

How a new realistic mobility model can affect the relative performance of a mobile networking scheme[†]

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Summary

The validity of the mobility model used to evaluate a cellular network determines the validity of the evaluation. In the literature, unrealistic assumptions on mobility are exercised for the sake of simplicity. In this paper, we present a novel mobility model which is realistic in the sense that it captures the *moving-in-groups*, *conscious traveling* and *inertial* behaviours of the subscribers while respecting the *non-pass-through* feature of structures like households and preserving the autonomy of the subscribers. The mobility and call patterns of the subscribers are determined according to the locus of the subscriber over a real map. Thus, our model allows the subscribers to leave home or arrive home, walk or drive in the streets, get on the highways at specific entry points together with numerous hot and blind spots in the terrain, like city centers and lakes. The call pattern of a subscriber is affected by the type of structure he is in. The model can work on real maps to simulate the mobility patterns in real life. We have evaluated the proposed model against the well-known way point mobility model. We also analyzed the effect of the mobility model on systems with and without guard channels. Copyright © 2004 John Wiley & Sons, Ltd.

KEY WORDS: cellular networks; mobility model; mobility patterns; performance evaluation of mobile networks

1. Introduction

Evaluating a scheme proposed for cellular mobile networks is a cumbersome process. The effect of thousands of autonomous mobile subscribers on the system performance can be examined by either analytical methods or simulations. The analytical methods are favorable since they provide fast and theoretical results. However, such methods consider the society as a whole, disregarding the individual behavior of the subscribers. Furthermore, many unrealistic assumptions must be made in order to

simplify the underlying mathematics. On the other hand, simulators can implement the individual subscribers at the cost of long run times. Thus, in simulations, instead of approaching the problem as a bulk of subscribers, the society is constructed from the individuals.

Implementation of the autonomy of the subscribers is the crucial point of a mobility model. Each subscriber chooses his direction individually, as in real life. However, in real life one can observe that the direction of a subscriber is also dictated by the terrain. Although each subscriber makes his decisions

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independent of the other subscribers, he cannot decide to drive over a house. If the street has a turn to the left, everyone on the street is supposed to turn to the left as long as they stay on the street. Thus, although the subscribers are autonomous, they drive or walk together on the streets and highways. This is called the *moving-in-groups* behavior of the society.

An autonomous subscriber updates his direction randomly, so that the subscribers exhibit stochastic mobility patterns. However, determining the new direction independent of the old one will result in a simulator where subscribers make unconscious moves, back and forth. A realistic mobility model should capture the *conscious traveling* feature of the subscribers where the subscribers tend to keep their directions towards a destination. However, this tendency is still subject to the *non-pass-through* feature of some structures in the terrain, as explained in the previous paragraph. The model should also force the subscribers to enter and leave the highways only at specific entrance and exit points. Furthermore, each subscriber exhibits an *inertial* behavior to preserve the type of structure he is on. A subscriber driving on a street is more likely to keep driving on the street than entering a household. However, the tendencies to switch from one type of structure to another should also be defined so that subscribers may prefer getting from the street to the avenue and vice versa. In addition to the mobility pattern, the call pattern of a subscriber is also affected by the structure on which the subscriber resides. Thus, the call pattern of the subscriber is altered when the mobile leaves home and starts driving.

The distribution of the subscribers over the service area is one of the crucial points in cellular systems. Unrealistic assumptions, like uniform distribution of the subscribers over the service area, result in even sharing of the load among the base stations. However, this contradicts with the real life case. The population density must differ throughout the service area denoting hot and blind spots like city centers and lakes.

Finally, the underlying air interface should also be considered since the signal propagation is determined by the coordinates of the mobile. The mobility and call patterns, together with the population density affect the signal propagation, which becomes more crucial if code division multiple access (CDMA) technology is to be considered for the air interface, as in the 3rd generation systems. The approximation for interference propagation in CDMA systems, given in Reference [1], is commonly adopted in the literature. However, this approximation is based on

the assumption that the mobiles are distributed evenly over the service area. If such an unrealistic assumption is to be avoided, one must also devise a method for interference propagation.

In this paper, we propose a novel mobility model that captures the moving-in-groups, conscious traveling, and inertial behaviors of the subscribers while respecting the non-pass-through features of the structures in the terrain. The mobility and call patterns of the subscribers are determined according to the locus of the subscriber in the terrain where the terrain is defined by real maps including hot and blind spots. The real life mobility patterns like walking, driving on the roads, entering and exiting highways, arriving and leaving home, even rowing across the Bosphorous can be implemented. We have evaluated the proposed model against the well-known way point mobility model and obtained promising results. Since we defer the assumption that the mobiles are evenly distributed over the service area, we have also devised a method to calculate the actual interferences. The rest of the paper is organized as follows. In the next section, we discuss the previous work in the literature. The proposed model is presented in Section 3, followed by simulation results in Section 4. We give the conclusions and future work in Section 5.

