

# An Obstacle Based Realistic Ad-Hoc Mobility Model for Social Networks

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**Abstract** – An efficient deployment of a mobile ad-hoc network (MANET) requires a realistic approach towards the mobility of the hosts who want to communicate with each other over a wireless channel. Since ad-hoc networks are driven by human requirements, instead of considering the random movement of mobile nodes, we concentrate on the social desire of the nodes for getting connected with one another and provide here a framework for the mobility model of the nodes based on Social Network Theory. In this paper, we capture the preferences in choosing destinations of pedestrian mobility pattern on the basis of Social Factor ( $\Psi_F$ ) and try to find out the essential impact of  $\Psi_F$  on the Pause Time of the nodes. Also, instead of considering an unobstructed terrain, we carry out our simulations in presence of obstacles which block the node movement. Thus, we present here a more realistic mobility distribution pattern. Further, a relative comparison of the proposed model with the popular Random Way-Point (RWP) Model is also done.

**Index Terms** – MANET, mobility, Social Network Theory

## I. INTRODUCTION

In an ad-hoc network, a group of mobile users, strewn across a location, desire to interact with each other over a wireless channel without any centralized control. Such networks are helpful in emergency search and rescue operation, in battlefields, and for setting up instant communication among the business delegates assembling in a lecture hall. In some cases, the topology of the network remains stable after an initial setup period, for example, once the business delegates are seated around a table or in their respective rooms, their laptops may be moved fairly infrequently. In some other cases, the network topology may be subjected to a rapid change due to frequent link failure and the mobility of the nodes.

Further, wireless channels experience high fluctuation in channel quality due to several reasons including multipath, fading, dynamic change in topology and obstacles. For this reason, instantaneous creation of such networks and its maintenance is not an easy task.

For providing an environment for specific advantages over real world studies of MANET, simulation is performed; an important component of which is the mobility model. Once the nodes are initially placed within an ad-hoc environment, the mobility distribution of the nodes dictates the efficiency of the network. With the help of these distributions, quantitative information can be drawn on the link change rate, successful packet delivery and the degree of connectivity of mobile hosts.

A good number of research works have been published regarding different issues like routing protocols, mobility model, Quality of Service (QoS), bandwidth optimization for MANETs. In the absence of established properties of real mobility patterns, it is not yet clear today, what are the essential parameters to consider while constructing a mobility model [1]. The current scenarios on the available mobility models for MANETs are synthetic models based on simple, homogeneous, random processes [2, 3]. For example, Random Walk Mobility Model is used to represent pure random movements of the entities of a system. A slight enhancement of this is the Random Way-Point (RWP) Model, in which waypoints are uniformly distributed over the given convex area and the nodes have so called “thinking times” (pause times) before moving to next destination. Alternately, the waypoints can be uniformly distributed on the border of the domain, and this model is referred to as the “Random Way-Point on the Border” (RWPB) model. The spatial node density resulting from RWPB model is quite different from the RWP model, i.e. the probability mass shifts from the center of the area to the borders [4].

However, all such synthetic movement models generally do not reflect the real world situations regarding the mobility of nodes. In practice, a mobile user, within a campus or in any geographic location does

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not roam about in a random manner. Though the present synthetic models are more tractable for mathematical analysis and easy for trace generation, they do not capture the delicate details like time-location dependence and community behavior of pedestrian mobility. Human decisions and socialization behavior play a key role in typical ad-hoc networking deployment scenarios of disaster relief teams, platoon of soldiers etc. In [5,6], the authors used SNMP and syslog trace obtained from 802.11 access points to get partial information about mobility, but these traces are based on usage pattern and may fail to represent the social dimensions.

In this paper, we emphasize on the mobility pattern of individual nodes biased by strength of social relationships. The reviews of the social network analysis may be found in [7]. We argue in favor of the social behavior of the mobile nodes and try to find out effects of these behaviors on their movement. Here, we have systematically developed some social indicators out of the needs of an ad-hoc environment and then, we have transformed it into mathematical domain to formulate key factors. These factors are then mapped to a topographical space to show the distribution pattern for our model. Thus, we present the design and analysis of the individual as well as group mobility model based on the social network theory.

The proposed mobility model is made more realistic with the incorporation of obstacles in the simulation scenario. The obstacles placed within the network area may represent, for example, the buildings, trees etc in a college campus and these obstacles block the node movement as well as signal transmission. The simulation results show significant effect on node distribution due to the presence of these obstacles, which in turn would have a great impact on the ad-hoc network performance.

The rest of the paper is organized as follows: In section II, we give a brief overview of the related works. Section III provides an introduction to the concept of social network theory. In section IV, the proposed mobility model is presented. Section V provides our simulation results and analysis. Finally, the conclusion is given in section VI.

