A New Mobility Model for Performance Evaluation of Future Mobile Communication Systems

Enrico Jugl and Holger Boche*

Technische Universität Ilmenau, P.O. Box 100565, D–98684 Ilmenau/Germany,
E-Mail: jugl@e-technik.tu-ilmenau.de

*Heinrich–Hertz–Institut für Nachrichtentechnik Berlin GmbH, Einsteinufer 37, D–10587 Berlin/Germany,
E-Mail: boche@hhi.de

Abstract— **Investigating the performance of the new upcoming third and fourth generation mobile communication systems the mobility behavior of the subscribers has to be taken into account. So far mainly simple mobility models are used, leading to high risk of false or too optimistic results. Hence, a more realistic new mobility model is proposed where local as well as temporal properties can be regarded. Thus, it becomes possible to model typical topologies like shopping streets and campus areas. Consequently, more realistic results are obtained, needed for performance evaluation and planning of mobile communication systems.**

I. Motivation

The new upcoming third and fourth generation mobile communication systems will support a large number of mobile subscribers as well as higher data rates compared to current systems. Because of higher data rates the carrier frequencies become higher and higher, 2 GHz for the Universal Mobile Telecommunications System (UMTS) and up to 60 GHz for inhouse systems are under consideration. This leads to a decrease of the cell sizes. Hence, the performance of mobile communication systems strongly depends on mobility and calling behavior of the subscribers. Consequently, realistic mobility models are needed to specify the movement of the subscribers on different scales. On the one hand, they serve to determine the amount of mobility-related signaling traffic like handover and location update signaling as well as the number of database transactions. As a result, the cell and location area crossing rates can be estimated. On the other hand, these models are needed to investigate the capacity gain using Space Division Multiple Access (SDMA) techniques, e. g. by applying a fixed sectorization of radio cells or by applying adaptive antennas. A further aspect is the determination of the channel holding time (dwell time or cell residence time) in a cell which is needed to investigate call blocking and forced termination probabilities. In [1,2] an extensive overview about mobility and teletraffic modeling is given.

Moreover, mobility models are needed for a fair performance evaluation of different system concepts, e. g. by standardization bodies. The standardization of mobile communication systems is a difficult process and often it takes a long time. Usually standardization bodies like the European Telecommunication Standards Institute (ETSI) will pass a selection procedure for that, e. g. included in the technical report concerning the third generation UMTS [3]. Since there is no complete demonstrator available for performance evaluation, several proposals are investigated by means of simulations using extremely simple scenarios. So only very simple parts of the over-all system can be captured, but the system performance under real conditions cannot be verified. Therefore more realistic mobility and traffic models are of essential importance. Those models should reflect reality as good as possible. In the following an example for a too optimistic assessment of the system capacity of the Code Division Multiple Access (CDMA) based North American digital cellular standard IS–95 (Qualcomm proposal) [4] is given. Here, the authors calculated optimistically that a fixed sectorization of the radio cells increases the cell capacity in approximate proportion to the number of sectors [4, 5]. This statement is based on uniformly distributed subscribers without any movement. In [6, 7] it was shown that this gain is not constant over the time and will vary very strongly as a function of the mobility behavior of the subscribers. Consequently, these examples show that by using too simple models the risk to obtain false or too optimistic results is high which of course will influence the standardization bodies.

Concerning the standardization of UMTS the above mentioned technical report [3] was passed by the ETSI. Therein very simple mobility models were applied. A Manhattan-like structure is used as a model for an urban environment which will be introduced in the next section. At each intersection the same turning probabilities are used, $p = 0.25$ for left and right and $p = 0.5$ for straight on direction. A drawback of this model seems to be that no preferred direction of movement of the subscribers can be modeled. Therefore it is not possible to consider typical topologies like shopping streets, campus areas and so on. Furthermore, the mobiles are uniformly distributed in the streets. This seems also to be disadvantageous. Realistic models have to cover local as well as temporal changes. For example at specific instants of time the subscribers will stay at their residences or workplaces. If they go to work they will prefer designated routes.

