Application of a Realistic Mobility Model to Call Admissions in DS-CDMA Cellular Systems[*]

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Abstract

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 behaviors of the subscribers while respecting the non-pass-through feature of some 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. 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.

1. Introduction

Evaluating a scheme proposed for cellular mobile networks is a cumbersome process. The effect of thousands of autonomous mobile stations 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 with possible upper and lower bounds. 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 simulation runs. Thus, in simulations, instead of approaching the problem as a bulk of subscribers, the society can be constructed from the individuals. Implementation of the autonomy of the subscribers is the crucial point of a mobility model. Each subscriber must choose 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. 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. A realistic mobility model should also 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 exit 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. In addition to the mobility pattern, the call pattern of a subscriber is also effected by the structure on which the subscriber resides. Thus, the subscriber's call pattern can be altered when the mobile leaves home and starts driving. The distribution of the subscribers over the service area is another crucial point in cellular systems. Unrealistic assumptions like uniform distribution of the subscribers result in even sharing of the load among the base stations which is contrary to real life. Finally, the underlying air interface should also be considered since signal propagation is determined by the coordinates of the mobile. The mobility and call patterns, together with the population density effect signal 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 autonomously according to the locus of the subscriber in the terrain, where the terrain is defined by real maps including hot and blind spots. Real life mobility patterns like walking and driving on the roads, entering and exiting highways, arriving and leaving home. We have evaluated the

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proposed model against the well-known way point mobility model, and obtained promising results. The rest of the paper is organized as follows. In the next section, we discuss the related work in the literature. The proposed model is presented in Section III, followed by numerical results in Section IV. We give the conclusions and future work in Section V.

2. Related Work

Most of the work in the literature on mobile networks assumes random walk [2],[3],[4],[5], Brownian motion, or cell change probability based on the side of the hexagon through which the subscriber leaves the cell [6],[7]. Although these models simplify analysis, they rely on unrealistic assumptions, and the mobility patterns produced do not resemble the human behavior in real life. In [8], Su et al use way point mobility modeling for ad hoc networks. In [9], 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 moulded into these three levels. In [10], 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 [11],[12]. 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 addition to the theoretic work, simulators like Opnet, NS2 and GloMo also implement mobility models. However, Opnet and NS2 have simple mobility models and they don't support CDMA air interface. GloMo has been developed for ad hoc military systems and it is not suitable for cellular civilian networks.

3. Proposed Mobility Model

Given a real map composed of different structures like houses, streets, highways, lakes, the proposed model distributes autonomous subscribers over the service area, and generates stochastic mobility and call patterns for these subscribers. The number of different types of structures in the terrain is not fixed, and depends on how detailed the map is. The discriminating 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 reflects hot and blind spots in the terrain, 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 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 real life the movement of a human is 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 if he is moving on a road that terminates at the boundary. Allowing the mobile to move out of the service area will result in a decrease in the number of subscribers, which implies also a decrease in the load. In the literature reflecting boundaries, where a subscriber who is about to leave the service area is reflected back to the service area at the same point, are introduced to prevent the decrease in the number of subscribers. However, this approach prolongs the sojourn time of the subscriber in the current cell, which causes the load in that boundary cell to be increased. In the proposed model, we relocate the subscriber who has exited the service area according to the initial subscriber distribution. Thus, the model acts as if a new subscriber comes into play for each subscriber that leaves the system. This approach helps distribute the load due to the subscribers who leave the system according to the initial subscriber distribution instead of accumulating the load at the boundary cells. 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 [13] in our research. However, we still calculate the actual outer cell interference instead of employing Gilhousen's approximation [1] which is based on assumptions we have turned down.

3.1. 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 (like houses, streets, avenues, highways, sea) defines the service area. For each type of structure, mobility pattern (speed distribution), call pattern (idle duration, call duration) 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 is defined.

By 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.

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 duration*, until he chooses a new direction. As the step duration gets shorter, the trajectory of the subscriber approaches a curve, at the expense of longer simulations. The step duration 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.

Figure 1. Map of Asian side of Istanbul

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 duration, and choose his new direction. The probability of moving in any direction is determined according to the structure switching probabilities. For example, depending on the structure switching probabilities matrix, a subscriber moving a street may rather going to an avenue than home. Thus, most of the subscribers on the streets will get on the avenues whereas fewer subscribers go home. 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.

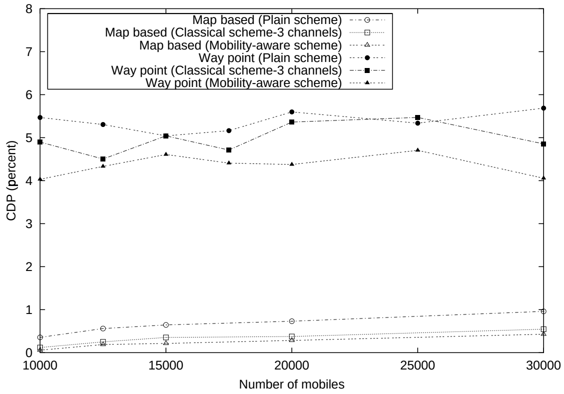

Figure 2. Effect of mobility pattern on different schemes (CDP)

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^o 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^o, 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. In order to avoid misleading statistics due to low load in the beginning of the simulation, a warm up period is introduced so that the system takes its load before we start gathering the statistics. All subscribers must have turned on their mobile equipments well before the end of the warm up period. Once the warm up period has expired, the statistics are gathered till the end of the simulation duration. When the simulation duration expires, no more statistics is gathered except for the on-going calls. On-going calls are not terminated immediately at the end of the simulation duration so that the statistics represent whether these calls are really successfully completed or dropped. Furthermore, to avoid any decrease in the system load while statistics are still being gathered, new call generations are allowed without contributing to the statistics.

