A Physical Layer Simulator Based on Radio Wave Propagation for LTE Cellular Networks

Xiang Xu, Florian Schroeder, Bayram Gevrekce, Gledi Kutrolli, Mingjian Ni and Rudolf Mathar
Institute for Theoretical Information Technology, RWTH Aachen University
Aachen, Germany 52074
Email: {xu,schroeder,gevrekce,kutrolli,ni,mathar}@ti.rwth-aachen.de

***Abstract*—In this paper, a simulation framework for the physical layer of LTE cellular networks is presented. In this frame work, a semi-stochastic channel model (SSCM) based on ray launching is adopted to provide accurate prediction of the channel. The movements of mobile stations are represented by a mobility model, which take the real world restrictions into consideration. The geographical information needed by the simulator can be collected from open source database. Furthermore, the location-specific channel information is sent back to the base station by the feedback of channel quality indicators (CQI).**

***Index Terms*—Wireless networks, LTE, simulation, ray launching, semi-stochastic channel model**

I. Introduction

With the world wide deployment of LTE networks, the need for simulating LTE systems becomes evident. Currently, there are simulators with their source codes publicly available [1] [2]. In these simulators, geometry-based stochastic models, such as WINNER model [3] or 3GPP spatial channel models (SCM) [4], are generally employed to describe wireless radio channels.

Additionally, there are works dedicated in predicting signal strength using ray launching for LTE systems [5]. However, these works commonly stop at macroscopic level, without producing the baseband channel matrices. Commercial LTE simulators using ray tracer are also available, but usually too expensive for academic usage.

As one of the important features of LTE, the self-organizing networks (SON) provide easy self-configuration, self-optimization and self-healing [6]. The self-organizing properties minimize human efforts in operating the networks, while machines must be able to assess the information about the network and make use of it. Consequently, the evaluation of SON functions requires simulation of networks operating in specific locations with specific network planning, user distributions, traffic distributions, etc..

In geometry-based stochastic models, limited information about the propagation environment is taken into account. The result is, that the outcome of such simulators is idealistic. Thus, geometry-based stochastic models do not meet the demand of SON applications. Therefore, in the proposed simulator, the radio channel is generated by a technique which combines deterministic radio wave propagation prediction and stochastic channel modeling.

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Although the concept of radio wave propagation prediction using ray launching is not new [7], recent developments in hardware for parallel computing have made it realizable for large area in a moderate amount of time [8]. A semi-stochastic channel model, which takes the output of the ray launcher as input and provide site-specific channel models, is used to generate radio channels for the proposed simulator. The SSCM benefits from the knowledge of the propagation environment while keeping the randomness like the geometry-based stochastic models.

Other contributions of this work include:

- Mobility models for the mobile stations. By acknowledging the geographical restrictions for the mobile users, realistic mobility patterns are able to be recreated.
- Acquiring necessary geographical information from open source library. By using open source data, this simulator can be directly applied to most of the European cities.
- Generation of LTE standard feedback information. The parameters for generating CQI are obtained from a link level simulator. The channel condition of mobile stations is feed back to the base station for the purpose of simulating upper layer functionalities.

In LTE terms, base station and mobile station are also called eNodeB (eNB) and user equipment (UE), respectively.

II. Simulator Structure

A. Preliminaries

An important feature of LTE systems is self-organization. To achieve self-organization, eNB must repeatedly assess capacity and coverage for all the served UE and adjust certain parameters accordingly. Since the performance indicators should be constantly tracked, LTE simulators with the purpose of evaluating self-organization are meant to be time triggered rather than event triggered [9].

Furthermore, resource management of cellular systems strongly depend on the received signal strength of each UE. The centralized resource management mechanism at base stations requires channel state information from all UE. In LTE standards, this requirement is fulfilled by the feedback of CQI, where CQI is highly compressed information about the signal to interference and noise ratio (SINR).

