

# Mobility Model for Hybrid WLAN/Cellular Systems

P. Khadivi, S. Samavi, H. Saidi, and T. D. Todd

**Abstract**—Wireless communications and networking have had tremendous developments in recent years. Recently, some proposals are presented in the literature to build hybrid structures out of different wireless systems. Also, architectures have been proposed for co-operating cellular and WLAN systems. Due to high complexity of mobile networks, proposed protocols and algorithms are usually evaluated by simulations. In these simulations, when real mobility is considered, a certain mobility model must be used. A number of mobility models have been proposed for ad hoc networks. Different mobility models have different properties in terms of node distribution, stability and reality. In a cellular system, hotspots are locations with a large number of subscribers. In hybrid WLAN/Cellular systems, WLANs are used to cover the hotspots. Evaluation of the performance of these hybrid networks should be performed through simulations or analytical modeling. Therefore, special mobility models are needed for this purpose. In this paper, we propose a mobility model based on the original version of random waypoint. This model is applicable for the simulating of the hybrid WLAN/Cellular systems. The proposed strategy is analyzed through simulations and analytical modeling.

**Index Terms**—Mobility model, hybrid wireless networks, random waypoint, hotspot.

## I. INTRODUCTION

WIRELESS communications and networking have had tremendous developments in recent years. Cellular systems are infrastructure-based networks. In each cell there is a base station (BS) that serves a number of mobile stations (MSs). Ad hoc networks are another kind of wireless systems. These networks are infrastructure-less and each MS acts as a router in order to forward traffic of other nodes. Recently, some proposals are presented in the literature to build hybrid structures out of different wireless systems. As it is standardized in third generation of cellular systems, WLANs can be used to cover hotspot areas in traditional cellular systems [1]. This idea is similar to multi-layering [2]. Also, integrating ad hoc networks with cellular systems has been suggested in the literature [3]-[6]. The main goal of this integration is to increase system capacity by lowering the blocking rate as well as to improve the system coverage and reducing the bad effects of non-line-of-sight communication.

Due to high complexity of mobile networks, proposed protocols and algorithms are usually evaluated by

simulations. In these simulations one may or may not use real mobility behavior of the nodes. When real mobility is being considered, a certain mobility model must be used. The movement pattern of mobile stations is defined by the mobility models [7].

A number of mobility models have been proposed in order to study the performance of different algorithms in ad hoc networks. Different mobility models have different properties, in terms of node distribution, stability and validity. In the literature, some of these mobility models have been studied and compared [7]-[11].

One of the oldest mobility models is the *Random Walk* model. In this model, after choosing a direction, mobile stations move one unit in a random direction at each time step. This is something similar to Brownian movement of particles. The advantage of this model is its simplicity. It is clear that this model is far from reality [7], [8].

One of the well-known mobility models, used in most of the ad hoc simulations, is the *Random Waypoint* model. This mobility model has different variations. In this model, mobile stations are uniformly distributed over the simulation area. A random destination and a random velocity are assigned to each MS. An MS moves with the assigned velocity on a straight line toward its destination. At the destination, the MS may have a pause with a random duration. Then another random destination and velocity is assigned to it and the above procedure is repeated [7]-[10]. In the original version of random waypoint, node distribution on the simulation area is non-uniform. In fact, node-density is higher in the center than the edges. This problem can be solved by choosing directions instead of destinations in *Random Direction model*.

Random waypoint tries to choose every thing from a uniform distribution, which is not the same in real world. As an example, people who live in a city do not move randomly in random directions. There are some special locations such as shopping centers or downtown area that more people are present. In some variations of random waypoint, destinations are picked up non-uniformly. In *Location model* a predefined set of locations is considered. Destinations are randomly selected only from this set of locations. In *Home-Work model* each node selects a set of preferred destinations at the beginning of the simulation. Then the destination of each MS is chosen from its preferred set of destinations. The motivation behind this model is that people move between their home and work places more frequently [8].

Another problem of random waypoint is its stop-and-sharp-turn property. This is something unlikely to happen in the real movements. In *Gauss-Markov model*, the mobility is smoother than in random waypoint. In this model, each MS picks up a certain velocity and direction.

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The velocity and direction of MSs are updated in discrete time intervals. Each parameter is updated based on a normal distribution with the mean value equal to the old value of the same parameter [9]. In *Manhattan Grid* and *Graph-based* mobility models, MSs are moved on certain routes over the simulation area [9], [11].

In this paper, we propose a mobility model based on the original version of random waypoint, which is applicable in the hybrid WLAN/Cellular systems. The proposed mobility model is analyzed through simulations and analytical modeling.

In the following sections, after discussing the suggested mobility scenario in Section II, its properties are studied through analytical modeling and simulations in Section III. Section IV, concludes the paper.

## II. MOBILITY MODEL FOR HYBRID NETWORKS

Evaluation of the performance of hybrid mobile networks should be performed through simulations or analytical modeling. In this section a special mobility model is proposed for simulation of these networks.

