which allows to simulate joint optimization of mobility and communication for battery lifetime improvements.

Mobility prediction is an enabling method for anticipatory mobile networking. Thus, LIMoSim provides a mobility control-aware prediction mechanism that allows to forecast the future position $\mathbf{P}(t + \tau)$ for a given prediction horizon τ. The default implementation for the UAV mobility prediction is based on the proposed hierarchical prediction model of [28] which exploits knowledge about steering vectors as well as waypoint information if available. A similar method is implemented for the ground-based vehicles where navigation system knowledge is used to forecast position estimates in a trajectory-aware manner. The effectiveness of this approach has been proven in real world experiments [29] where mobility predictions are jointly used with network quality maps in order to schedule vehicular sensor data transmissions with respect to the expected network quality. All prediction mechanisms are impacted by uncertainties in the actual low-level mobility dynamics which depend on the traffic dynamics.

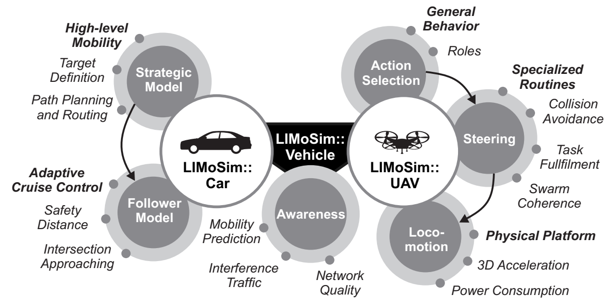


Figure 5: Overview about the core components of the hierarchical mobility models for cars and UAVs.

3.3 Air-to-Ground Channel Modeling

LIMoSim provides native support for OpenStreetMap (OSM) data and can optionally represent buildings as three-dimensional obstacles that cause attenuation to the radio signals via the `LimoSim::Building` class. Although ns-3 itself provides capabilities for simulating shadowing-related attenuations, we decided to implement this feature in the LIMoSim domain since buildings act as physical obstacles that require collision avoidance routines for the aerial vehicles and are logically non-communicating entities of the environment. `C++`-level access to buildings and all other world objects (e.g., road segments) is provided via the `LimoSim::World` singleton. For given receiver and transmitter positions $\mathbf{P}_{\text{RX}}(t)$ and $\mathbf{P}_{\text{TX}}(t)$, the attenuation model computes the three-dimensional obstructed distance d_{obs} with respect to the intermediate building intersections. Within ns-3, this information is then utilized for channel modeling with the `ns3::LIMoSimChannelModel`. In particular, the typical air-to-ground channel dynamics (see Sec. 2) between LOS and NLOS situations can be modeled automatically. A caching strategy is used to allow a resource efficient usage of the `ns3::LIMoSimChannelModel` to determine attenuation caused by the buildings in the simulation scenario. Within the simulations, the channel conditions are frequently re-evaluated by ns-3 which leads to path loss computations being repeated multiple times for the same or similar spatial configurations, thus yielding the same results. Caching allows to reuse the results of previous computations for identical or similar receiver and transmitter positions in order to reduce the computational overhead.

4 CASE STUDIES

In this section, we present two case studies that show the usage of LIMoSim in hybrid mobility applications and in coexistence with established ns-3 extension frameworks. The traffic patterns of the communicating vehicles are chosen with respect to the application-specific requirements discussed in [38]. The evaluations are performed within a suburban environment near a university campus. Fig. 6 shows a map of the resulting simulation scenario within LIMoSim. The simulation parameters are summarized in Tab. 1.

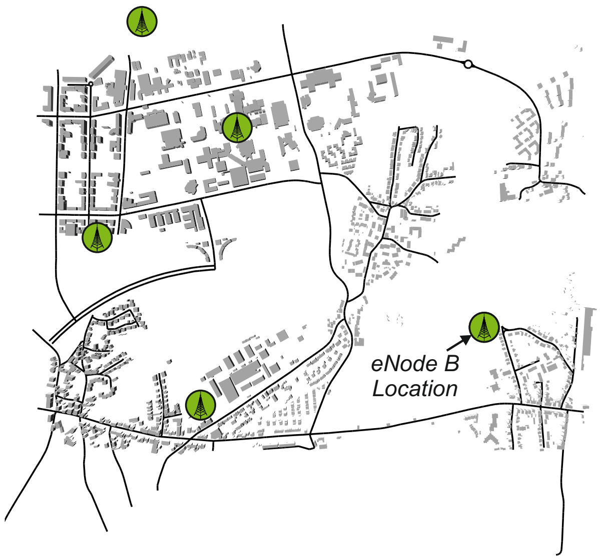


Figure 6: Overview about the considered evaluation scenario. (Map data: © OpenStreetMap contributors, CC BY-SA).