## II. RELATED WORKS

A great deal of attention has been paid towards finding out a realistic mobility model for MANET and the performance of the ad-hoc protocols under these mobility models. Such examples include [3, 8, 9]. While [8] gives a mobility model based on grouping of the mobile nodes, [9] describes scale-free and stable structures in complex ad-hoc networks.

The authors of [10] have introduced a canonical mobility measure to predict link change rates for various simulation scenarios. However, the basic models adopted by them for simulation environment are the RWP model, the Random Gauss-Markov (RGM) model [11], and the Reference Point Group Mobility (RPGM) model [12]. In [13], mobility pattern is obtained from the survey-based approach and from the simulation results of their model,

the authors suggest that converging to a steady state distribution is not necessarily a requirement of realistic mobility models.

Mathematical models of complex and social networks have been shown to be useful in describing many relationships, including real social relationships [14]. In [15], an approach has been presented towards a mobility model on the relationships of people though the paper lacks a rigorous mathematical representation of the relationship between individuals. The authors of [16] have presented a mobility model based on Social Network Theory from a theoretical point of view. The social network is represented using a weighted graph, where weights associated with each edge of the network are indicators of direct interactions between individuals.

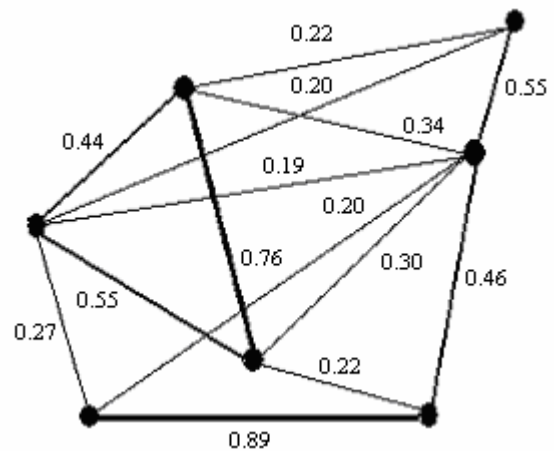


Figure 1. The relationships between different social neighbors have been shown as the weight of the connecting edges. Deeper edges indicate deeper connectivity. Interestingly, the degree of social connectivity is independent of geographical locations.

They have used a matrix, called Interaction Matrix, whose diagonal elements are '1' and other elements  $m_{ij}$  (lying between 0 and 1) represent the interaction between two individuals 'i' and 'j'. Their work provides a framework for the mathematical analysis based on the social relationships of the nodes; but certain assumptions make their formulations unsuitable for implementation in real world cases.

Inclusion of obstacles in the network simulation has been performed in [3], wherein the obstacles are used both to define movement pathways for mobile nodes and to obstruct the transmission between the nodes. The nodes move in the network area using pre-defined paths which are determined from the Voronoi diagram of the obstacle vertices. Nodes are randomly distributed along the paths and selection of the path to reach destinations is determined by shortest-path route computations. The obstruction cone in which the obstacles block wireless transmission is also calculated in [3]. Though the paper uses the obstacles effectively to design a mobility distribution pattern, the assumption of randomness makes this model unrealistic and unsuitable for properly modeling real world situations.

### III. SOCIAL NETWORK IN AD-HOC MODE

A network is a set of items, which are called vertices or sometimes nodes, with connections between them, called edges. There has been extensive study of networks in the form of mathematical graph theory. Networks have also been studied extensively in social sciences. These involve calculating the interaction between individuals and reconstructing the network such that vertices represent the individuals and the edges represent the interaction between them. Typical social network studies address issues of centrality and connectivity. Before going into the detailed discussion of social network theory, we would like to explain the following terms for clarity.

- **Vertex:** This fundamental unit of a network is also called a node in case of computer networks. Users are denoted by vertices.
- **Edge:** It is the link between the nodes. For social networks, they can carry weights representing, say, how well people know each other. They may also be directed, pointing only in one direction.
- **Directed / Undirected:** An edge is directed if it runs only in one direction and undirected if it runs in both directions. Graphs containing directed edges are called directed graphs or digraphs.
- **Degree:** It is the number of edges connected to a vertex. For social networks, it can be used as one of the measures of degree of interactions.
- **Component:** The component to which a vertex belongs is that set of vertices that can be reached from it by paths running along the edges of the graph. From the point of view of a social network in an ad-hoc mode, these are the nodes with whom the node under consideration can make interactions.

A social network can be defined as a set of people with some definite pattern of contacts or interactions between them. The patterns of friendship between individuals, business relationship between companies and intermarriage between families are all examples of such networks.