### A. Hybrid WLAN/Cellular Systems

The higher bandwidth, lower latency, and easier deployments of WLANs make them a way of public wireless communications. The importance of WLANs in the mobile wireless communication is such that the *Third Generation Partnership Project* (3GPP) builds up a standard architecture for co-operating cellular-WLAN systems. The main motivation is to enable 3GPP system operators to provide public WLAN access as an integral component of their services [1], [12]-[14].

Hybrid WLAN/cellular systems can improve system capacity and coverage. WLAN technologies can be employed in home and office environments, shopping centers, university campuses, airports, and so on. Hotspots are locations in a cellular system where subscribers' density is high. Airports, university campuses and shopping centers are examples of hotspots. Since WLANs are mainly employed in these locations, hotspot and WLAN are used interchangeably.

Due to the importance of the hybrid WLAN/cellular systems in the future, special protocols and algorithms are being developed for this kind of systems. When the performance of these protocols is evaluated through simulations, special mobility models should be employed. In the following subsection, a special version of random waypoint model is proposed for simulation of this kind of hybrid networks.

Bettstetter and Wagner propose a similar hotspot mobility model based on random waypoint [10]. The difference between our mobility model and the model proposed in [10] is the way that the hotspot is generated. In fact, we try to build up *two parallel random waypoint mobility models* that MSs can switch in between, while, the model of [10] tries to implement only one random waypoint model with non-uniform destination selection. Therefore, this makes our model much closer to what happens in the real world. Also, in our model, the velocity and pause time of the stations inside and outside of the hotspot are considered to be different.

### B. Hotspot Random Waypoint Mobility Model

Due to simplicity of the random waypoint, the hotspot mobility scenario is proposed based on the original random waypoint model. We call the proposed scenario as the hotspot random waypoint (HRWP) mobility model. In the following paragraphs, HRWP is proposed for a simple environment where only one hotspot (WLAN) is used inside the only cell of a hybrid WLAN/cellular system. The model can be extended to more complex environments in a straightforward manner.

The hotspot and the cell are assumed to be circular areas. The center of the cell is assumed to be at the origin of a Cartesian coordinate system. The  $x$  and  $y$  coordinates of the hotspot center (access point position) are named  $AP_X$  and  $AP_Y$ , respectively.

In HRWP, mobile stations are classified as *Inside* MSs and *Outside* ones. An *Inside* (*Outside*) MS is an MS, which is inside (*outside*) the hotspot. For each class of MSs a *random waypoint* mobility model is used. At the beginning of the simulation, a certain fraction of nodes, *Initial-Fraction*, are initially considered as *Inside* nodes and distributed randomly inside the hotspot. The remaining nodes are considered as *Outside* ones and distributed outside the hotspot at random. In order to pick up a random location a random number,  $r$ , is generated based on a uniform distribution between 0 and  $R$ , where  $R$  is the radius of the hotspot for inside locations and the radius of the cell for outside points. A random angle  $\alpha$  is generated uniformly at random. Then, the  $x$  and  $y$  coordinates, in the Cartesian coordinate system, are generated as follows

$$\begin{cases} x = r \cos(\alpha) + x_0 \\ y = r \sin(\alpha) + y_0 \end{cases} \quad (1)$$

where,  $(x_0, y_0)$  is equal to  $(AP_X, AP_Y)$  for inside locations and  $(0, 0)$  for outside points. Each MS moves from its current position toward its random destination with a random velocity. The destination of an *Inside* MS is selected outside the hotspot with probability of  $P_{out}$  while the destination of an *Outside* MS is selected inside with probability of  $P_{in}$ .

In real world, the velocity of mobile nodes could be different inside and outside a hotspot. Specially, if a hotspot is used to cover an inside environment, the velocity of *Inside* MSs is much lower, compared with the outside ones. Also, inside a hotspot, MSs have longer pause times than outside. In the HRWP model, the velocity of *Inside* MSs has uniform distribution between  $V_{min}^I$  and  $V_{max}^I$  m/sec while the velocities of *Outside* MSs are uniformly distributed between  $V_{min}^O$  and  $V_{max}^O$ . When an *Inside* MS arrives at its destination, it waits there for a random period of time between 0.0 and  $T_{max}$  seconds. This period of time is named as *pause time*. In this paper, it is assumed that *Outside* MSs have no pause, but it can be generalized easily.

In Fig. 1, the state diagram of MSs in HRWP mobility model is illustrated. Let us start with an *Inside* MS. When an *Inside* MS reaches at its destination point, it waits there for a random pause time. Then, the next destination is generated randomly. This new destination could be outside the hotspot with probability of  $P_{out}$ . When the destination

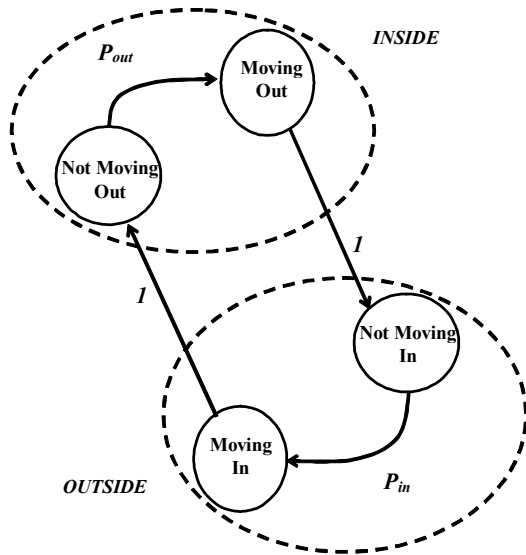


Fig. 1. State diagram of MSs in HRWP mobility model.