In the following some drawbacks of using the model of

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Brownian motion as mobility model will be introduced. By looking at this Manhattan-like structure from a certain distance, the motion of the subscribers looks like Brownian which is also the theoretical basis of some other models in the literature [8–10] (discrete models of Brownian motion). The disadvantage of mobility modeling with Brownian motion is that each direction can be chosen with the same probability. Thus, no determined direction of movement can be modeled. Moreover, two additional drawbacks can be found:
1. Because of choosing the same turning probabilities for each intersection of the homogenous lattice of the Manhattan-grid, any finite region will be left after a certain instant of time has passed. Therefore the model can only be used for short durations. Additionally, there are also no verifications available how accurate these approximations will be. By choosing the distances of the lattice smaller and smaller and thus executing the limiting process the real Brownian motion is obtained.
2. Since the derivation of the trajectory of the real Brownian motion with respect to time does not exist, it follows that the velocity will be not exist. This is not practical, but it is a problem of the model of the Brownian motion. In physics, the same problem appears if the model of Brownian motion is applied to the motion of molecules. In [11] the mathematical proofs can be found.

In the following a new mobility model is proposed which supports preferred directions of movement. Furthermore one can choose a certain divergence from the preferred direction. This way it is possible to model typical topologies. Consequently, more realistic results are obtained needed for performance evaluation and planning of mobile communication systems.

The paper is organized as follows: section II shows the Manhattan-like structure used by ETSI. In section III the new mobility model is introduced. In section IV a real test environment is implemented, as an example the campus area of the Technical University of Ilmenau. Section V will present some simulation results and a comparison of these two models. Section VI will discuss some problems of fitting the dwell time distribution. Finally, a conclusion and an outlook are given.

II. Manhattan-like Structured Mobility Model

In Fig. 1 the random movement of a subscriber through the Manhattan-like structure used by ETSI [3] is depicted. The following parameters as well as agreements were fixed. The block size is 200 meters and the street width amounts to 30 meters. The total area of the considered region is up to 6.5 km^2. The model is based on a 5 meters grid pattern, therefore the labeling of the axes in Fig. 1 goes from 0 to 512. If a mobile subscriber is located on an intersection ("+"-mark in Fig. 1) he may turn his direction with a turning probability of 0.5. So the subscriber may turn to the left or to the right with a probability of 0.25. If the mobile subscriber is located within a street

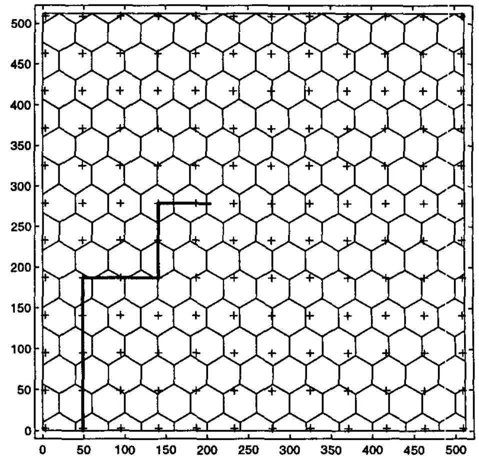

Fig. 1. Manhattan-like structure, 11×11 blocks, random movement of a subscriber, "+"-mark – intersection

segment, he is not able to turn his direction. The position of the subscribers is updated after every 5 meters and the velocity can be changed at each position update according to a probability of 0.2. The velocity is assumed to be a Gaussian process with a mean of 3 km/h and a standard deviation of 0.3 km/h. The minimum velocity is 0 km/h. Thus, one has to make sure that the area below the shape of the probability density function (PDF) is equal to 1. The subscribers are uniformly distributed in the streets and their directions are randomly chosen at initialization. By applying identical turning probabilities for each intersection, the subscribers will leave the defined region after a certain instant of time has passed (see above). However, by choosing special turning probabilities for the intersections on the edge of the region, it can be managed that the subscribers will stay within the defined region. To find the PDF of

- the cell residence time T_c
- the travel length L_c of a subscriber within a cell
- the number of cell boundary crossings N_c

as well as the mean crossing rate $\overline{R_c}$ a hexagonal cell structure with variable edge length R was overlayed (Fig. 1). Furthermore, investigations regarding a modification of the edge length R are possible.

III. New Mobility Model

In this section a new mobility model is presented regarding local specialties like street layout or shopping areas. A squared region with a 5 meters grid pattern serves as a base for our model. This grid can be changed and accommodated to special conditions. Within this region several areas with different mobility parameters are defined. There are 5 parameters available:

- approximate preferred direction of movement α, $0° \leq \alpha < 360°$
- divergence σ from the preferred direction, $0 \leq \sigma \leq 1$
- the mean velocity v_{mean}

• the deviation of the velocity v_{dev}
• probability p for staying in this area at initialization.