2. Previous Work

Most of the work in the literature on mobile networks assumes random walk [2–6], Brownian motion [7,8] or cell change probability based on the side of the hexagon through which the subscriber leaves the cell [9,10]. Although these models simplify analysis, they rely on unrealistic assumptions and the mobility patterns produced do not resemble the human behavior in the real life. In Reference [11], Chiang *et al.* propose a simple random walk model that simplifies the two-dimensional Markov chain by benefiting from symmetry and lumped processes. In Reference [12], Zonoozi *et al.* develop a mathematical formulation for systematic tracking of the random movement of the subscriber. The authors show that the cell residence time can be described by the gamma distribution and the channel holding time by the negative exponential distribution. In Reference [13], Tonguz *et al.* use a straight-line motion, a two-dimensional random walk model and a biased Markovian motion. In the activity-based model proposed in Reference [14], the mobility patterns of the subscribers are based on an activity transition matrix. The authors use the matrix created

by the Regional Municipality of Waterloo, Ottawa. However, it is very difficult to obtain such a matrix for other cities. In Reference [15], Bettstetter smoothes the sudden changes at the turning points during a subscriber's movement by introducing acceleration. However, group movement and change in mobility patterns due to physical obstacles is disregarded. In References [16–18], way point mobility model is used for ad hoc networks. In Reference [19], Yang *et al.* propose a model based on the mobility patterns of traveling salesmen. It is basically a stop-or-move method between cells and it remembers the roaming direction. However, their scheme relies on a regular hexagonal cellular layout and does not model hot and dead spots. In Reference [20], Markoulidakis *et al.* have proposed a model with three levels: city area model, area zone model and street unit model, therefore the geographic area needs to be molded into these three levels. In Reference [21], Leung has modeled a highway with multiple entrances and exits as a deterministic fluid model. Different kinds of mobility models have been proposed in publications on ad hoc networks [22,23]. However, since such networks are designed for disaster areas and military applications without any fixed cellular network, their mobility patterns differ from those in a cellular system. In Reference [24], Kim *et al.* consider three-dimensional mobility for indoor environments.

ETSI has defined test scenarios for the indoor office, outdoor pedestrian and vehicular environments [25]. A Manhattan-style street structure is defined for the outdoor pedestrian environment and a random mobility model without any street structure for the vehicular environment. Furthermore, the speed of the cars is assumed to be fixed at 120 km/h.

In addition to the theoretic work, simulators like Opnet, NS-2 and GloMoSim also implement mobility models. However, Opnet and NS-2 have very simple mobility models. GloMoSim has been developed for ad hoc systems and it is not suitable for cellular networks.

3. Proposed Mobility Model

3.1. Basic Idea

The proposed model generates stochastic mobility and call patterns according to a given real map (e.g. Figure 1). The model is independent of the map, therefore mobility and call patterns for different scenarios can be generated easily. The map is composed of



Fig. 1. Map of Asian side of Istanbul.

different structures like houses, streets, highways, lakes, etc. and there is no limit on the number of these structures. Mobility pattern parameters (e.g. speed distribution), call pattern parameters (e.g. idle duration), probability of switching to other structure types and probability of a mobile device being turned on in that type of structure are specified as parameters to the model. Each block (pixel) in the map has a different color, where the color represents the type of structure. The users are initially distributed over the service area according to the type of blocks. The mobility and call patterns of the users are also determined according to the block type parameters. Thus, the proposed model is able to distribute autonomous subscribers over the service area and generate stochastic mobility and call patterns for these subscribers. The distinguishing feature of the model is that mobility and call pattern generations, together with the initial subscriber distribution, are based on real maps. In this manner, initial subscriber distribution is realistic and subscribers in the same region of the terrain exhibit similar mobility and call patterns. For example, although the subscribers are autonomous, all subscribers on a road have to turn to the right if the road has a curve to the right. Furthermore, some structures in the terrain, like households, may be set to be more likely places for the subscribers to turn their handsets on.

Once a mobile terminal has been turned on, its direction is determined by the surrounding structures.

This does not violate the fact that subscribers make autonomous decisions, since in the real life the movements of a human are also restricted by the environment. A subscriber decides whether he will switch to a different type of structure based on a matrix of structure switching probabilities. The change in the type of structure the subscriber is residing on implies a change in the mobility and call patterns of the subscriber.

It is possible that the subscriber reaches the boundary of the terrain while moving in a definite direction. Allowing the mobile to move out of the terrain will result in fewer subscribers in the service area, which may lead the simulation to end before the lifetime of all of the subscribers have expired. In the literature, reflecting boundaries are introduced to prevent such cases. In the reflecting boundaries approach, a subscriber who is about to leave the service area is reflected back to the service area at the same point. Since this sudden turn of the subscriber is not very realistic, we introduce the symmetric insert approach. In the symmetric insert approach, a subscriber who is about to leave the service area will be re-inserted from the other boundary of the service area. Thus, we add a new subscriber to the system when another one leaves the system, so that the total number of subscribers does not change.

Signal propagation in wireless systems requires special attention. Since the details of signal propagation is beyond the scope of this work, we simply employ free space signal propagation [26] in our research. However, we still calculate the actual outer cell interference instead of employing the approximation introduced in Reference [1] which is based on assumptions we defer (see the following Section for details).

In a stochastic system design, the implementation of the distributions determines the validity of the system. We have used the CNCL package for our distributions since it is a widely used and proved-to-be-correct library.

3.2. Features Implemented by the Proposed Model

The proposed mobility model distributes the subscribers unevenly over the service area and determines the mobility and call patterns of each mobile according to the structure the mobile is residing on. A real map with different types of structures (houses, streets, avenues, highways, sea, etc.) defines the service area. For each type of structure, the following parameters are defined:

- Mobility pattern parameters: Speed distribution, lifetime distribution.
- Call pattern parameters: Idle duration distribution, call duration distribution.
- Rate at which a subscriber may turn on his mobile terminal on such a structure.
- Probabilities of switching from this type of structure to all other types.

With the help of the mobile turn on rate, the unrealistic assumption of uniform distribution of the subscribers over the service area is avoided. Some structures may be set to be favored more than others for the initial distribution. The lifetime of the mobile, the duration for which the mobile station remains turned on, is determined when the mobile is turned on.