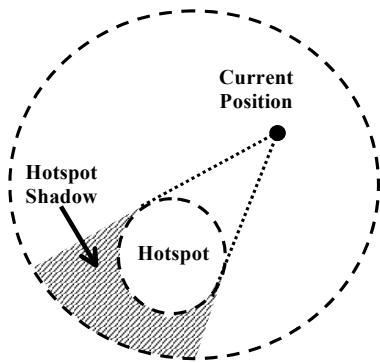


Fig. 2. Hotspot shadow area.

of an Inside MS is outside the hotspot it moves toward outside but it is not going to be an Outside one before crossing the hotspot border. Inside MSs with inside destinations are in "Not Moving Out" state and those with outside destinations are in "Moving Out" state. The same thing happens for Outside MSs. An Outside MS with outside destination is in "Not Moving In" state. When it reaches its destination a new point is selected as the next destination. This new destination is inside the hotspot, with probability of  $P_{in}$ . If this happens, the MS is in "Moving In" state. Such an MS will change to an Inside one only after crossing the hotspot border.

Now assume that an MS is outside the hotspot. Also, assume that its destination is located outside too. In other words, the MS is in "Not Moving In" state. In this case, the MS's path may not cross the hotspot. Therefore, for any Outside MS which is in "Not Moving In" state, there is an area outside the hotspot, *Hotspot Shadow*, where the MS's destination can not locate there. An example is shown in Fig. 2. Hotspot shadow area of each MS is different from the others and depends on the current position of the node.

### III. PROPERTIES OF HRWP MOBILITY MODEL

In this section, properties of the proposed mobility model are studied through simulations and analytical modeling. A large number of simulations have been performed to evaluate the performance of the proposed method. In this paper, we will describe some of the most important ones. Table I shows the initial parameter settings.

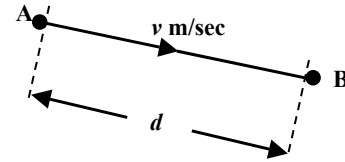
Fig. 3. An MS moves with velocity of  $v$  m/sec.

TABLE I  
INITIAL PARAMETER SETTINGS FOR SIMULATIONS

Parameter	Value	Parameter	Value
$AP_x$ and $AP_y$	500, 500	$P_{out}$	0.35
Hotspot Radius	100 m	$P_{in}$	0.1
Cell Radius	1000 m	$V_{min}^I, V_{max}^I$	0.5, 2.0 m/sec
$V_{min}^O, V_{max}^O$	1, 15 m/sec	$T_{max}$	300 sec
No. of Nodes	1000	Initial-Fraction	0.5

Each time, only one of these parameters is changed. The measured metrics in each simulation run include:

- Average number of nodes inside the hotspot
- Average velocity of mobile stations
- Hotspot border crossing rate

The hotspot border crossing rate is the average number of MSs moving in or out of the hotspot per second. The above parameters are measured only when the simulator is in the steady state. Before going to describe the results, let us build up an analytical view.

In Fig. 3, a mobile station is moving from point A to point B. The velocity of this MS is  $v$  m/sec and the distance between A and B is  $d$  meters. The MS waits  $\tau$  seconds in B and then moves toward its next destination. This is exactly what happens for MSs in "Not Moving Out" state. If  $t$  is the time between leaving point A and leaving point B, we have

$$t = \tau + \frac{d}{v} \quad (2)$$

For simplicity, let us assume that  $\tau$ ,  $v$ , and  $d$  are deterministic values, i.e., they are not generated at random. The MS of Fig. 3 traverses  $d$  meters in  $t$  seconds. Therefore, its average velocity in this time is  $\bar{v}$  and we have

$$\bar{v} = \frac{d}{t} = d \left( \tau + \frac{d}{v} \right)^{-1} \quad (3)$$

In the proposed model, for Outside MSs,  $\tau$  is zero. Also, it is noticeable that  $t$  is equal to the time between generating two consequent destinations for each MS. If  $\delta$  is the rate of destination generation for an MS we have

$$\delta = \frac{1}{t} = \left( \tau + \frac{d}{v} \right)^{-1} \quad (4)$$

Now, if we have  $N^I$  Inside and  $N^O$  Outside MSs and the total number of MSs is equal to  $N$ , we have

$$\begin{aligned} \rho^O &= N^I \delta^I P_{out} \\ \rho^I &= N^O \delta^O P_{in} \end{aligned} \quad (5)$$

where,  $\delta^I$  and  $\delta^O$  are the destination generation rates for Inside and Outside MSs, respectively. With the rate of  $\rho^O$  a destination is generated outside the hotspot for one of the Inside MSs. Destination of one of the Outside MSs is

