# MOBILITY MODELS FOR CEILLIJLAR SYSTEMS: CELL TOPOGRAPHY AND HANDOlFF PEtOBABILIllCY

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Abstract - In this paper we develop models that incorporate general mobility patterns that are induced by the cell topography (e.g., road layout, street orientation, density of intersections). In particular, we study the effect of the different mobility patterns on the handoff probability. The mobility patterns are induced by common terrains such as Random, Manhattan, Circular and Highway. We study the circular mobility pattern in detail and examine the impact of the base station placement on the handoff probability. The results in this paper suggest that we may be able to estimate the handoff probabilities from a knowledge of the cell terrain, the mobile trajectory, and the vehicular movements in a cellular network, and thus may serve as a useful guide for cellular network engineering.

## I. INTRODUCTION

Teletraffic and mobility modelling is essential for studying various design and tradeoff issues in a cellular system. In these systems, efficient handoff is important and any potential improvement of handoff performance in cellular systems is very beneficial. Note that the number of handoffs required for a particular call is directly proportional to the number of boundary crossings a mobile undergoes during the period of the call [4].

An important measure of cellular system performance is the handoff probability. In an earlier paper [l], the authors have studied the dependence of the handoff probability on the cell topography in some detail. The results in this paqer are an extension to the results in [l]. Several researchers suggest that the individual mobile trajectories are unimportant in a cellular system, and instead, lay stress on the *cell dwell time*, i.e., the residence time of a mobile in a cell. Even though the cell dwell time is an important measure in the computation of the handoff probability, in literature the distribution of cell dwell time has been found to be general [ti], [3]. We believe this limits the usefulness of the cell dwell time. Further, the models studied earlier do not capture the effect of the cell topography on the mobility patterns, and it is with this in mind that we study the mobile trajectory in some detail. Since most of the parameters of interest in a cellular system are stochastic quantities, one would expect the pith of a mobile to be a random trajlectory. These parameters could be, for example, the mobile speed, miobile direction or the call holding time. In reality, however, the cell topography stratifies certain paths and thereby constrains the trajectory of the mobile. This has a significant impact on important parameters in a cellular system, such as, the handoff probability.

In this paper, we study varilous mobility patterns and their effect on the handoff probability. These mobility patterns are, in turn, induced by the topography of the cell, such as the road layout, street orientations, density of intersections etc. We study the circular mobility pattern in detail and examine the impact of the base station placement on the handoff probability.

The organization of this paper is as follows: In Section 2, we state the assumptions that are used in the simulation study. In Section 3, we characterize mobility patterns induced by some common cellular

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terrains and study the difference in the handoff probability among cells with different mobility patterns. We describe some issues in base station placement in a cell with a circular layout in Section 4, and, conclude in Section 5.

## 11. THE SIMULATION MODEL

In this section, we describe the simulation model and state the assumptions that are used in the simulation of a cellular system.

The cell topography (i.e., road layout, density etc.) constrains the mobility pattern and hence defines the decision instance (the point at which a mobile changes its velocity and direction), termination instance, decision time (time interval between two decision instances) and the direction set (the feasible set of angles that a mobile follows at a decision instance) . These variables in turn define the trajectory of the mobile.

Discrete Event Simulations are performed in the JAVA programming language to study the performance of the cellular system. For simplicity, we consider a single cell system. This assumption is justified when all cells in the system generate the same traffic and each cell has the same average rate of call initiation (see 121). In the simulations, we consider only active mobiles. The arrival process of new calls in a cell is assumed to be a homogeneous Poisson process with rate A. At call initiation, a mobile is assigned a random initial position from a uniform distribution over the cell area. The call is also assigned a random total duration (called the call holding time) sampled from an exponential distribution with rate p.

The discrete random variable *N* defines the number of decision instances (turns) of a mobile. N is assumed to have a geometric distribution with parameter *p*. This assumption may seem simplistic but it ensures that the distribution of the call holding time is exponential (a geometric sum of exponential random variables is also exponentially distributed [5]). The decision times, Ti, $i = 1, \dots, N$, (i.e., the random time until a change in the mobile direction) are independent and identically distributed (i.i.d.) random variables. We assume that the Ti's are exponentially distributed with a rate equal to *w* defined by (151) w = &. At each decision instance, we sample the velocity *(v)* and the current direction (cy) of the mobile. The direction of the active mobile depends upon the cell topography; this will be elaborated in the next section. The mobile velocity is sampled from a truncated Normal distribution with a given mean and variance. In Table 1, we show the parameters that have been used in the simulation study. Note that we have used the *fied* channel assignment strategy [4] in the simulations.

