A universal realistic scenario for wireless communication network simulations

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Abstract—The increasing demand for higher data rates and better quality of service necessitates the development of new mobile communication systems. For the evaluation and assessment of these systems, network simulations play a decisive role since the complexity of these systems does not always allow for analytical system performance evaluations. Due to higher computation time and a high expenditure of work in developing a realistic simulation scenario, hexagonal scenarios are still state of the art in wireless network simulations. The trouble is that hexagonal simulation scenarios do not reflect the irregularities of the reality and this may cause design defects. Hence, we propose a realistic simulation scenario that covers the important characteristics of real wireless communication networks.

I. INTRODUCTION

The roll-out of wireless networks with new communication technologies is always a high risk for mobile network operators. Due to high investment cost for the network expansion, the operators are interested in evaluating the prospective capabilities of the communication technology before the deployment. Beyond that the performance has to be evaluated to assure a high quality design of the new wireless communication technology. Hence, system simulations that model the effects of user mobility, the radio channel and the environment including buildings and vegetation have to be accomplished.

Due to the high complexity of realistic network scenario layouts, hexagonal scenarios are state of the art in wireless network simulations. However, some important effects that influence the system performance might not be covered by hexagonal scenario assumptions. On the other hand freely available environment data and open source software ease the development of realistic simulation scenarios. The open source project Openstreetmap for instance provides detailed information about the street network that can be used to build up a mobility model for car movement. The same data base can be used to create land-use maps for the simulation area.

In this paper we will describe how a realistic simulation scenario can be developed using freely available data and open source software as follows. In chapter II we present the modeling tools that were used to create the realistic simulation scenario. The geographical data that is needed for the development of a realistic scenario is described in chapter III. Chapter IV describes the realistic simulation scenario in Braunschweig that we created and chapter V gives some example applications for the realistic scenario. The final conclusions and outlook are given in chapter VI.

II. MODELING COMPONENTS

**SUMO - Simulation of Urban MObility:** SUMO is an open source, microscopic road traffic simulation package that is mainly developed by the Institute of Transportation Systems at the German Aerospace Center [1][2]. Based on the road network, the inflow and outflow of cars into the scenario and the turning ratios at the street intersections, SUMO calculates the car positions in the street network in a given time interval. The level of detail of this microscopic road traffic simulation includes the interaction of the cars (lane changes, braking, acceleration, overtaking, etc.) as well as traffic light control.

**Ray-Tracer:** A 3D ray-tracing approach determines the complex behavior of the frequency-selective radio channel as shown in Figure 1. For each ray, polarization matrices and full-polarimetric antenna patterns are used. In the current implementation, the direct path, specular reflections as well as diffuse scattering are considered. The reflections are calculated with the aid of the image method up to 3rd order reflections. Scattering is taken into account by determining single scattering processes on all visible surfaces. The scattering loss is calculated using the model of a Lambertian emitter. The path loss is calculated by a complex superposition of all multi path components of the determined channel impulse response.

![The 3D ray-tracer](image)

III. GEOGRAPHIC DATA

In this chapter, the different types of geographical data that are needed to create a realistic simulation scenario are listed.

**Building data:** The shape of buildings and the arrangement of buildings, transmitter and receiver in a wireless communication network influences the wave propagation between...
the transmitter and receiver. This effect is known as shadow fading or slow fading. In order to increase the accuracy of the propagation model the building data should be available as vector data. Besides the network operators and the individual city councils, Internet platforms like Google Earth or Bing Maps provide information about the buildings in 3D. However, this information is still limited to the most important buildings in the cities and depends on the user contributions in the individual area.

Land-use data: Land-use data is used for two different purposes: to distinguish between indoor and outdoor locations and to provide additional environment information for empiric propagation models. In the OpenStreetmap project [3], freetime cartographers collect geographic information to create a freely available map of the world. The maps include the street network, commercial and residential zones, train tracks, rivers and lakes, forests and grassland, etc. The data can be converted using a huge variety of software tools. Thus the land-use information can easily be extracted from the OpenStreetmap maps.

Terrain height data: The shape of the terrain influences the wave propagation as well. The height information becomes more important if the height variation in the simulation scenario is larger. For large variations, the terrain height has an influence on the line-of-sight or non-line-of-sight condition of a transmitter and receiver. Terrain height data is publicly available from the Shuttle Radar Topography Mission (SRTM) [8].

Road network: Users that travel with high speed through a wireless communication network are always a challenge in terms of radio channel variations, handovers and Doppler frequency shift. Hence, high-speed users are crucial for many system simulations. Users that are located inside vehicles belong to the group of high-speed users and since they are present in rural, urban and dense-urban areas they should be included in system simulations. The basis for a street mobility model is the road network of the simulation area. Possible sources for the road network data are again the OpenStreetmap project or the vector data for navigation systems.

Traffic data: The traffic density influences the load of the individual eNodeBs and therefore the call generation in the system simulations. Besides the network operators that keep this information a secret traffic maps can be generated from the land-use information. An exemplary model has been developed in the MOMENTUM project[9].

Network layout: The position, height and the arrangement of the eNodeBs and antennas are the basis for system simulations. This information is only available to the network operators for their real networks. Local knowledge of suitable antenna locations, a mean site-to-site distance based on the used transmission frequency and the building information can be used to create a simulation network. In this case, the network might need some optimization to increase the performance.

IV. THE BRAUNSCHWEIG SCENARIO

Based on the modeling components and geographic data that we described in the last two chapters we have built a realistic simulation scenario in the city center of Braunschweig. The building data was taken from vector data of the city council of Braunschweig that is available at our institute. Figure 2 shows the building data in the simulation area. The simulation area is 1.5 times 1.5 kilometers large. The terrain height information was provided by the city council as well.