Subject to the structure switching probabilities matrix, the subscribers move over the map. The trajectory followed by a subscriber is the concatenation of multiple line segments. In other words, once a subscriber has chosen a direction, he will move in that direction for a definite duration, called the step size, until he chooses a new direction. As the step size gets smaller, the trajectory of the subscriber approaches a curve, at the expense of longer simulations. The step size can be drawn from a distribution so that the time between two direction updates varies. The speed of the subscriber is also updated every time the subscriber updates its direction. If the type of structure the subscriber is on has changed, the speed, idle duration and call duration distributions of that subscriber also change. Thus, the subscriber will change his speed and call pattern when he switches from one structure to another. For example, when the subscriber leaves home and starts driving on the streets, both his speed and call pattern will change.

The structure switching probabilities are also used in determining the direction of the subscriber. When it is time to update the direction, the subscriber will look at his surrounding at a distance he can cover in one step, dictated by the step size, and choose his new direction. The probability of moving in any direction is determined according to the structure switching probabilities. For example, a subscriber moving on a street may rather go to an avenue than his home. Thus, most of the subscribers on the streets will get on the avenues whereas fewer subscribers go home. The simulation time is limited to several hours (enough to simulate rush hours traffic) to avoid accumulation of subscribers on the highways. By utilizing the structure switching probabilities, it is also possible to implement the non-pass-through feature of some

structures and the special entry and exit points to the highways. By setting the switching probability to a structure to zero, the structure will gain the non-pass-through feature. Similarly, by setting the switching probabilities to/from the highway structure, except the connection roads, the special entry and exit points to the highways through the connection roads are implemented.

The inertia behavior of the subscribers is implemented by setting the switching probability from a type of structure to the same type to a value higher than other probabilities. Thus, a subscriber will prefer keeping the type of structure he is on. The inertia behavior helps avoiding subscribers who change their minds very frequently. Without the inertia behavior, subscribers will visit every house on a street, like a postman.

If the new direction of the subscriber is determined by just considering the structure change probabilities, a subscriber going on a street may suddenly turn 180° backwards, go in that direction for one step and turn back again. Since humans will not make such unconscious moves, a subscriber in our model favors directions close to his current direction. After the probabilities of moving in all directions have been calculated from the structure switching probabilities matrix, these probabilities are updated to favor directions closer to the current direction of the subscriber. Thus, although it is possible that the mobile may turn 180°, it is less likely. We call this kind of behavior as conscious traveling.

Although subscribers are autonomous entities, each subscriber is subject to the mobility pattern determined by the terrain. Therefore, most of the subscribers on the same structure will tend to exhibit, not the same but similar, mobility and call patterns. Thus, the moving-in-groups behavior of the society is implemented. For example, not only will most of the subscribers on a street prefer staying on the street, they will also have close speeds and call patterns.

The implementation of all these features in a mobility model is a novel approach. Furthermore, the ability to support a stochastic mobility model with a real map adds power to the proposed model. The integration of the real map enables examining subscriber mobility on different service areas, like suburbs and rural areas.

The validation of the proposed model is a difficult task since it employs features based on subjective measures. Although it cannot substitute a formal proof, the best validation for such a model is visualization. We have implemented a graphical interface

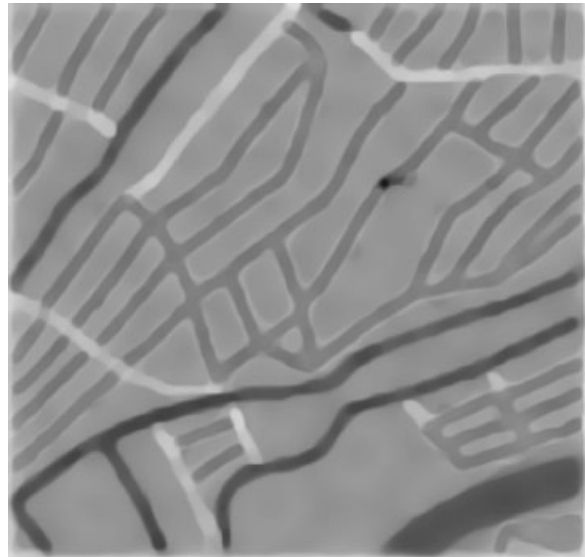


Fig. 2. A screen capture from the graphical interface.

(Figure 2) for the validation by using the EZD tool developed by DEC. By the help of the graphical interface, we have validated that the proposed model provides the features claimed. The reason for choosing EZD is the support for EZD by the CNCL library. However, EZD is not powerful enough to handle thousands of mobiles. Since the implementation of such a powerful graphical interface is beyond the scope of this research, the authors have been contented with EZD.

3.3. Algorithm of the Proposed Scheme

The proposed mobility scheme is implemented with an event-driven algorithm. There are nine events: StartSimulation, WarmupFinished, StopSimulation, MobileTurnOn, MobileActivate, DirectionUpdate, CallStart, CallTermination and Handoff. The first three events are global to the system whereas the rest of the events are scheduled per mobile. Since an event-driven approach is used, the algorithm is demonstrated by explaining the actions to be taken on the reception of each event. The algorithm is given in Figure 3.