Given the parameters α and σ the probabilities p_u, p_d, p_l, p_r for the choice of the directions upstairs, downstairs, to the left and to the right in the two-dimensional plane have to be calculated, where $p_u + p_d + p_l + p_r = 1$. The divergence σ is defined as ratio between the probabilities not controlling the preferred direction and the minimum of the probabilities controlling the preferred direction. For the first quadrant with $0° < \alpha < 90°$ the divergence σ is defined as

$$\sigma = \frac{p_d}{\min(p_u, p_r)} \ . \tag{1}$$

The probabilities not controlling the preferred direction are identically, for this example $p_l = p_d$. For $\sigma = 0$ a directed movement is obtained. The divergence $\sigma = 1$ is allocated for the Brownian motion, where $p_u = p_d = p_l = p_r = \frac{1}{4}$. Otherwise for the first quadrant with $0° \leq \alpha < 90°$, where $0 \leq \sigma < 1$, the following probabilities are obtained

$$\begin{array}{rclcl}
\alpha = 0° & : & p_r & = & \frac{1}{3\sigma+1} \\
 & & p_u & = & p_d = p_l = \frac{1-p_r}{3} \\
\alpha < 45° & : & p_u & = & \frac{1}{1+2\sigma+\frac{1}{\tan(\alpha)}} \\
 & & p_r & = & \frac{p_u}{\tan(\alpha)} \\
 & & p_l & = & p_d = \frac{1-p_u-p_r}{2} \\
\alpha \geq 45° & : & p_r & = & \frac{1}{1+2\sigma+\tan(\alpha)} \\
 & & p_u & = & p_r \tan(\alpha) \\
 & & p_l & = & p_d = \frac{1-p_u-p_r}{2} \ .
\end{array} \tag{2}$$

Fig. 2 illustrates these facts for the first quadrant. The calculation for the other quadrants is done in analogy to the first quadrant.

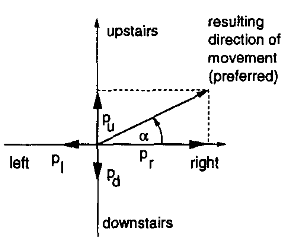

Fig. 2. Probabilities for the choice of direction in the two-dimensional plane, first quadrant

The declarations about the velocity and the hexagonal cell structure are the same as in section II. The parameter p determines the probability for staying in a defined area at initialization. Thus, a non-uniform distribution of the subscribers is possible allowing for more realistic scenarios. E. g. in the early morning most of the subscribers will stay at their residences. If a subscriber reaches the boundary of the region then a velocity 0 km/h is assigned to him. After that he stays for a certain delay in this state (e. g. $T_{delay} = 10$ s) until a direction is chosen which leads into the midst of the region. Therefore, the subscribers will not leave the region. To solve this problem other possibilities are thinkable like a reflection of the subscribers at the boundary.

IV. Implementation of a Test Environment

In this section an example for the implementation of a real environment is given, the campus area of the Technical University of Ilmenau (Fig. 3). 61 areas with different mobility parameters were defined. The movement of the

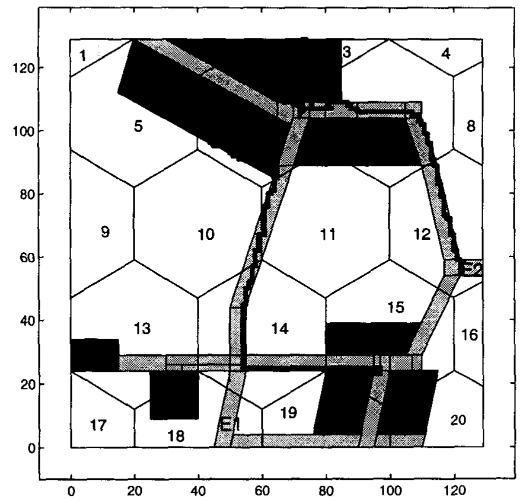

Fig. 3. Test environment: campus area, 650 × 650 meters, random movement of two subscribers (movement from W3 to A2, movement from E2 to A1)

people from their residences to the workplaces as well as lecture halls in the morning was simulated (only pedestrians which walk within a duration is 2000 seconds = 33 minutes 20 seconds). Areas marked with "A" are workplaces and marked with "W" are residences. The movement of the subscribers within the buildings is modeled more undirected. The light gray areas illustrate street segments, where the movement is modeled directed. If they are marked with "E" subscribers may stay within these segments at the beginning of the movement. At initialization the subscribers are distributed over the region as follows

$$\begin{array}{llllll}
\mathrm{W1}: & p = 0.15 & \mathrm{W3}: & p = 0.2 & \mathrm{E1}: & p = 0.15 \\
\mathrm{W2}: & p = 0.15 & \mathrm{W4}: & p = 0.2 & \mathrm{E2}: & p = 0.15 \, .
\end{array}$$

A hexagonal cell structure with an edge length of $R = 115$ meters was overlayed.