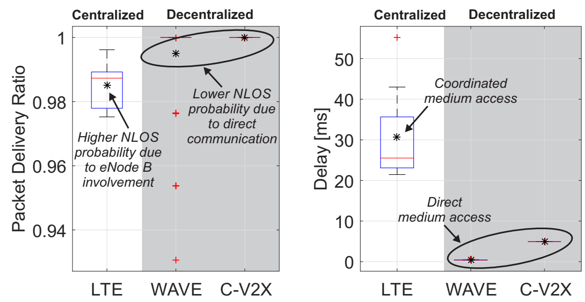
Table 1: Simulation Parameters

	Parameter	Value
General	Simulation duration per run	30 min
	Number of simulation runs	50
	UAV fleight height	30 m
	Channel model	ns3::LIMoSimChannelModel
C-V2X	Carrier frequency	5.9 GHz
	Bandwidth	20 MHz
	P_{TX} (UE)	23 dBm
LTE	Carrier frequency	2.1 GHz
	Bandwidth	20 MHz
	P_{TX}(UE)	23 dBm
	P_{TX}(eNB)	43 dBm
mmWave	Channel model	3GPP UMi Street Canyon (LOS)
	Carrier frequency	28 GHz
	Antenna array	Planar eight–by–eight
	Beamforming	Analog
	Beam alignment	Geometry–based LOS (ideal)

4.1 Case Study 1: UAVs as Aerial Sensors

In the first case study, UAVs are exploited as *aerial sensor* nodes that provide ground vehicles with potentially safety-relevant information for raising their situation-awareness. Similar to the ongoing discussions in Vehicle-to-Vehicle (V2V) networking, the usage of different communication technologies are in the focus of the analysis.

Implementation: Within LIMoSim, the use case is modeled with five vehicle pairs composed of one UAV and one car each. The latter move freely through the whole scenario based on a random direction mobility model. All UAVs operate at a constant flying height and aim to maintain a close distance to their assigned ground vehicle. Each 100 ms, the UAVs transmit Cooperative Awareness Messages (CAMs) consisting of 190 Byte sensor data to their corresponding cars. Three different communication technologies are applied and compared using the same mobility configuration. LTE (based on LTE-EPC Network Simulator (LENA) [4]) is used as benchmark technology that implements a *centralized* medium access approach. In addition, we compare WAVE-based IEEE 802.11p and C-V2X (based on [9]) as representatives of *decentralized* medium access approaches. For LTE, the evolved Node Bs (eNBs) are positioned according to corresponding real world locations as shown in Fig. 6.



(a) (b)

Figure 7: Comparison of end-to-end performance metrics for different communication technologies in the aerial sensors use case.

Results: The overall results for Packet Delivery Ratio (PDR) and delay for the different communication technologies are shown in Fig. 7. All technologies are able to provide robust communication links. However, the decentralized approaches represented by C-V2X and WAVE exhibit higher reliability with a PDR very close to 1. Due to the direct transmission path between sender and receiver, the probability for NLOS situations is lower than for LTE where the eNB is also involved in the communication process. In the considered scenario, C-V2X achieves a slight better reliability than WAVE due to the Semi-persistent Scheduling (SPS)-based medium access which takes the previous resource reservations into account in order to avoid resource conflicts in the future resource reservation periods. A similar tendency between both medium access approaches is observed when considering the latency. The decentralized approaches – which implement direct medium access strategies – yield a smaller latency as opposed to LTE which handles the resource reservations centrally.

For LTE, an example for the temporal dynamics of the Reference Signal Received Power (RSRP) for a cooperating pair of ground and flying vehicles is shown in Fig. 8. The different obstacle-related attenuation characteristics for the ground- and air-based vehicles can be clearly distinguished. While the car is subject to high attenuation peaks caused by signal shadowing from the nearby buildings, the flying altitude of the UAV results in a non-obstructed LOS to the eNB for the whole shown time period.