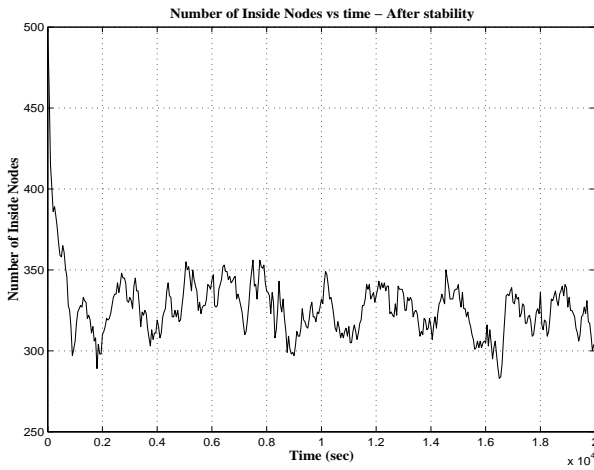


Fig. 4. Stability in the number of nodes inside the hotspot.

generated inside the hotspot with the rate of  $\rho^I$ . When the simulator is in the steady state,  $\rho^O$  and  $\rho^I$  must be the same. Fig. 4, shows how the simulator reaches the stability. This figure, illustrates how the number of Inside MS changes before and after system being in the steady state. It is expected that when the system is in steady state, the average rate of hotspot departure be equal to the average rate of entering the hotspot. This is illustrated in Fig. 5. Therefore, we have

$$N^I \delta^I P_{out} = N^O \delta^O P_{in} \quad (6)$$

Also, it is clear that

$$N^I + N^O = N \quad (7)$$

Hence, based on (6) and (7)

$$N^I = N \left( 1 + \frac{\delta^I P_{out}}{\delta^O P_{in}} \right)^{-1} \quad (8)$$

By substituting  $\delta^I$  and  $\delta^O$  by their definition based on (4), we have

$$N^I = \frac{N}{1 + \frac{P_{out}}{P_{in}} \times \frac{d^O}{v^O} \times \left( \tau^I + \frac{d^I}{v^I} \right)^{-1}} \quad (9)$$

where, values with O and I superscripts are related with Outside and Inside MSs, respectively. It is clear from this equation that any decrease in  $P_{out}$ ,  $d^O$ ,  $v^I$  or any increase in  $P_{in}$ ,  $d^I$ ,  $v^O$  or  $\tau^I$  will increase  $N^I$ .

Equation (9) shows the effect of different parameters on the behavior of the mobility model. However, it has been assumed that these parameters are deterministic values. From the HRWP description, it is clear that different parameters of the model, such as the nodes' velocities, are random variables. A simple estimation of  $N^I$  could be made based on (9) by replacing the random parameters with their expectations. In the HRWP model,  $v^I$  and  $v^O$  are uniformly distributed over  $[V_{min}^I, V_{max}^I]$  and  $[V_{min}^O, V_{max}^O]$ , respectively. Also,  $\tau^I$  is uniformly distributed over  $[0, T_{max}]$ . Furthermore,  $d^I$  and  $d^O$  are the distances between two points inside and outside the hotspot, respectively. The coordinates of these points in the Cartesian coordinate system are defined by (1). Then,  $N_{Simple}^I$  is the simple estimation of  $N^I$  and is defined as follows

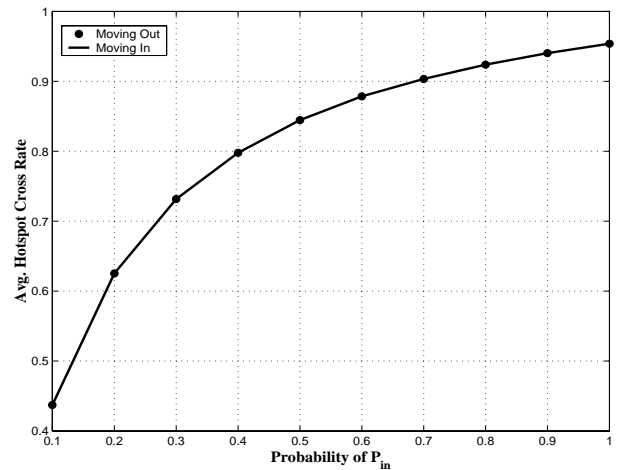


Fig. 5. Changes in the hotspot border crossing rates while  $P_{in}$  is changed.

$$N_{Simple}^I = \frac{N}{1 + \frac{P_{out}}{P_{in}} \times \frac{E[d^O]}{E[v^O]} \times \left( E[\tau^I] + \frac{E[d^I]}{E[v^I]} \right)^{-1}} \quad (10)$$

where,  $E[\cdot]$  is the expectation function.