| *Parameter* | *Value* |
|---|---|
| Number of channels in cell | 50 |
| Call arrival rate (A) | 30 calls/min |
| Call holding time ( P - L ) | 120 seconds |
| cell Radius | 700 m |
| Mean of Mobile Velocity | 10 m/s |
| Variance of Mobile Velocity | 5 m/s |

Table 1: The Simulation Parameters

## 111. MOBILITY CHARACTERIZATION

In an urban area, the road layout, street orientation and the density of road intersections constrain the degrees of freedom of mobile vehicles in that region. These parameters also determine the nature of the mobile trajectory and the feasible direction and velocity range of the mobile. It is therefore unrealistic to assume that the mobile speed is uniformly distributed or remains constant, and that the mobile paths follow straight limes throughout the call holding time. Moreover, in developing countries, sections of the urban areas are characterized by multiple road intersections over a small area, and it is reasonable to assume that the mobile trajectory has a large number of turns in a cell. Figure 1 shows the road map of a section of New Delhi. The distinct road patterns (Circular and Manhattan) are clearly seen in the figure.

### Handoff Probability Versus *E[N]*

The density of road intersections influence the hequency of direction change by the mobile. Typically, one expects that the greater the number of intersections encountered by a mobile, greater the expected number of direction changes by the mobile. The problem that is of interest to us is the dependence of the handoff probability on the density of road intersections in a cell. We study this behavior through discrete event simulations.

In this paper, we define *handoff probability* (Ph) as

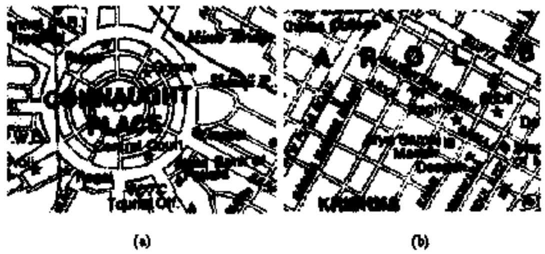


Figure 1: Road Map of a City Showing Different Road Patterns. (a) Circular Pattern, (b) Manhattan Pattern

the fraction of calls that are handed over to the neighbouring cells. Since we simulate only one cell, we consider those handover calls that move out of the representative cell to the neighbouring cells. Note that if the cellular system has a homogeneous traffic across the cells, then, the fraction of incoming calls to a cell is equal to the fraction of outgoing calls from the cell and simulation of a single cell is justified [2].

The dependence of the handoff probability on the average number of turns of a mobile (denoted by E[N]) obtained through *simulation* of a cell with a *random mobiZity pattern* is shown in Figure 2. In this paper we use the following interchangeably: the average number of turns of a mobile, the density of road intersections, the number of change Of direction decisions of a mobile. Note that, for a fixed call holding time (and therefore for a fixed total length traversed by the mobile with a constant velocity), the handoff probability decreases with an increase in the average number of turns. Similar behaviour is observed for the manhattan mobility pattern in a cell. An outline of the proof is given in [I].

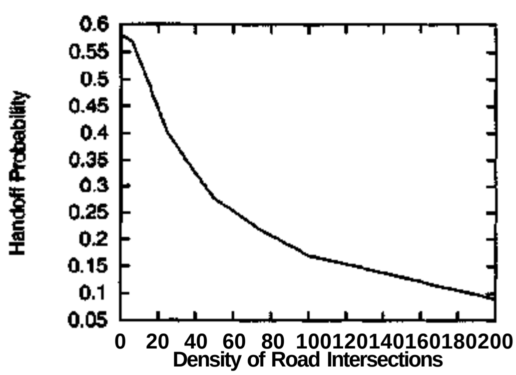


Figure 2: Handoff Probability versus Average Number of Turns of a Mobile

## Comparison of Handoff Probabilities

We srst describe the different cell terrain types in detail. We consider Random, Manhattan, Highway and Circular terrains in a clellular system, and, for each of these terrain types, define a feasible direction set for a mobile. The choice of a feasible direction set precludes a mobile taking unrealistic turns when moving in a particular direction.

In a cell with a random tenrain, there are very few mobility constraints. The direction set, *8,* for the mobile is uniformly distributed between [— $ +(I!, $+ *a],* where *a* is the current direction of the mobile. In a manhattan terrain (see Figure l(b)), the typical layout would be roads that are perpendicular to each other. Tlhe direction set *8* in this case would be limited to { a - | , a , a + 5 }, where each direction is equally likely.