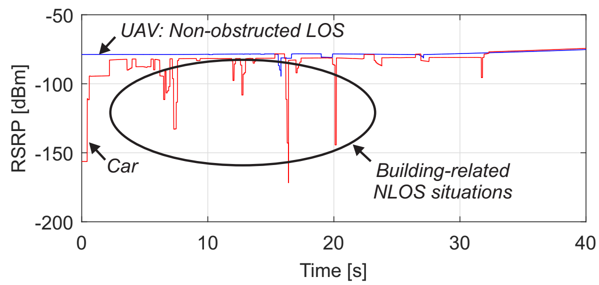
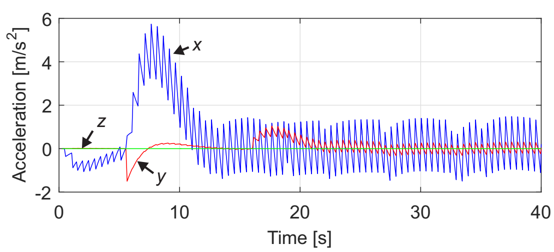
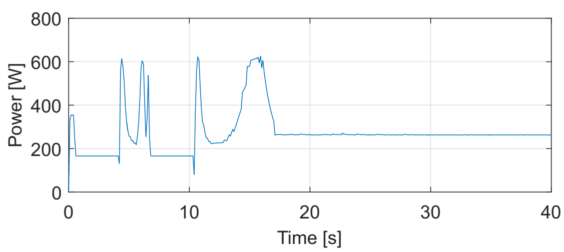


Figure 8: Example temporal behavior of RSRP for aerial and ground vehicles.



(a)



(b)

Figure 9: Exemplary excerpt of the temporal dynamics of the three-dimensional acceleration and resulting power consumption for an example UAV operating at a constant operation height.

Furthermore, an example for the interdependency between acceleration dynamics and resulting power consumption for the UAV is shown in Fig.9. Since the UAV operates at a constant flying height in the considered case study, there is no acceleration in the z dimension. The resulting power consumption is the effect of the acceleration dynamics.

4.2 Case Study 2: Millimeter Wave-based Data Transfer

Due to the vast amount of available radio spectrum, mmWave communications is appealing for increasing throughput demands within 5G mobile radio networks and beyond. However, the higher frequencies offer more challenging radio conditions, which are believed to be compensated by means of beamforming, antenna arrays and directional communications, among others. This means, exploiting the antennas' electronically

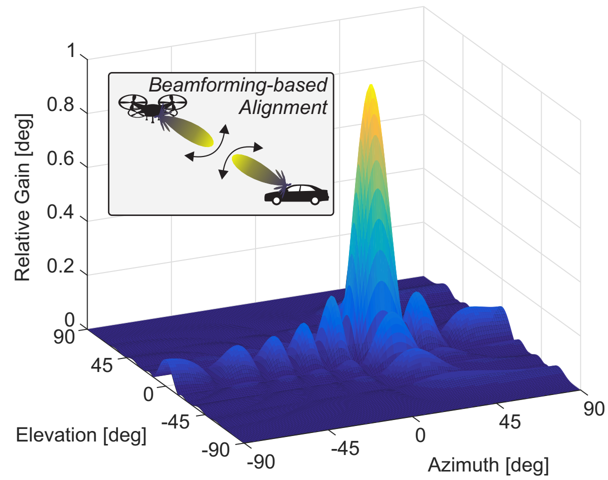


Figure 10: Exemplary pencil beam pattern for pointing direction of azimuth = 20° and elevation = 0° generated by means of analytical models of microstrip patch elements and an eight–by–eight boresight array with half–wavelength element spacing.

steerable, directional gains is crucial for a stable connectivity. Subsequently, the utilization of beamforming antennas necessitates a proper alignment of the beams. For this reason, the applicability of this approach within dynamic scenarios and user mobility states a major field of scientific research. Together with the ns-3 mmWave module, LIMoSim offers the possibility of merging mobility simulation into mmWave beam alignment related research topics. In a first step, the physical mobility characteristics are provided for exemplary channel models. However, more sophisticated models and communication–aware mobility may be implemented on demand by leveraging the prepared interfaces and subroutines.

Implementation: For the assessment of the behavior of mmWave-based data transfer in vehicular scenarios, a common analytical model of the pencil beam characteristic is implemented according to [3]. An eight–by–eight planar broadside array is assumed to contain microstrip patch elements at a half–wavelength spacing. Due to the patch characteristic, the angular coverage space is limited to reasonable pointing directions with a maximum deviation from boresight of 60°. In Fig. 10, a model of the directional antenna gain is illustrated for an exemplary pointing direction of 20° and 0° for azimuth and elevation, respectively. This antenna model can be regarded as a generic implementation, which may be extended as required. However, it suffices for simulating beam alignment of transmitter and receiver. The antenna gains derived using the analytical pencil beam characteristic from [3] are supplied to the mmWave module [20] thus enabling online beamforming gain computation. An ideal beam tracking according to the geometric LOS direction is used as preliminary beam alignment method for the mmWave link. Within the case study, a mmWave communication link between a base station UAV and a ground vehicle as mobile subscriber is considered. The scenario defines a travel route for the ground