The dynamic behavior of the HRWP model could be determined based on (5) and (6). Let us assume that  $N_j^I$  and  $N_j^O$  are the  $j$ -th samples of the number of Inside and Outside MSs. Then, based on (5), we have

$$\begin{bmatrix} N_{j+1}^I \\ N_{j+1}^O \end{bmatrix} = \begin{bmatrix} -\delta^I P_{out} & \delta^O P_{in} \\ \delta^I P_{out} & -\delta^O P_{in} \end{bmatrix} \begin{bmatrix} N_j^I \\ N_j^O \end{bmatrix} \quad (11)$$

Then, with a large number of samples we have

$$N_{Dynamic}^I = \frac{1}{K} \sum_{j=1}^K N_j^I \quad (12)$$

where,  $K$  is the number of samples.

Simulation results show that the estimation of the  $N^I$  by  $N_{Dynamic}^I$  is better compared with  $N_{Simple}^I$ . However, for simplicity, some minor facts, such as hotspot location and the shadowing effect of the hotspot are not considered in this estimation. Therefore, the simulation results are to some extent different from the analytical ones.

In order to modify the estimation of (12), a correction factor,  $\xi$ , is used as follows

$$N_{Modified}^I = \xi \times N_{Dynamic}^I \quad (13)$$

where,  $\xi$  is defined based on the following equation

$$\xi = \frac{N_{Simulation}^I(Reference\ Point)}{N_{Dynamic}^I(Reference\ Point)} \quad (14)$$

The value of  $N_{Simulation}^I$  is determined based on the simulations. Also,  $N_{Dynamic}^I$  is defined by (12). In this paper, the *Reference Point* is the same as the parameter settings defined by Table I.

In the following subsection, simulation results are compared with the analytical estimations defined by (10), (12), and (13).

#### A. Node's Distribution and Velocities

In the original version of random waypoint model, the distribution of the nodes is not uniform and the node-

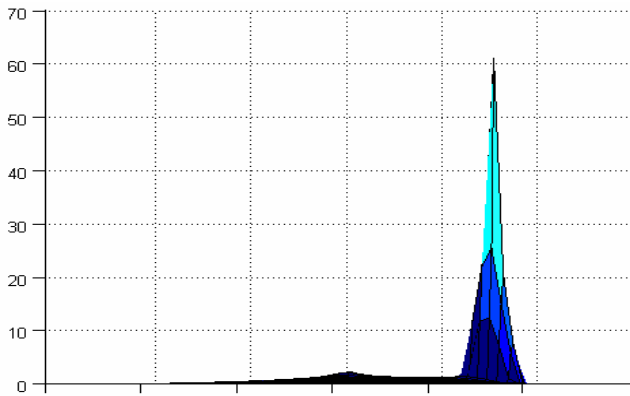
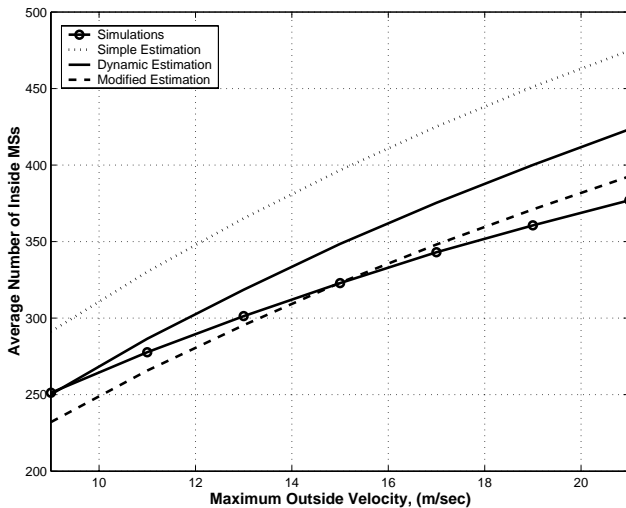


Fig. 6. Distribution of nodes on the simulation area.


 Fig. 7. Number of nodes inside hotspot when  $V_{\max}^O$  is changed.

density is higher in center than the edges. Because HRWP is developed based on the original random waypoint, a similar distribution is expected. Fig. 6 shows the distribution of the nodes over the simulation area.

Average number of Inside MSs,  $N^I$ , versus  $V_{\max}^O$ ,  $P_{out}$ , and hotspot radius, are illustrated in Figs. 7-9. The illustrated results are consistent with the analytical result of (9). It is clear from these figures and (9) that any decrease in  $P_{out}$  or  $V_{\max}^O$  will increase  $N^I$ . In Figs. 7-9, simulation results are also compared with the analytical estimations based on equations (10), (12), and (13). It is clear from this comparison that, while the simple estimation of (10) shows the behavior of the model, the modified estimation of (13) is the best one.