The direction set *8* on a highway is equal to the current direction of motion of tlhe mobile *(a).* A mobile moves in either positive or negative *2* direction and continues on the path till either call termination or handoff initiation. Now consider a circular terrain (Figure LCa)). A junction point would typically be the center of a circular terrain. The road layout at these junctions would appear as a number of roads converging to the junction point and circular concentric roads at varying radial distances around the junction.

We now compare the handoff probabilities for different road Ilayouts. For this comparison, we keep the simulation parameters for different terrains to be the same. These parameters are the call holding time, cell radim, distribution of mobiles in a cell, the mobile velocity distribution arid the decision time distribution. The mean length travelled by a mobile is the product of the average mobile velocity and the mean call holding time.

In Figure 3 and Figure 4, for each of the terrains, we plot the handoff probability versus the mean length travelled by a mobile. Figure 3 corresponds to $p$ = 0.99 (i.e., & = 100 decision points), Figure 4 corresponds to $p$ = 0.92 (see Section 2 for definition of *P)**

In Figures 3 and 4, we see that for all terrain types, the handoff probability increases with an increase in the expected length travelled by the mobile, and this is as expected. Obsenre also that as the mean length increases, the plots for different terrain types, excluding the circular terrain, converge. Beyond a

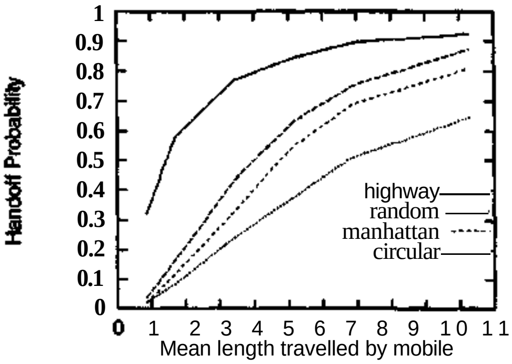


Figure 3: Handoff Probability versus Mean Call Holding Time for $p$ = 0.99

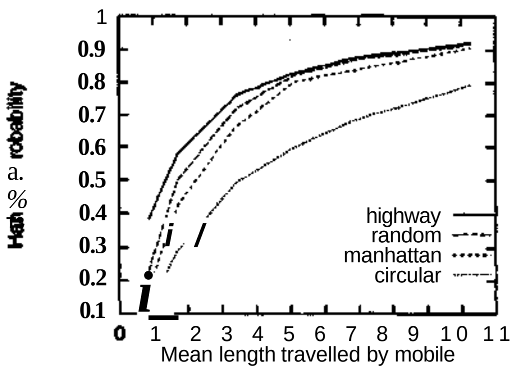


Figure 4: Handoff Probability versus Mean Call Holding Time for $p$ = 0.92

threshold, a further increase in the expected length travelled by the mobile (which essentially is the mean call holding time) does not seem to effect the handoff Probability significantly.

In Figure 3, we observe that for the highway terrain the handoff probability is the maximum and that the circular terrain has the least handoff probability. These observations are not surprising and we we give an explanation for the above. In a highway cell, mobiles can travel only in the positive or the negative *2* direction. If the call holding time is comparable to the diameter of the cell (i.e., the highway length), handoffs will be large. On the other hand, in a circular terrain, a large fraction of mobiles move either (i) along circular paths at a fixed distance from the center of the cell, or, (ii) towards the interior of a cell, (i.e., radially and towards the center). This results in low boundary crossing rates and hence low values of handoff probability.

What is interesting is that when the number of mobile turns are large, and this is the case in Figure 3, the random terrain handoff probability bounds from above the handoff probability in the manhattan terrain. We give an intuitive proof of the result when the direction set of the mobile varies from 0 to ?rf2. We assume that the mobile velocity is a constant. The outline of the proof is as follows.

Consider a Manhattan terrain. A mobile moves in the positive $x$ direction with probability (w.P.) 0.5 and in the positive $y$ direction w.p. 0.5. Assume that the number of turns of a mobile is zero and the length of the path traversed by the mobile is equal to 1 unit. It follows trivially that the average distance covered by the mobile in the positive $z$ direction is equal to 0.5. Now consider a Random terrain in which a mobile that originates at the origin moves a unit distance at an angle *6* from the positive $z$ axis. Note that *8* is uniformly distributed between 0 and f. The average distance covered by the mobile in the positive z direction is equal to *E,[cos6]* = ⅔. Thus, for the same call holding time, the distance covered by a mobile in the Random terrain ($) is greater than that in the Manhattan terrain (i). The argument can be extended to the case when (i) the number of turns of a mobile is a discrete random variable greater than or equal to one, (ii) the length of the path between two turns of a mobile (i.e., the decision interval) is a random variable.