4. Numerical Results

The choice of the mobility model used in the evaluation has a significant role in the performance of mobile systems. Features such as initial distribution of the subscribers over the service area, effect of

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switch (received_event)
• case StartSimulation:
  - For all base stations  $BS_i$ ,
    * assign the frequency bands,
    * initialize all resources in the cell as free.
  - Create all mobiles (MSs).
  - Create the random variables for:
    * physical block in which MS will reside,
    * distribution of MSs to the blocks according to map,
    * displacement of MSs inside the blocks,
    * MS turn on rate.
  - Schedule the MobileTurnOn event for each MS.
  - Schedule the WarmupFinished event.
• case WarmupFinished:
  - Verify all MSs are turned on before warmup period is
    finished.
  - Instruct all MSs and BSs to start gathering statistics.
• case StopSimulation:
  - All gathered statistics are evaluated.
• case MobileTurnOn:
  - Assure MS is not in a partially covered cell at service
    area boundary.
  - Initialize MS attributes and statistics.
  - Find MS class according to the physical block.
  - Set random variables for idle and call durations, and
    speed distribution.
  - Find speed and direction according to MS class and map.
  - Find the controlling BS for MS.
  - Schedule MobileActivate event for MS.
• case MobileActivate:
  - Schedule DirectionUpdate event for MS.
  - Schedule CallStart event for MS.
• case DirectionUpdate:
  - Move MS to new position according to speed, direction,
    and step size.
  - If MS has moved out of service area:
    * Terminate any ongoing call prematurely, but do not
      consider it as a call drop since the reason for
      termination is not lack of resources.
    * Release the resources allocated for the call.
    * Schedule new CallStart event.
    * Re-locate MS in a new block according to the map.
    * Find the controlling BS.
  - Find MS class according to the physical block.
  - If MS class has changed, set the random variables for
    idle duration, call duration, and speed distribution.
  - Find speed and direction according to MS class and map.
  - If MS has moved into a new cell, find controlling BS.
  - If there is an ongoing connection:
    * Find handoffs points till the next DirectionUpdate
      event.
    * Schedule a Handoff event for each handoff point.
    * Propagate interference to other MSs in neighbor
      cells.
  - Schedule DirectionUpdate event for MS.
• case CallStart:
  - Check the resources in the current BS to find if the
    call request can be accommodated.
  - If the call is accepted:
    * Update "successful call start" statistics.
    * Schedule CallTermination event.
    * Find handoff points till the next DirectionUpdate event.
    * Schedule Handoff event for each handoff point.
    * Propagate interference to other MSs in neighbor
      cells.
  - If the call is rejected:
    * Update "blocked calls" statistics.
    * Schedule a new CallStart event.
• case CallTermination:
  - Update "successful call termination" statistics.
  - Release the resources allocated for the call.
  - Schedule CallStart event for MS.
• case Handoff:
  - Move MS to the handoff point.
  - Check the resources in the new BS to find if the hand-
    off request can be accommodated.
  - If the handoff request is accepted:
    * Update "successful soft handoff" or "successful hard
      handoff".
    * Propagate interference to other MSs in neighbor
      cells.
  - If the handoff request is rejected:
    * Update "dropped calls" statistics.
    * Schedule a new CallStart event.

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Fig. 3. Algorithm of the proposed scheme.

physical terrain on the subscribers' mobility patterns, and similarity in the behaviors of subscribers on the same physical structure is difficult to capture with stochastic methods. We set up the experiments so that the effects of the mobility model and the map of the terrain are highlighted.

We compared the proposed realistic mobility model against the way point model. The speed of each subscriber in the realistic mobility model is drawn from a distribution, which is determined according to the structure he is on. However, the speeds of all of the subscribers in the way point model are drawn from the same distribution. We have set the mean speed used in the way point model to be the mean of the *observed* average speeds of all subscribers in the proposed mobility model.

We used two different kinds of maps for the underlying topology of the realistic model in order to study the effect of the map on the performance of the model. One of these maps is a 38 km² portion of the real map in Figure 1 with 4 m resolution. The other map is a handmade, grid-structured Manhattan-style network (Figure 4). We also introduced some irregularity and a hot spot in the Manhattan-style network.

We also analyzed the effect of the mobility model on different call admission schemes. We considered three different call admission schemes:

- Plain scheme: All channels in the cell are assigned in first-come-first-served manner, without giving any priority to handoff calls.

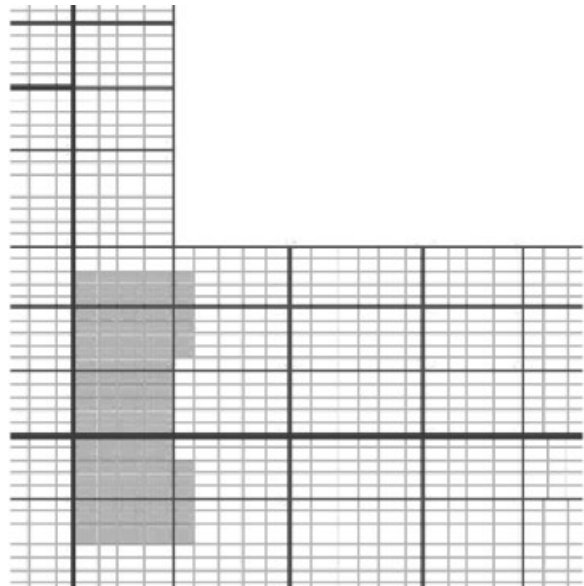


Fig. 4. Manhattan-style network.

Table I. Block type change probabilities for the heavy load and the light load scenarios.

	1	2	3	4	5	6
1	0.60	0.30	0.10	0.00	0.00	0.00
2	0.15	0.50	0.30	0.05	0.00	0.00
3	0.05	0.15	0.45	0.30	0.05	0.00
4	0.00	0.03	0.20	0.47	0.30	0.00
5	0.00	0.00	0.05	0.20	0.20	0.55
6	0.00	0.00	0.00	0.00	0.10	0.90

- Classical scheme: In each cell, a fixed number of *guard channels* are set aside to handle possible handoff calls. Handoff calls are prioritized over new calls in this manner as long as such a channel is available. These channels cannot be utilized if there are not enough calls. We have set the number of guard channels to three, since this is the value frequently used in the literature.
- Reservation-based scheme: Channels are reserved dynamically for handoff calls. The performance of this scheme is sensitive on mobility since the cells in which reservations will be made are determined according to the mobility of the subscriber in the near past. This scheme is described in more detail in Reference [27].