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 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.

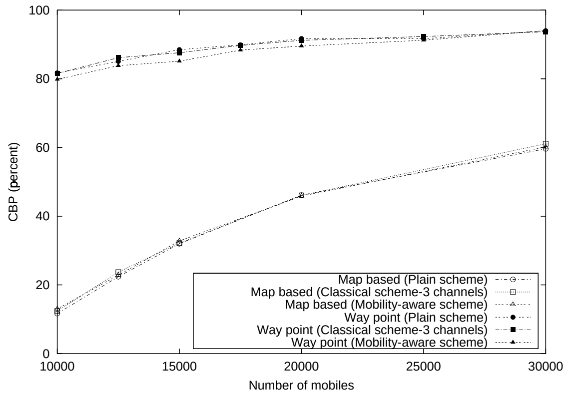

Figure 3. Effect of mobility pattern on different schemes (CBP)

4. Numerical Results

We have tested the proposed model against the well-known way point method. A real map of 6.4 km x 4.8 km with 4 m resolution (Fig. 1) and a handmade pure Manhattan-style map have been used in the experiments. The maps contain seven different types of structures with the speed of each subscriber drawn from a normal distribution with the mean ranging from 1 km/h to 90 km/h, depending on the structure he is on. The direction of each subscriber is updated every 5 seconds.

The subscriber searches his environment at increments of 21^o at each step to determine his new direction. Since the way point model does not utilize the map, and treats each subscriber in the same way, a single distribution with mean 35 km/h, which is the average of the observed speeds of the subscribers in the proposed model. Both for the map based and the way point models, a CDMA air interface (subject to IS-95 specifications) has been considered. Every point in the graphs is the average of multiple runs with different random seeds.

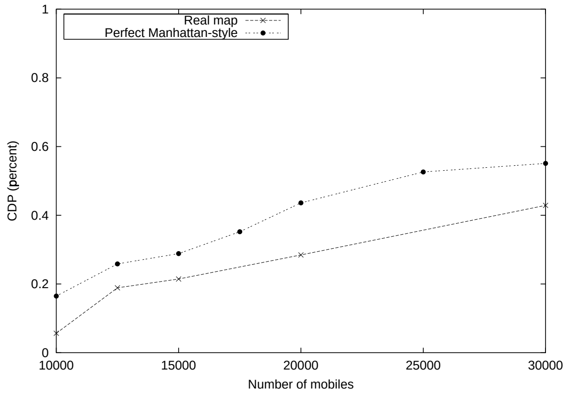

Figure 4. Effect of map type on proposed mobility model (CDP)

The comparison of the proposed and the way point mobility models is presented in Fig. 2-3 in terms of call dropping and call blocking probabilities. The effect of the mobility model on three call admission schemes (the plain scheme without any guard channels, the classical scheme with 3 guard channels in every cell, and a mobility-aware scheme which adjusts the number of guard channels based on reservations) is analyzed. The figure points out to two major differences between the proposed and way point mobility models. The first point to note is that the call dropping and blocking probabilities vary vastly although the mean speeds are the same. This results from the fact that there is only one type of subscriber in the way point model whereas the proposed model allows subscribers with different mobility patterns. The second point is that the proposed scheme results in a monotonic increase in the call dropping and blocking rates, as expected, whereas the way point model results in a jumpy behavior. The reason for this jumpy behavior is the complete randomness in the mobility patterns of the subscribers which does not occur in real life.

The effect of the map type has been sketched in Fig. 4-5. The mobility-aware call admission scheme has been used in the experiments. Since the streets are straight lines and the corners are at 90^o, the moving direction of the subscribers can be estimated, resulting in a lower call dropping rate without increasing the cost in terms of call blocking rate.

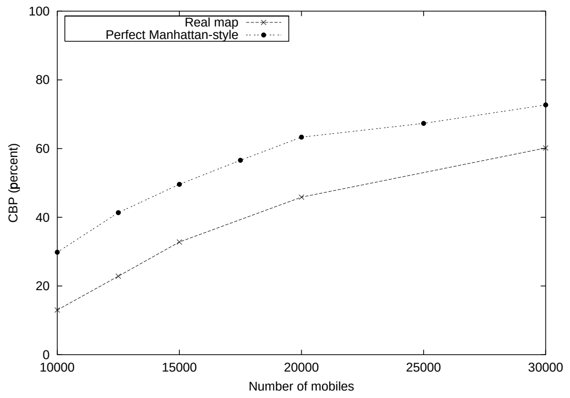

Figure 5. Effect of map type on proposed mobility model (CBP)

However, such a map is not realistic although it is easier to produce.

5. Conclusions and Future Work

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 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 may be effected by the choice of the mobility model significantly.

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 real life, this implies that the subscriber has suddenly jumped on to the bridge. As a future work, the third dimension will be supported for the bridges.

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