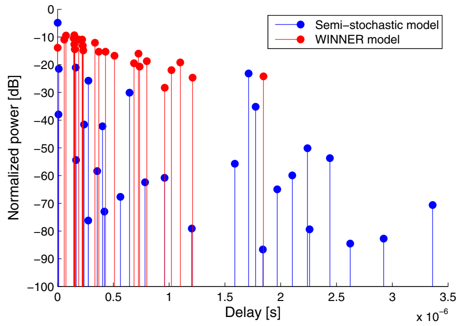


Fig. 1. Comparison of power-delay profile between WINNER C2 model and SSCM

Therefore, to simulate LTE networks, the wireless channel between eNB and UE should be generated periodically using the geographical information. After that, SINR can be calculated and compressed into CQI accordingly.

The work flow of the LTE simulator is as follows. Firstly, in the pre-processing part, necessary environment data is provided for the ray launcher to calculate macroscopic field strength and identify propagation paths. Secondly, in the main part, with knowing the position of UE, multi-path channel impulse responses can be generated according to a semi-stochastic process. Finally, the channel condition is summarized into a single CQI value at the UE as feedback.

B. Macroscopic Field Strength Prediction

Ray launching has been proved to be an effective tool for predicting field strength in a macroscopic level [10]. With efficient implementation, the ray launching tool PIROPA (Parallel Implemented Ray Optical Prediction Algorithm) can achieve close-to-measurement performance in a moderate amount of time [8]. However, most of the previous researches only focused on predicting field strength, taking neither the frequency selectivity caused by multi-path propagation nor spatial diversity caused by multiple antennas into consideration. Since spatial and frequency diversities play a central role in LTE resource management, these properties should not be neglected. As a feature of PIROPA, necessary information about propagation paths can be provided for the purpose of MIMO multi-path channel modeling.

The performance of ray launcher heavily depends on the maps. As a compromise of computational complexity, PIROPA works on 2.5 D maps, which assume the flatness of the rooftops. The map can be obtained from open source libraries, as described in Section III-A.

Due to the time consumption and deterministic nature of the ray launcher, this step is done for the whole simulated area only once before the main simulation and the results are saved for further use.

C. Channel Modeling based on Radio Wave Propagation

In most of the existing LTE simulator, physical channels are simulated by geometry-based stochastic models (e.g. WINNER model),

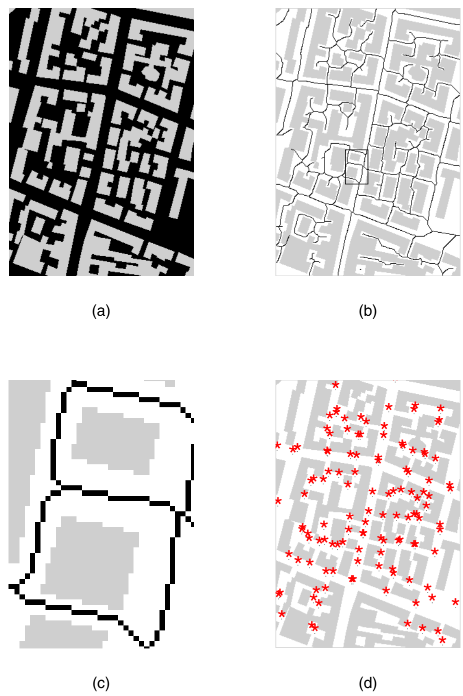


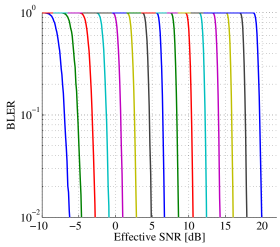
Fig. 2. (a). Original map with information about streets and buildings. (b). Map after thinning algorithm. (c). A close view of the one pixel wide skeleton for chosen area in (b). (d). Automatically detected intersection points

which define the propagation environment with only a small number of propagation scenarios [3]. Although some stochastic characteristics of the wireless channel are catched, location specific geographical data can not be utilized to improve modeling accuracy. For example, the terrain of Budapest is flat on the side of Pest and uneven on the side of Buda. However, with geometry-based stochastic models, one can only choose "Urban" scenario to simulate both areas, and neglect the definite differences between the propagation environments.