4.1. Simulation Parameters

We used two scenarios with different system loads in the experiments. Thus, we analyzed the effect of different mobility models on these schemes under both heavy and light load cases. For each experiment, the call dropping probability (CDP) and the call blocking probability (CBP) values are sketched.

The block type change probabilities are given in Table I. The simulation parameters for the heavy load and the light load scenarios are given in Tables II–III and Tables IV–V respectively.

4.2. Effect of the Mobility Model on Different Call Admission Schemes

The effect of the mobility pattern under heavy load is analyzed on both the plain scheme (Figure 5) and the proposed scheme (Figure 6). Since the subscribers are accumulated at specific parts of the terrain with the realistic mobility model, its CBP is well above that for the way point model. The reason for higher CDP in the way point case can be explained by considering the mobility patterns of the subscribers as follows. In the way point model, all subscribers exhibit similar mobility patterns. However, in the realistic model,

Table II. Simulation parameters for the heavy load scenario.

Parameter	Value
Service area	6.4 km × 6 km (real map and pure Manhattan style)
Cell radius	0.6 km
Number of cells in interference range	18
Data rate	9600 bps
Chip rate	1 228 800 chips/sec
E_b/N_o	5
N_f	$5.2908 \cdot 10^{-16} \frac{\text{mW}}{\text{chips/sec}}$
α	0.375
γ	4.0
Map granularity	4 m/step
Step duration	5 sec/step
Number of directions	17
Number of block types	7
Subscriber call and mobility patterns	See Table III
Block type change probabilities	See Table I

Table III. Subscriber call and mobility patterns with respect to block type for the heavy load scenario.

Block type	Pattern	Type of distribution	Parameter(s) of distributione
0	—	—	—
Empty region			
1	Idle duration	Normal	(1 min, 1 min)
Households	Call duration	Exponential	600 sec
	Speed	Normal	(5 km/h, 5 km/h)
	Life time	Normal	(300 min, 300 min)
	Effective weight	—	5
	2	Idle duration	Normal
Streets	Call duration	Exponential	300 sec
	Speed	Normal	(30 km/h, 30 km/h)
	Life time	Normal	(300 min, 300 min)
	Effective weight	—	5
	3	Idle duration	Normal
Avenues	Call duration	Exponential	300 sec
	Speed	Normal	(60 km/h, 60 km/h)
	Life time	Normal	(300 min, 300 min)
	Effective weight	—	15
	4	Idle duration	Normal
Boulevards	Call duration	Exponential	360 sec
	Speed	Normal	(80 km/h, 80 km/h)
	Life time	Normal	(300 min, 300 min)
	Effective weight	—	40
	5	Idle duration	Normal
Connection roads	Call duration	Exponential	480 sec
	Speed	Normal	(110 km/h, 110 km/h)
	Life time	Normal	(300 min, 300 min)
	Effective weight	—	80
	6	Idle duration	Normal
Highways	Call duration	Exponential	480 sec
	Speed	Normal	(140 km/h, 140 km/h)
	Life time	Normal	(300 min, 300 min)
	Effective weight	—	150

Table IV. Simulation parameters for the light load scenario.

Parameter	Value
Service area	6.4 km × 6 km (real map and pure Manhattan-style network) 3.28 km × 3.36 km (Manhattan-style network with hot spot)
Cell radius	1 km (real map and pure Manhattan-style network) 0.2 km (Manhattan-style network with hot spot)
Number of cells in interference range	18
Data rate	9 600 bps (real map and pure Manhattan-style network) 19 200 bps (Manhattan-style network with hot spot)
Chip rate	1 228 800 chips/sec
E_b/N_o	5
N_f	$5.2908 \cdot 10^{-16} \frac{\text{mW}}{\text{chips/sec}}$
α	0.375
γ	4.0
Simulation duration	30 min
Warmup period	5 min
Map granularity	4 m/step
Step duration	5 sec/step
Number of directions	17
Number of block types	7
Subscriber call and mobility patterns	See Table V
Block type change probabilities	See Table I

Table V. Subscriber call and mobility patterns with respect to block type for the light load scenario.

Block type	Pattern	Type of distribution	Parameter(s) of distribution
0	—	—	—
Empty	—	—	—
1	Idle duration	Normal	(60 min, 60 min)
Households	Call duration	Exponential	60 sec
	Speed	Normal	(1 km/h, 1 km/h)
	Effective weight	—	1
2	Idle duration	Normal	(30 min, 30 min)
Streets	Call duration	Exponential	60 sec
	Speed	Normal	(10 km/h, 10 km/h)
	Effective weight	—	100
3	Idle duration	Normal	(30 min, 30 min)
Avenues	Call duration	Exponential	60 sec
	Speed	Normal	(35 km/h, 35 km/h)
	Effective weight	—	100
4	Idle duration	Normal	(30 min, 30 min)
Boulevards	Call duration	Exponential	60 sec
	Speed	Normal	(50 km/h, 50 km/h)
	Effective weight	—	100
5	Idle duration	Normal	(30 min, 30 min)
Connection roads	Call duration	Exponential	60 sec
	Speed	Normal	(70 km/h, 70 km/h)
	Effective weight	—	150
6	Idle duration	Normal	(20 min, 20 min)
Highways	Call duration	Exponential	60 sec
	Speed	Normal	(90 km/h, 90 km/h)
	Effective weight	—	250

subscribers at home almost never encounter handoffs. In other words, the number of subscribers subject to handoffs is higher in the way point model, although the average speeds for both models is the same. Therefore, since fewer subscribers may be moving at higher speeds in the realistic model, the number of handoff attempts is less than the number of handoffs created by all subscribers in the way point model.