The land-use maps are based on the maps provided by the OpenStreetmap project. The converted land-use maps contain five different land-use classes: street, building, natural, water and rail. A small part of the land-use map that includes the simulation area is depicted in figure 3.

The road network is build from vector data for navigation systems from the company Tele-Atlas (version 2003.3). In this version the information about the number of lanes per road where not included. Hence this information is added manually from local knowledge.

The antenna positions and teletraffic maps were provided by a network operator for the Braunschweig scenario. Nevertheless this information could have been added from local knowledge and from the land-use maps as well.
The pathloss between the users and the eNodeBs is calculated by the ray-tracer introduced in chapter II. The ray-tracer computes the pathloss in a 10 time 10 meter grid. In a real network the channel conditions change in a much finer grid than the ray-tracer can provide. The reason for this is the large computation time that is needed to compute the pathloss information. Hence we add additional shadow fading with a standard deviation of 3 dB and a resolution of 1 times 1 m to the pathloss to account for accuracy deficiency of the ray-tracer pathloss resolution. The shadow fading maps for the eNodeBs are computed using a shadow fading model including the alternating projection method that is further described in [7]. A small part of the resulting fading map is shown in figure 4.

![Two dimensional correlated fading map](image)

Fig. 4. Two dimensional correlated fading map

In the current configuration the Braunschweig scenario includes mobile users only. The users positions are generated using the microscopic road traffic tool SUMO. Hence all users are located on the streets and travel with speeds between 0 and 50 km/h. Every 0.1 s a new position is available for every user in the simulation.

V. FIELD OF APPLICATION

In this section we show how the realistic scenario can be used for dynamic simulations of different wireless systems like LTE or V2V communication (IEEE 802.11p). Figure 5 shows the concept of our integrated simulator. The basis for the simulation is the scenario data described in this paper which provides the input to both the road traffic simulator and the radio channel simulator. The core of the whole simulator is the network simulator interacting with the two other simulators via dedicated interfaces. Positions of the mobile devices are generated by the road traffic simulator and forwarded to the network simulator, which asks the radio channel simulator for the path loss values on the TX-Rx-link. Both the road traffic and the propagation channel simulator can be operated in an online and an off-line mode. In the off-line mode positions and path loss values are pre-processed, whereas in the online mode this data is generated during the simulation runtime. The network simulator can be exchanged depending on the specific system to be simulated. For V2V communication OMNet ++ is used [4] whereas for LTE an in-house developed simulator based on MATLAB is used [5].

**LTE system level simulator:** We introduce the LTE system-level simulator as an example application for the realistic simulation scenario. The flowchart of the LTE system-level simulator is depicted in Figure 6. This network simulator is used to examine the network performance, e.g. the handover performance for different handover parameter settings. The considered control parameters for the handover optimisation are the time-to-trigger and the hysteresis.

![Flowchart of the LTE system-level simulator](image)

Fig. 6. Flowchart of the LTE system-level simulator

Figure 7 shows the network performance in terms of the call dropping ratio for different handover parameter combinations for the realistic Braunschweig scenario and for a reference hexagonal scenario. The high ratio of call drops for small time-to-trigger and hysteresis values in the realistic scenario can only be explained by the characteristics of the environment. Some of the mobile users that stop at a red traffic light handover to a cell with a main beam along a street canyon. This cell is not visible anymore after the users left the street intersection. This behavior results in a high call dropping ratio that can only be observed in the realistic simulation scenario. In the reference hexagonal case call drops can only be observed for very high time-to-trigger values.

Another application is the analysis of the impact of different scheduling approaches on the system throughput. Figure 8 shows the performance of a round robin and a proportional fair scheduler over time. For these simulations the same system level simulator is used.

**V2V communication simulator:** For the investigation of
different aspects of Vehicle-to-Vehicle (V2V) communication systems, the network simulation part is replaced by either a Physical (PHY) or a higher layer simulator.

On the one hand, a PHY simulation environment is used in order to explore the feasibility of future V2V communication systems. The simulation environment emulates a complete transmission chain in the complex baseband according to the IEEE 802.11p standard, which is the dedicated standard for future V2V communication systems. For the description of the radio channel, the ray-optical model is used. For each antenna pair, a time-variant channel impulse response, which completely characterizes the frequency-selective channel, is available. The resulting system performance can be evaluated by means of bit error (BER) and packet error rates (PER). Dependent on the data rates, which range from 3 to 27 Mbit/s, and different dense urban propagation conditions, the behavior of the BER and PER depending on the signal-to-noise ratio can be determined. In particular, the investigation of state-of-the-art channel estimation approaches [6] is of interest.

On the other hand, a network simulation, based on OMNeT++ and its INET Framework extension for the investigation of the higher protocol layers, is used [4]. The network simulation is an important instrument in the development process of protocols for vehicular networks. Since the detailed simulation of the PHY layer including small-scale channel effects is very time-consuming, only an abstracted PHY is included. For each communication link, the signal-to-noise ratio based on the time-variant channel impulse response is determined and mapped to a specific BER. This mapping procedure is derived from the results of the PHY simulations for the corresponding propagation environment.

VI. CONCLUSION & OUTLOOK

Network characteristics that are not covered by hexagonal simulation scenarios may influence the system performance of modern wireless communication networks. In this paper it has been shown how realistic scenarios can be generated based on mainly publicly available data. The benefits of realistic scenarios compared to traditional hexagonal scenarios are shown. The further increasing availability of freely accessible geographic data will pave the way for the application of realistic scenarios instead of hexagonal scenarios even in dynamic system level simulations.

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