From Figure 4, it is seen that as the number of intersections decrease, (i.e., as we decrease $p$), the handoff probabilities in the random, manhattan and the highway terrain converge, whereas, the circular terrain continues to be characterized by the least handoff probability. This implies that, for the manhattan, random and highway layout, *the diflerence in the handoff probability is insignificant when the nzlmber of change of direction decisions are small.*

The results in this section are interesting: they suggest that we may be able to estimate the handoff probabilities from a knowledge of the terrain, the mobile trajectory, and the vehicular movements in a cellular network.

# IV. CELLULAR SYSTEM LAYOUT

We have seen in the previous sections that the handoff probability is an important measure in a cell and it is not desirable to have high values of handoff probability. In this section, we attempt to answer the following: given the topography of a region, what

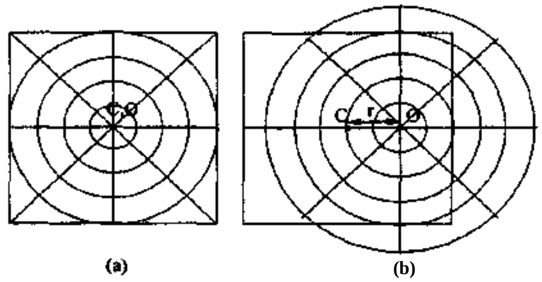


Figure 5: A Circular b a d Layout in a Cellular System: (a) Junction Point (at 0) coincides with Center of the Cell (at C), (b) Junction Point is at a Distance r from C.

is the optimal cell layout, i.e., where should the base station (implying the cell boundaries) be placed so as to minimize the handoff probability?

A cellular system with circular road layout is shown in Figure 5. For simplicity, we consider a square shaped cell and study the mobility pattern in a circular terrain. We call the center of a circular terrain a *junction point.* Assume that the base station (BS) is placed at the center of the square cell. Denote the distance of the BS from the junction point by *T.* When the base station is placed at the junction point itself, i.e., the junction point (0) coincides with the center of the cell (C), T = 0 (see Figure 5 (a)). In general, this may not be so (Figure 5 (b)), and we investigate the impact an increasing *T* may have on the handoff probability in a cell with a circular topography.

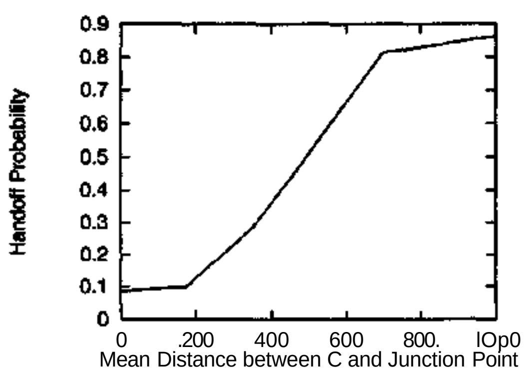


Figure 6: Handoff Probability versus Distance of BS from Center of Circular Terrain

In Figure 6, obtained from simulation, we plot the handoff probability versus *r* and observe that the function is close to a *sigmoid curve.* This suggests that there is a neighbourhood around the junction point in which the handoff probability is insensitive to the placement of the base station. Note that after a threshold (200 *m* in Figure S), the handoff probability increases rapidly with *T* and becomes almost constant for large values of *T (T* $\underline{2}$ 700 m in Figure 6).

## V. CONCLUSION

This paper is an attempt tal study how the handoff probability in a cell depends upon the mobility patterns that, are in turn induced by the cell terrain. The results in this paper itre new and interesting, and show that the individual mobile trajectories in a cellular system are also :significant in that they govern the boundary crossiiig rate of mobiles. The difference in handoff proba,bility with varying cell terrain and base station placement may serve as a useful guide for cellular network engineering.

In a multicellular system, the parameters which determine the mobility pattern in a cell may depend on the mobility patterns in the neighbouring cells. It is therefore unreasonable to assume that the cell topography in the adjacent cells is independent of each other. This could be one of the areas of future work.

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