The effect of mobility model on the plain, classical and reservation-based schemes is also studied under light load (Figures 7 and 8). One can observe that with the way point model, the plain scheme cannot be distinguished from the classical guard channel scheme. The reservation-based scheme performs slightly better than both of the other schemes, but the difference is not significant. However, we should

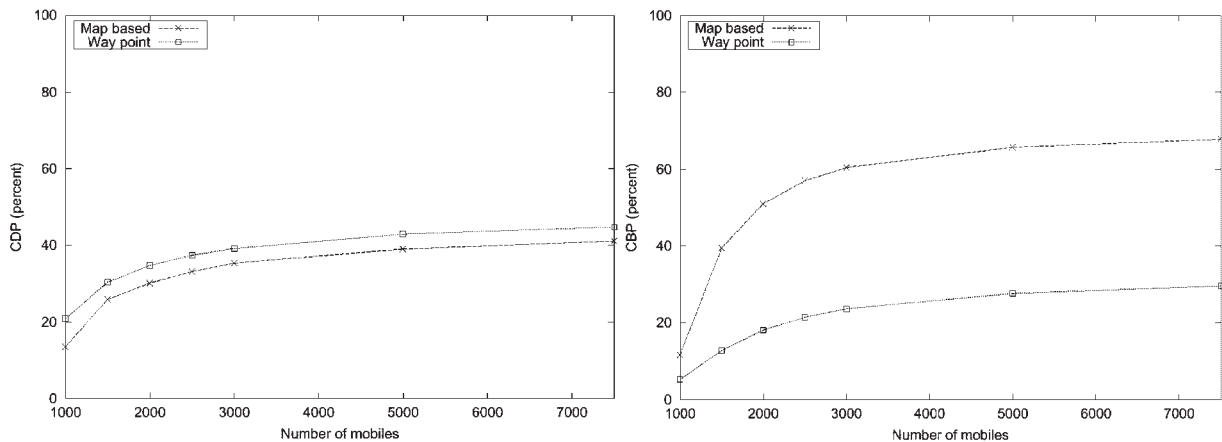


Fig. 5. Effect of mobility pattern on the plain scheme.

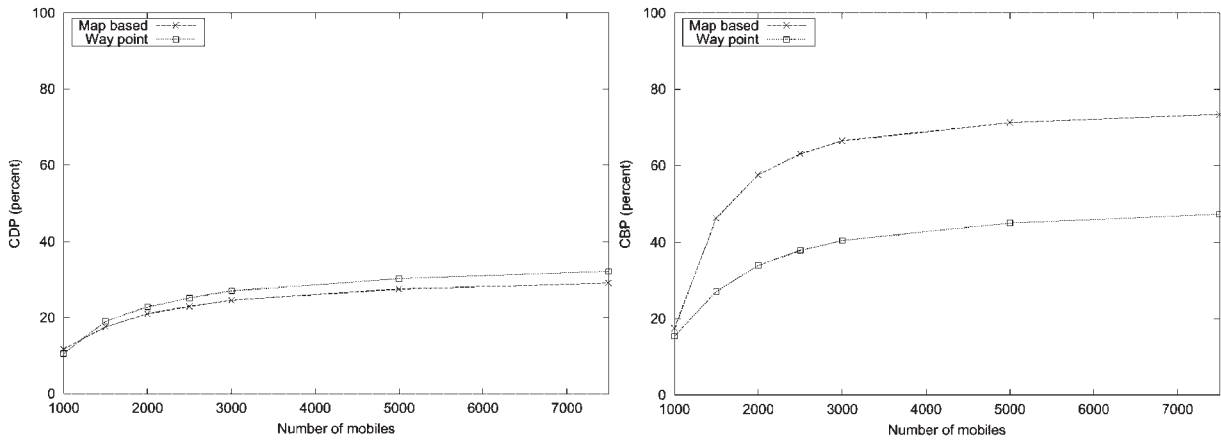


Fig. 6. Effect of mobility pattern on the reservation-based scheme.

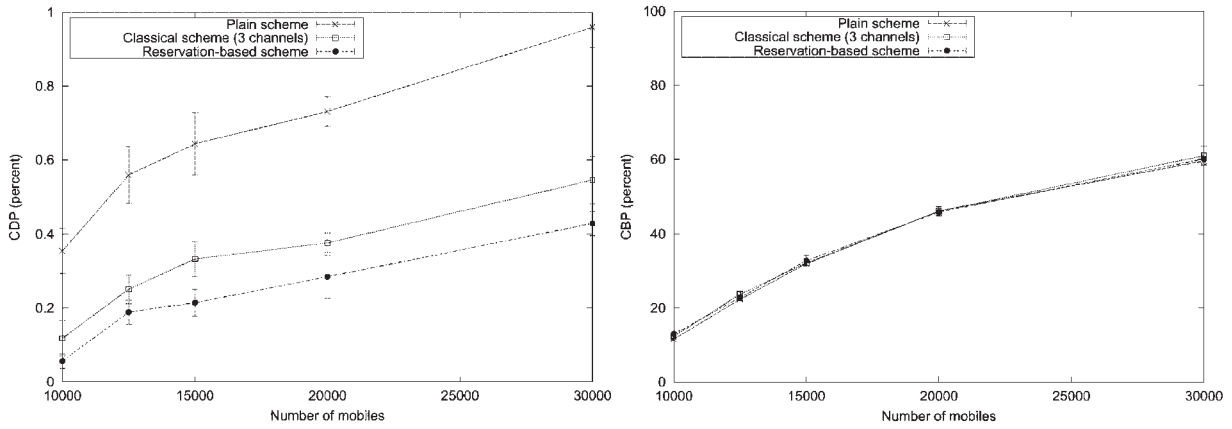


Fig. 7. Different call admission schemes with the realistic mobility model.