Effects of different simulation parameters on the average speeds and the average fraction of nodes inside the hotspot are summarized in Table II. Any increase in the value of  $V_{\max}^O$  cause the Outside MS's to reach their destinations faster. Hence, the destination generation rate will be higher for the Outside MS's and therefore, these mobile nodes will enter the hotspot with a higher rate. For this reason, increasing the value of  $V_{\max}^O$  will increase the fraction of Inside mobile nodes. For a similar reason, when  $V_{\max}^I$  is increased, the number of MS's inside the hotspot is decreased. When  $T_{\max}$  is increased, the average number of Inside MS's is increased too. In fact, using greater values for  $T_{\max}$  means that the average pause time inside the hotspot is longer. Therefore, destination generation rate is decreased for the Inside MS's and hence, Inside MS's will

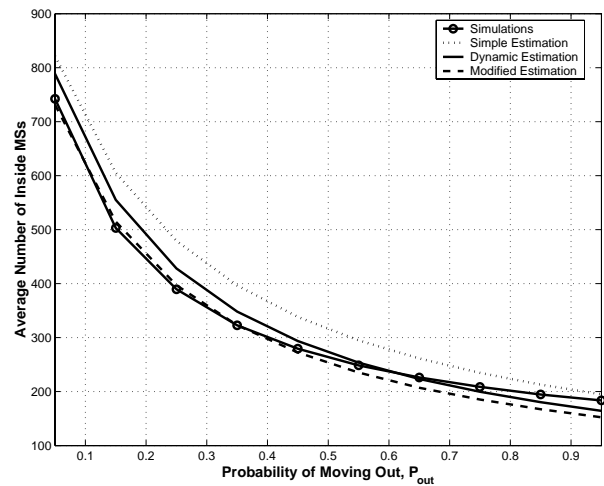
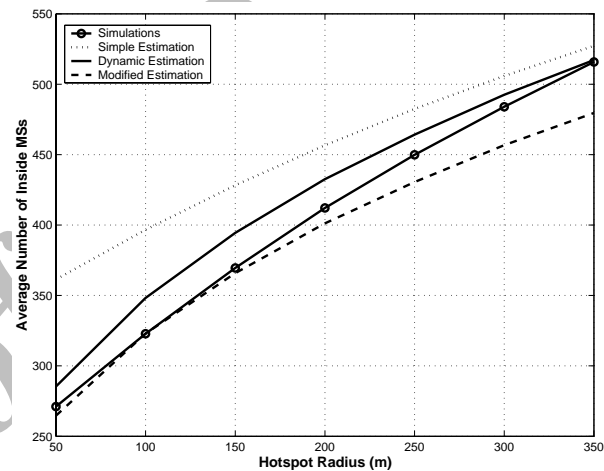

 Fig. 8. Number of nodes inside hotspot when  $P_{out}$  is changed.


Fig. 9. Number of nodes inside hotspot when hotspot radius changes.

 TABLE II  
EFFECTS OF AN INCREASE IN DIFFERENT PARAMETERS

Parameter (increased)	Number of Inside MSs	Average Inside Speed	Average Outside Speed
$V_{\max}^O$	Increase	No Effect	Increase
$V_{\max}^I$	Decrease	Increase	No Effect
$T_{\max}$	Increase	Decrease	No Effect
Hotspot Radius	Increase	Increase	No Effect
Cell Radius	Decrease	No Effect	No Effect
$P_{out}$	Decrease	Increase	No Effect
$P_{in}$	Increase	No Effect	Decrease
Initial-Fraction	No Effect	No Effect	No Effect

leave the hotspot with a lower rate. With a greater value of  $P_{in}$ , Outside MS's move toward the hotspot with a higher rate. Hence, the number of Inside MS's is increased as shown in Table II. For a similar reason, when  $P_{out}$  is increased, the number of MS's inside the hotspot is decreased. When the hotspot's radius is increased, the average distance between the current position of MS's and their destinations for Inside MS's,  $E[d^I]$  is increased. Therefore, destination generation rate is decreased for the Inside MS's and hence, Inside MS's will leave the hotspot with a lower rate. The same argument holds for the cell radius.

Nodes' distribution on the simulation area may be influenced by the hotspot's location. The effect of hotspot location on the number of Inside nodes is illustrated in Fig. 10. As it is clear from this figure, a change in the

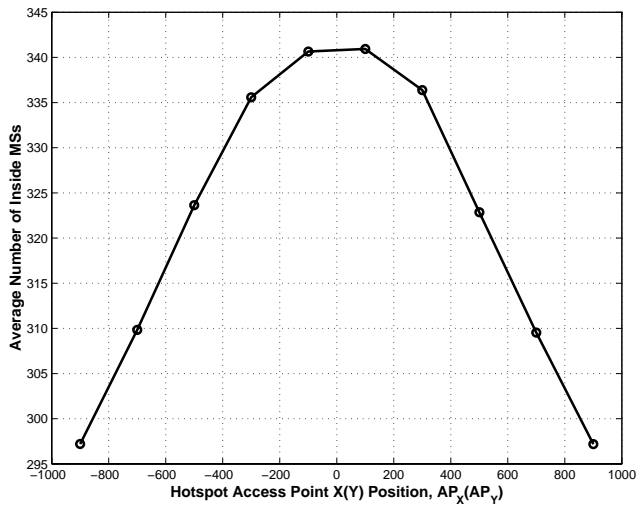


Fig. 10. Effect of hotspot location on number of inside nodes.