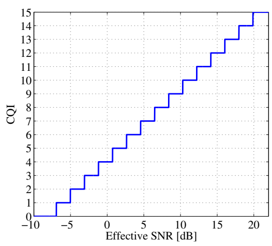
The SSCM takes the information of propagation paths calculated by the ray launcher, such as delay, angle of arrival, as input, and generate the small scale fading channel coefficients using stochastic means. The stochastic behavior of the wireless channel is characterized, while the modeling accuracy is preserved [11]. The normalized power-delay profile (PDP) for WINNER model and an example from SSCM is compared in Fig. 1. Notice that in SSCM, PDP differ even for different location in the same scenario. However, for WINNER model, as long as the scenario is not changed, the PDP stays the same.

D. User Mobility

The most commonly used mobility models for simulating wireless networks are random walk model and random waypoint model. However, both of them ignore limitations on the randomness in moving directions and speeds in real world scenarios. Other models, like Manhattan model and



(a)



(b)

Fig. 3. (a) BLER for CQI 1-15 in AWGN channel. (b) SNR to CQI mapping.

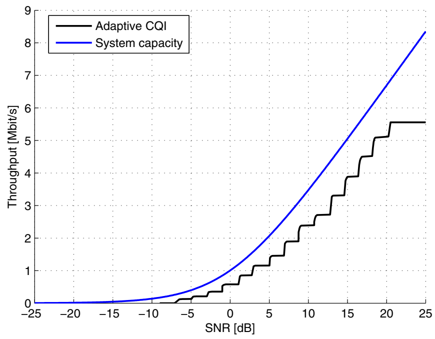


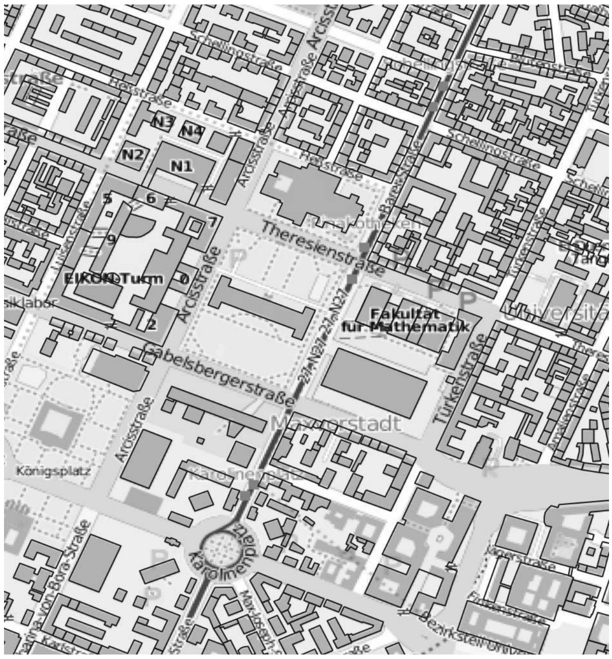
Fig. 4. Compare data throughput from theory and with discrete CQI

restricted random way point model, assume artificial grid-structured maps [12]. Considering the real world constraints for the movements of UE, a hybrid mobility model is adopted in the proposed simulator.

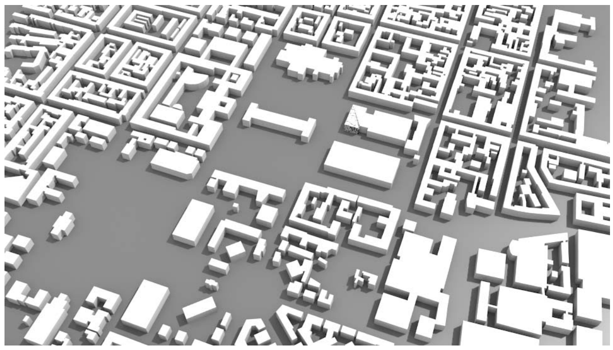
In the novel hybrid mobility model, UE are cataloged according to their movement constraints, e.g. pedestrians have low average speeds with access to most of the place of the map, the movement of the vehicles are faster however restricted by the streets. The streets are described by a set of intersection points, where the vehicular users can only go from one intersection to another. As shown in Fig. 2, the intersection points can be automatically detected on a pixel-based map by first shrinking the streets into single pixel lines and then taking the points which has more than three neighboring pixels. Line thinning algorithms are performed in order to obtain single pixel lines [13].