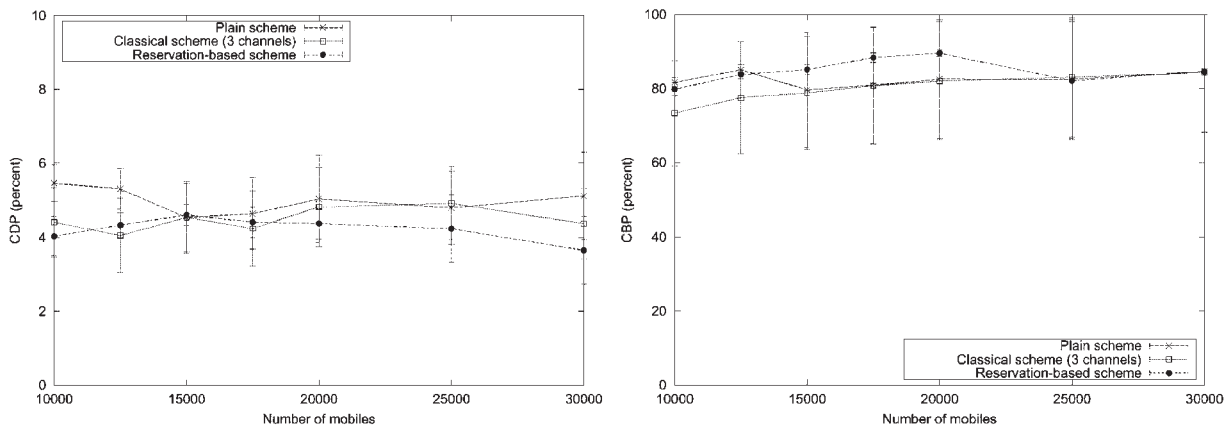


Fig. 8. Different call admission schemes with the way point model.

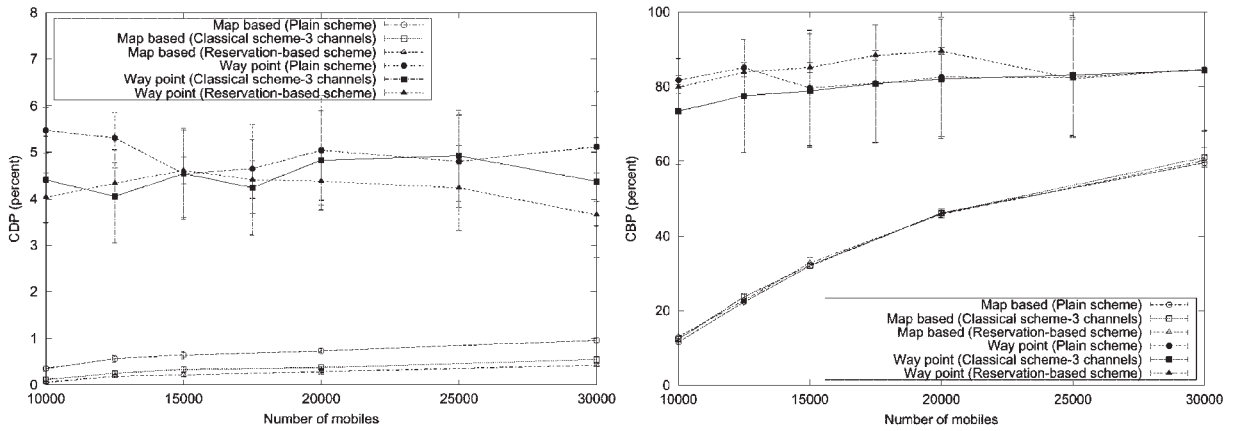


Fig. 9. Effect of mobility pattern on different call admission schemes.

note that the reservation-based scheme is more stable than the other two schemes in terms of load, i.e. the number of subscribers. The number of seeds used for the experiments in Figures 7 and 8 are the same. The high variation in Figure 8 represents the unstable nature of the way point model. The reason for the low-dropping probabilities, with respect to the high-blocking rates is that the mean speed of the mobiles in the way point model is only 35 km/h.

The results obtained in Figures 7 and 8 are plotted together in Figure 9 to emphasize the difference. It is apparent that the way point model drastically overestimates CDP and CBP. The more important point to be noted in the graphs is that with the way point model, for all of the three schemes, it is difficult to follow the trend in the system performance as the number of mobile stations increase. Furthermore, the variation in the way point model is very large whereas it is almost negligible in the realistic model although the number

of seeds is the same for both the cases. Our realistic mobility model, in addition to giving lower CDP and CBP values, gives steadily increasing CDP and CBP values for all three schemes as the load increases.

4.3. Effect of Map Type on the Performance of the Realistic Mobility Model

The effect of the map type on system performance is analyzed in Figures 10 and 11 under heavy and light loads. It is visible from the graphs that the change in the type of map does not cause a significant change in the trend of the behavior of the system but there is a considerable difference in the values of both CDP and CBP with respect to the real map. The main reason for this difference is that the corners in the Manhattan-style network are very sharp and a subscriber who re-evaluates his direction just before the corner will not choose to turn at the corner. Even subscribers who