V. Simulation Results

In this section the PDF of T_c and N_c as well as a comparison of the two introduced models are given. For the purpose of comparison the regions covered by the models should have about the same size. Thus, for the ETSI model from section II a size of 3 × 3 blocks (720 × 720 meters) was used. For both models a hexagonal cell structure with an edge length of $R = 115$ meters was overlayed. All investigations were performed for 1000 subscribers considering a duration of 2000 seconds.

The obtained results show that by using the test implementation of the more realistic model very short travel lengths appear very frequently. But indeed, also very long distances can be covered within a cell, however with a low probability. As a result, the mean travel length and therefore the mean cell residence time is shorter than in case of the ETSI model (see Table I). Applying the ETSI model shows that certain lengths occur many times due to the Manhattan-like structure. In Fig. 4 the PDF's of the cell residence times for both models are shown. Here similar characteristics as in the previous discussion can be observed. Only the discrete values of the travel lengths are smeared due to the Gaussian-distributed velocity. In Fig. 5 the PDF's of the number of cell boundary crossings for both models are depicted. It turns out that the obtained PDF's are different. In case of the ETSI model a Gaussian-like distribution is obtained in contrast to the test implementation where a gamma-like distribution arises. In case of our test implementation the number of subscribers within a cell is highly dependent on time as well as on local specialties. This number varies between 0 and more than 500 subscribers. In case of the ETSI model this difference is not that big. However, a nearly constant distribution is obtained. In Table I the mean output results are summarized. Even though the mean crossing

	ETSI model	Our model
$\overline{L_c}$ in m	140.0	117.5
$\overline{T_c}$ in s	169.5	144.1
$\overline{N_c}$	11.0	9.6
$\overline{R_c}$ in crossings/s	0.0055	0.0047

TABLE I

COMPARISON OF THE TWO MODELS: MEAN OUTPUT RESULTS

rate estimated by the test implementation is lower than the one obtained by the ETSI model, the mean cell residence time is lower for our realistic model. Short cell residence times will occur very frequently in reality. This fact could not be observed using the ETSI model.

As a result, we can remark that it is not possible to approximate the obtained PDF of T_c and N_c by standard PDF's with a significance level greater than 5%. Moreover, a linear combination of different standard PDF's will approximate the obtained results accurately which is hard to determine. Thus, the performance analysis of mobile communication systems cannot be done without mobility models precisely.

VI. PDF of the Dwell Time

A lot of papers tried to determine the dwell time distribution (dwell time – a random variable that describes the amount of time a subscriber remains in a cell). Their specifications based on assumptions or on fitting of data obtained from simulations or measurements.

By investigations of the dwell time in clusters consisted of small cell sizes it can be observed that the deviation of the dwell time is greater than the mean value. Consequently, in [12] a sum of hyperexponential distribution functions was chosen for the dwell time distribution, because the coefficient of variation is greater than one. It does not succeed to obtain this distribution function from a given mobility model. The dependence of the mobility on time and place is not exchangeable only by a dependence on time.

In [13, 14] the dwell time was determined by means of an analytical model which is very simple since the subscribers keep constant directions. Thus, an analytical expression for the PDF of the dwell time is obtained which is not a standard PDF. In [15] simulations as well as analytical investigations were done. The exponential distribution was fitted to the obtained results. But only for a specific set of parameters the dwell time distribution can be approximated by an exponential distribution. Additionally, in [15] some statements about the applicability of the exponential distribution can be found which we can confirm. Without any change of direction as assumed in [14] the handover process is not memoryless and therefore the exponential distribution cannot be applied. By looking at the Brownian motion the rate of change of direction is very large. Also in this case the approximation of the dwell time distribution by an exponential distribution fails. Only if the rate of change of direction reaches a specific value an exponential distribution can be fitted to the obtained dwell time distribution, e. g. if the velocity in the ETSI model is chosen in such a way that the rate of change of direction is about 2 changes per minute. In summary, no universal statement about the dwell time distribution can be made.