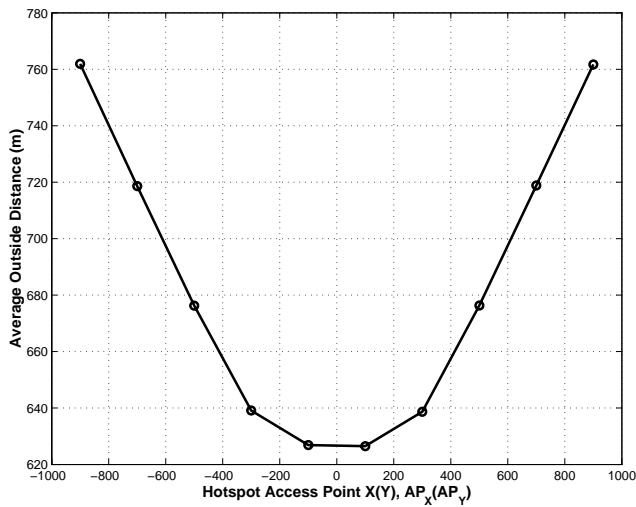


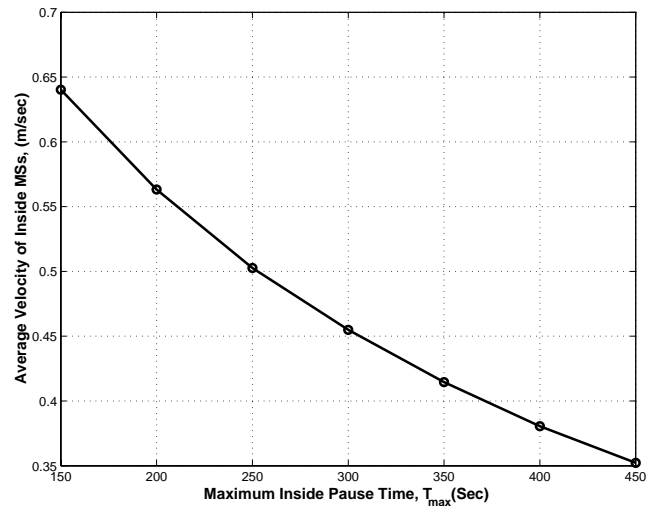
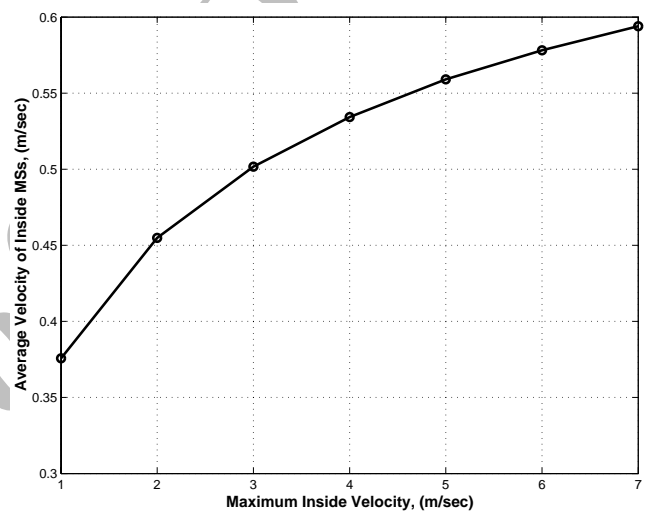
Fig. 11. Average distance between current and destination points of Outside Nodes.

hotspot location may change the number of Inside MSs. In fact, any change in the hotspot location changes the average distance between current and destination points of Outside nodes,  $d^O$  in (9). This is illustrated in Fig. 11. When  $d^O$  is increased, the destination generation rate is decreased for the Outside MS's and hence, Outside MS's will enter the hotspot with a lower rate. Therefore, the value of  $N^I$  is decreased.

The effect of different parameters on the average velocity of MSs inside and outside the hotspot is illustrated in Figs. 12 and 13 and Table II. It is expected from the HRWP model and (3), that any increase in the value of  $T_{max}$  or any decrease in the value of  $V^I$  results in a lower velocity for Inside mobile stations. With a longer pause time, mobile stations traverse the same distance in a longer period of time. This is illustrated by (2). Therefore, the average velocity of mobile stations is decreased. Same argument could be used for Outside MSs.

### B. Comparing with the Original Random Waypoint

Even in the original random waypoint (RWP) mobility model, nodes inside (outside) the hotspot will move outside (inside) with a certain probability. These probabilities depend on the area and location of the hotspot, the area of the cell and the velocity of nodes. In this section, we compare the proposed HRWP mobility model with the

Fig. 12. Average speed of inside nodes when  $T_{max}$  is changed.Fig. 13. Average speed of inside nodes when  $V_{max}^I$  is changed.

original version of RWP. In the original random waypoint, there is no Hotspot Shadowing effect. Mobile stations move freely from their current positions toward their random destinations. Therefore, they can move through the hotspot, even if their destination and current positions are not located there. On the other hand, in HRWP model, MSs do not move through the hotspot if their current positions and their destinations are outside. Hotspot Shadowing effect is the immediate result of this behavior. For comparing the HRWP with the RWP model, we add Hotspot Shadowing to RWP. It is important to notice that we can not model a hotspot inside a cellular system, by RWP mobility model. We assume that there is a hotspot inside the cell, but the node-distribution is not similar to the hotspot-node-distribution.