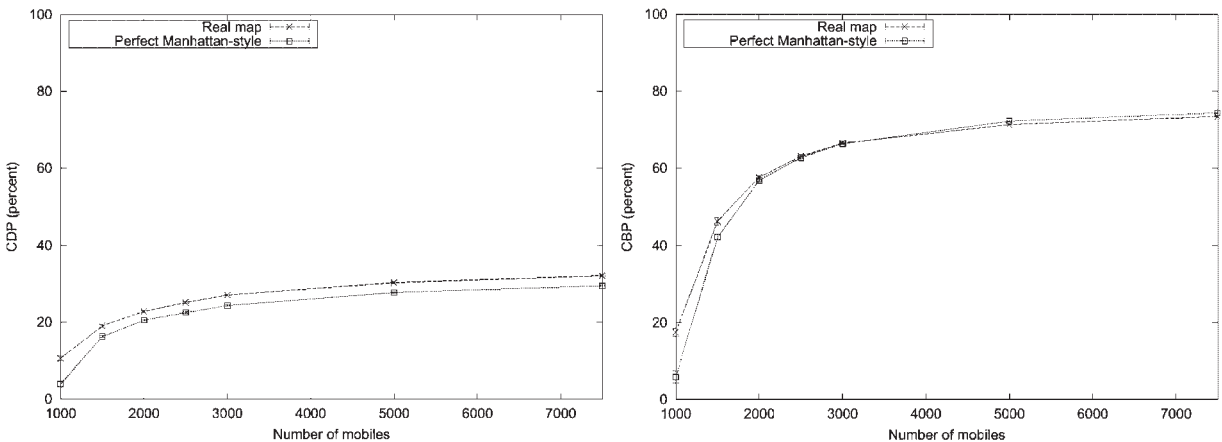


Fig. 10. Effect of map type under heavy load.

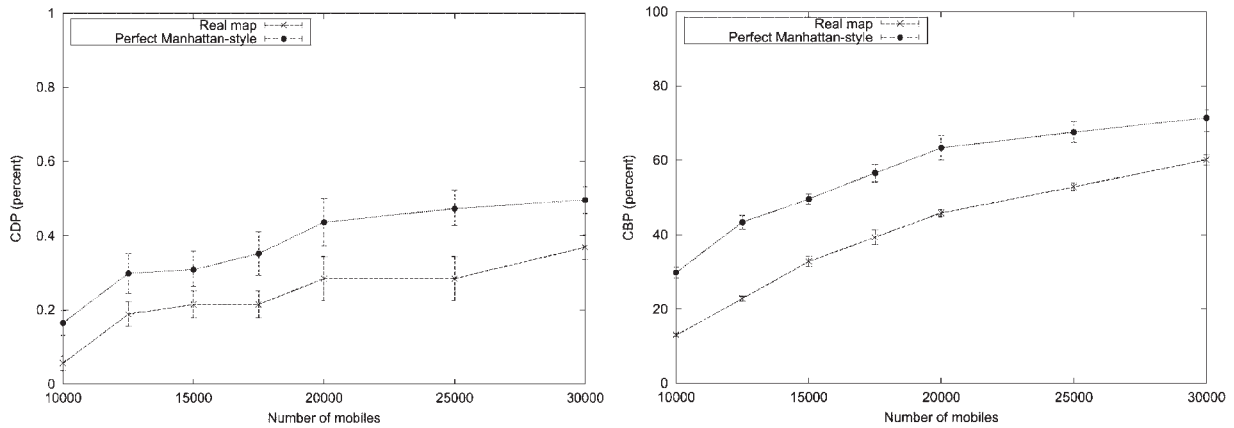


Fig. 11. Effect of map type under light load.

re-evaluate their direction just at the corner will choose turning at the corner with a very low probability since turning implies a major change (90°) in direction. Therefore, it is very likely that a subscriber tends to keep his direction and stay on the same street for a long time. Thus, the reservation area becomes very narrow. The results obtained using the Manhattan-style network heavily depend on the step duration (time period during which the subscriber does not change his direction and speed), since with smaller steps it will be more likely that the subscriber re-evaluates his direction at the corner. On the other hand, when a real map is used, most of the corners are smoother, allowing smaller changes in direction. Furthermore, in the Manhattan-style network, the subscribers also make very sharp turns at the corners, suddenly moving out of the narrow reservation area. The reason for the increase in blocking can be explained by the distance between the avenues, which seems to be closer than the real map. The reader should note that the Manhattan-style network has been created simply by the repetition of a small segment. The service area in the Manhattan-style network is equal to the available service area in the real map, that is, what remains after unused regions (like the sea) are extracted.

We also studied the effect of the type of map under light load (Figure 11). As in the heavy load scenario, the change in the type of map does not cause a significant change in the trend of the behavior of the system, but both CDP and CBP values differ vastly. The same reasons, i.e. the effects of the sharp corners in the Manhattan-style network, explain the similar but shifted curves obtained from two different maps.

5. Conclusions

In this paper, we propose a novel mobility model for cellular networks. The mobility and call patterns of the subscribers together with their initial distribution are based on a given real map. Our model captures the moving-in-groups, conscious traveling and inertial behaviors of the subscribers in the real life, and respects the non-pass-through feature of structures like households while preserving the autonomy of the subscribers. CDMA technology has been considered for the air interface and actual outer cell interference has been propagated instead of the approximations commonly used in the literature. We have compared our model against the well-known way point model and shown that the call dropping and blocking probabilities are affected by the choice of the mobility model significantly. We have shown that the choice of the mobility model has a significant impact on the performance of the mobile systems. The effect on the relative performance becomes more important especially when the algorithms try to predict the mobility of the subscriber.

Since a flat map of only two dimensions is used, bridges running over other roads cannot be specified in the map. Therefore, such bridges are represented as two crossing roads. Thus, the proposed model allows subscribers driving in one road to pass to the other one. However, in the real life this implies that the subscriber has suddenly jumped on to the bridge. As a future work, the third dimension can be supported for the bridges. We will also apply the proposed mobility model to other schemes and analyze its effects against the classical schemes.

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