VII. Conclusions and Further Work

In this paper a more realistic new mobility model was proposed which allows for local as well as temporal specialties. By means of the new model a real environment, the campus area of the Technical University of Ilmenau, was implemented. Furthermore, we investigated this test implementation in comparison with a mobility model used by ETSI. Several differences were found out. E. g. our test implementation provides shorter cell residence times than the ETSI model. Furthermore, the PDF's of several output results were quite different. Also the fluctuations of the number of subscribers within a cell over the time are much higher using our test implementation. These results will influence further performance evaluations. Finally, we have realized that it is not possible to approximate the dwell time distribution of subscribers, which move realistically, by standard PDF's. Thus, for realistic results the application of mobility models is unavoidable.

At present we are implementing our mobility model in

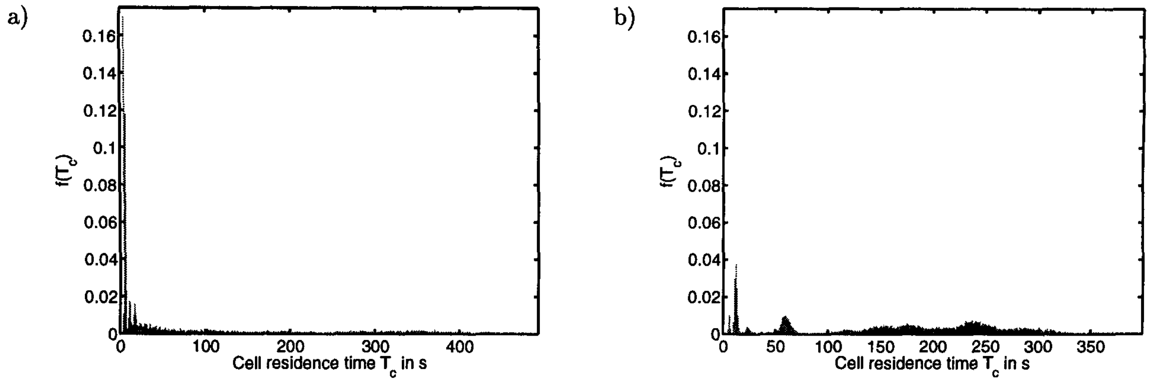

Fig. 4. PDF of the cell residence time for the test implementation (Figure a) and for the ETSI model (Figure b)

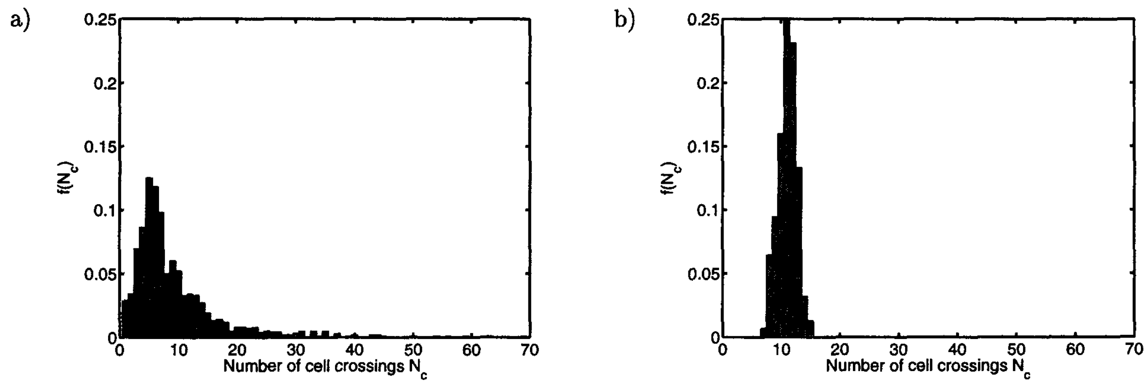

Fig. 5. PDF of the number of cell boundary crossings for the test implementation (Figure a) and for the ETSI model (Figure b)

the simulation tool "Ptolemy". Based on this implementation, investigations concerning losses of system capacity due to mobility and soft handover can be done. Moreover, the performance analysis using adaptive antennas under different mobility patterns can be included. Finally, the signaling load caused by user mobility can be estimated.

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