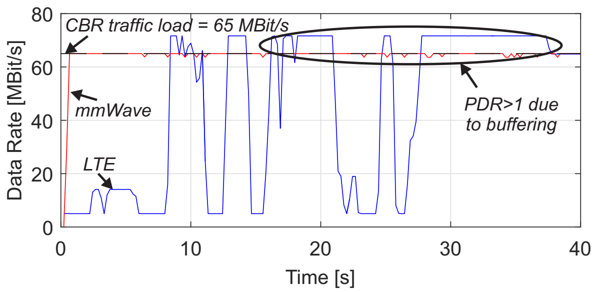


Figure 11: Temporal behavior of the resulting data rate for LTE and mmWave with 65 MBits/s traffic load.

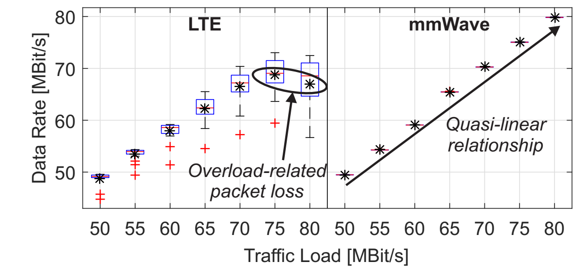
vehicle, while the UAV is following the latter at a constant altitude. Simultaneously, the mmWave radio link is used for data streaming. We consider different intensities of User Datagram Protocol (UDP)-based Constant Bitrate (CBR) traffic load and compare the behavior of the mmWave data transfer with a reference LTE-based setup.

Results: At first, the temporal dynamics of the CBR data stream are analyzed for both technologies. Fig. 11 shows an excerpt of the resulting behavior characteristics for a targeted traffic load of 65 MBit/s. While mmWave provides a constant performance level close to the targeted traffic load, the LTE transmission link behaves much more dynamic and alternates between periods of low and high data rates. The latter is because the transmission buffers are filled and flushed with respect to the network congestion. Hence, the resulting data rate sporadically exceeds the targeted traffic load.

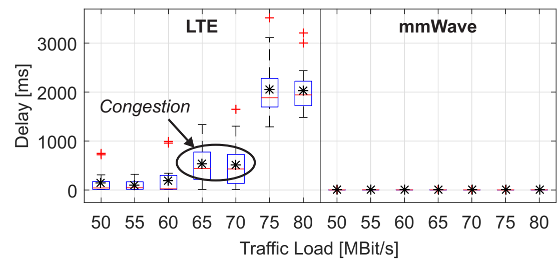
The overall results for data rate and delay are shown in Fig. 12 for different amounts of traffic load. While the mmWave variant achieves a homogeneous performance for all simulated amounts of traffic load, different phases can be identified for LTE: For lower traffic loads, the achieved data rate and delay behave similar for both radio link types. The effects of a raising congestion level first manifest in the delay performance. For medium traffic loads, the average delay as well as the delay variance are significantly increased due to the involved buffering effects. For high traffic loads, the network overload results in packet loss and a reduced data rate. On the contrary, the large amount of available bandwidth allows the mmWave technology to provide an approximately linear relationship between the offered traffic load and the resulting data rate with a low variance. Additionally, the delay appears consistently low regardless of the offered traffic.

5 CONCLUSION

In this paper, we presented the open source LIMoSim framework which extends the ns-3 ecosystem with support for joint simulation of hybrid ground-based and aerial communication networks based on the foundation of well-known analytical models for the low-level motion. In contrast to existing approaches, LIMoSim couples mobility and communication simulation in an integrated way and in a single system process. This method enables direct (code-level) interactions between the entities of the different logical domains. Based on two



(a)



(b)

Figure 12: Data rate and delay of mmWave communications compared to a conventional LTE link.

different case studies that focus on recent topics of vehicular networking, we have shown how LIMoSim can be integrated into ns-3-based hybrid vehicular network simulations. Currently, we are investigating the integration of reinforcement learning-based mechanisms for mobility control and networking. Furthermore, we aim to bring together LIMoSim with Data-driven Network Simulation (DDNS) [33]. In addition, we will provide online visualization capabilities also for the communication processes.

ACKNOWLEDGMENT

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