Let us assume that  $A_{hotspot}$  and  $A_{cell}$  are the areas of the hotspot and the cell, respectively. Under the original RWP model, if the destinations are selected uniformly from the simulation area,  $A_{hotspot}/A_{cell}$  is the probability that a destination locates inside the hotspot. This is something similar to the concept of  $P_{in}$  and  $P_{out}$  in the HRWP.

For comparing the HRWP with the RWP with and without Hotspot Shadowing, we change some of the parameters, illustrated in Table I. We assume that the pause time is zero inside and outside the hotspot ( $T_{max} = 0$  sec). The velocity of nodes inside and outside the hotspot is a

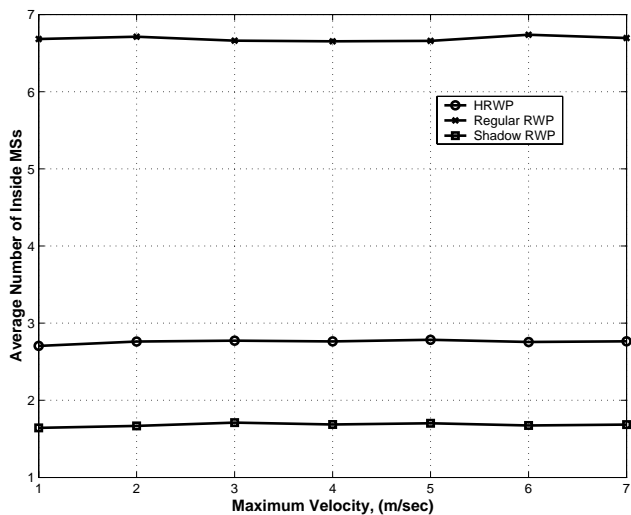


Fig. 14. Number of Inside Node under different models vs. maximum velocity.

random number between  $V_{\min} = 0.5$  m/sec and  $V_{\max}$ . There is no difference between the velocity of Inside and Outside nodes. For HRWP,  $P_{in}$  is considered to be  $A_{hotspot} / A_{cell} = 0.01$  while  $P_{out}$  is equal to 0.99. Figs. 14 and 15 compare these mobility models when  $V_{\max}$  is changed between 1.0 m/sec and 7.0 m/sec.

Fig. 14 compares the number of Inside MSs under the HRWP and the original RWP with and without Hotspot Shadowing. As it is expected, the number of Inside nodes under the regular RWP, is greater than those of HRWP, because MSs can move through the hotspot even if their current and destination points are located outside. Fig. 15 compares the average velocity of nodes inside the hotspot under different mobility scenarios. The average velocity of nodes, inside and outside the hotspot, is almost the same under different mobility models. As it is expected, the RWP with Hotspot Shadowing is a special case of our HRWP model.

#### IV. CONCLUSIONS

In this paper, we proposed and evaluated a mobility model, HRWP, for hybrid WLAN/cellular systems based on the well-known random waypoint mobility model. In the proposed model, one can change the average number of MSs inside a hotspot by manipulation of different parameters. The effects of these parameters on the simulator behavior are studied through analytical modeling and simulations. Also simulations show that the suggested mobility model arrives at the steady state after an acceptable period of time. Results show that the nodes' distribution inside and outside the hotspot is not uniform. Using an improved version of the random waypoint model may solve this problem. Although the model is described for a simple environment, it can be extended to more complex environments in a straightforward manner.

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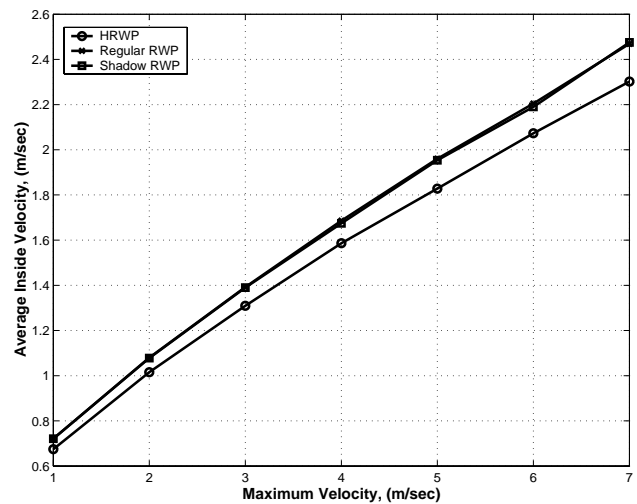


Fig. 15. Average velocity of nodes Inside hotspot under different models vs. maximum velocity.

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