E. Channel Quality Feedback

In each simulation circle, the mobility model is used to determine the location and speed of the mobile user. Based on the location information, the channel between UE and eNB is simulated then. According to LTE standards, the CQI consists of only 4 quantized bits, corresponding to 15 different modulation and coding schemes (CQI=0 means out of range). The corresponding modulation and coding scheme can be transmitted with a block error rate not exceeding 10% as depicted in Fig. 3 (a). The discretized CQI is generated with two steps. Firstly, the SINR over one subframe is averaged to an effective signal to noise ratio (SNR). After that, the effective



(a)



(b)

Fig. 5. (a) Building information of a part of Munich. Building edges are marked with solid lines. (b) Reconstructed 2.5 D geographical data using uniform building height.

SNR is mapped to CQI with a step function as shown in Fig. 3 (b) [14]. Due to the discrete CQI values, the data throughput differs from the theoretical value, as illustrated in Fig. 4.

With the help of CQI feedback, the eNB is aware of the chnnel condition of UE. Thus, algorithms and protocols for resource management and self-organization can be tested.

III. Implementation Issues

A. Obtaining Geographical Information

To use the semi-stochastic model, precise geographical data is necessary, however usually unavailable. The open source database OSM (Open Street Map) [15] provides free information about the accurate building shapes. The coverage of OSM includes the majority of populated area in Europe. Fig. 5 (a) shows a part of the city Munich.

Since the purpose of OSM is map usage, there is only little of height information, which has to be obtained from other

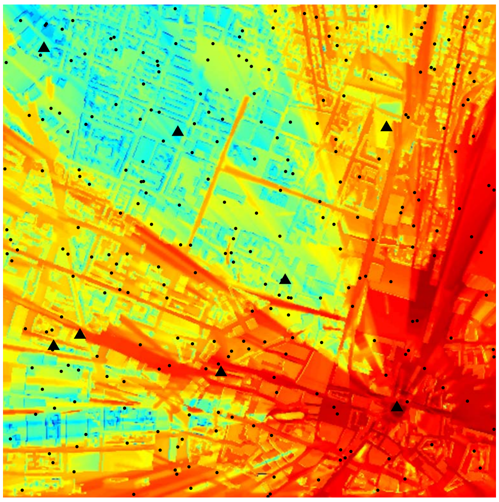


Fig. 6. A snapshot of the LTE simulator for the city of Munich, black dots indicate UE and triangles indicate eNB, signal strength of the lower right eNB is presented in color

sources. As a feature of most European cities, neighboring buildings generally have similar heights. Thus, a uniform height can be assigned to the buildings to achieve a good estimation [16]. Fig. 5 (b) is constructed from the OSM data and an estimation of the height.

Another possible source of height information is the Shuttle Radar Topography Mission (SRTM) data. SRTM is a research project, which gathers elevation data of the surface of earth by using space shuttles [17]. The database is publicly accessible [18]. However, the main problem is resolution of such radar image is generally not enough for determine building heights without extra effort [19]. Therefore, it is an ongoing work to extract building height from SRTM.

B. Software implementation

The implementation of the proposed simulator take both efficiency and availability into consideration. The most time consuming part, namely the ray launcher, is written in `C++` for the sake of efficiency. And the rest is written in `Matlab` to make it easy to use. The computational complexity of the deterministic ray launching grows proportionally to the number of eNB and heavily depends on the density of the buildings and scale of the simulated area, whereas the complexity of the main simulation grows only linearly to the number of UE. The scale of the simulation is only limited by the physical memory of the computer. A snapshot of the simulator is given in Fig. 6.

IV. Conclusion

In this paper, a novel LTE simulator is introduced. Using the SSCM, this simulator is able to provide accurate yet stochastic channel realizations for simulating LTE networks. Other techniques, including mobility models, open source maps and feedback information mapping, make the proposed simulator ideal for recreating physical layer phenomena and generating realistic parameters for testing SON functionalities of LTE networks.

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