Traditional social network studies often suffer from problems of inaccuracy, subjectivity and small sample size. Survey data, which is the basic source of data for social network studies, are influenced by subjective biases on the part of the respondents; i.e.; how one defines degree of friendship could be quite different from how another one does. Although much effort is devoted for eliminating possible sources of inconsistency, there remains large and uncontrolled errors in these studies.

Because of these flaws, many other methods have been adopted for probing social networks. One source of relatively reliable data is from collaboration networks, which are affiliation networks in which participants collaborate in groups and links between them are established by common group membership. Another reliable source of data about personal connections is from

communication records of certain kinds like mails, telephone calls etc.

The Mobile Ad-Hoc Networks are a type of technological networks, a wireless network established between computers or other devices for the exchange of information. But the mobile devices are usually carried by humans and hence movement of such devices is based on human decisions and socialization behavior. In order to capture this social dimension, it is important to model the behavior of individuals moving in groups at different locations under different constraints. Herein comes the application of social network theory in ad-hoc mode of networks. The results of social network theory can be used to effectively model human behavior and which can be used to design a near-actual mobility distribution of nodes in an ad-hoc environment on the basis of which the ad-hoc protocols can be formulated.

### IV. THE PROPOSED MODEL

Instead of using heuristic approach, we develop our mobility model on the basis of the following assumptions, which also make our model more advantageous than the popular RWP model. The assumptions are:

- A<sub>1</sub>: The mobile nodes tend to select a specific destination and follow a well-defined path to reach that destination.
- A<sub>2</sub>: Path selection process is biased by the social interaction and community demand and it is different at different locations and time.
- A<sub>3</sub>: The pause time of the nodes being a function of social network, is not random. Instead, it follows a specific user oriented distribution at different locations.

With the help of these assumptions, we try to find out the factors controlling the mobility of nodes and then study the effect of the factors on both the individuals and the groups. In all subsequent part of the paper, the terms host, node and individuals are equivalent and indicate a single moving entity in the MANETs.

#### A. Different social issues controlling mobility

In order to capture the social ties into a mathematical relation, we use the recent results in social network theory. We represent a social network using a weighted graph where weights associated with each edge of network are an indicator of the direct interactions between individuals. We assign a value in the range [0, 1] to signify the degree of social interaction between two people, where '0' indicates no interaction and '1' indicates strongest social interaction.

Since every relation between two mobile nodes is not strong, we introduce here the term Connection Threshold (CT), which indicates a limit of social connectivity. Contrary to [16], we do not assign an arbitrary value to CT and express it as a function of time, network

parameters and social issues. In this context, we define the following terms:

- Link Duration [LD (t)]: The average time duration along which a channel is formed between two mobile nodes.
- Frequency of Connectivity [FC]: The number of times a mobile node *i* is connected to *j* over a single existing time of ad-hoc network.

Let us first discuss how CT depends on LD (t) and FC. A high value of link duration between two nodes suggests that the social interaction between them is considerably high. Again, frequent connectivity between two nodes through out the life-time of the MANET is indicative of the fact that the nodes prefer specific social relation instead of general social relation involving large number of nodes. On the basis of the above, we relate CT with LD(t) and FC as follows: the connection threshold of a node *j* denoted by CT<sub>*j*</sub> in a group of *n* number of nodes is defined as

$$CT_j = \frac{\sum_{i=1}^n LD_i(t) * FC}{n * T_{total}} \quad (1)$$

where, *n* = total no. of nodes present in the current MANET with whom the node *j* gets connected and T<sub>total</sub> = total time elapsed by the node *j* in an ad-hoc environment.

A close observation to (1) reveals the fact that CT depends on both the total amount of social links formed and the high social relationship between two mobile nodes. Since the total time elapsed by the node *j* in an ad-hoc environment is much greater than the total communication time between two nodes, we can argue that

$$CT < 1 \text{ as } \sum_{i=1}^n LD_i(t) * FC < T_{total} .$$

Again, a lower value of CT suggests greater social interaction. It is to be noted that low value of CT is achieved by a high value of *n* i.e. the no. of separate social interactions a node performs reflect the real social network criteria.

In order to give a quantitative idea on the value of CT, we consider an ad-hoc environment in which T<sub>total</sub> for a node is 30 minutes. The Tables I & II, elucidate the dependence of the value of connection threshold for two nodes on their social behaviors.

Clearly, in case of node 1 the effect of more number of different social links and short duration of connectivity with the social neighbors reflect in the low value of CT; whereas the node 2 possesses a high value (more than four times than node 1) of CT due to the greater interaction with a specific number of hosts.

TABLE I.  
CONNECTION THRESHOLD FOR NODE 1

Interacting Nodes	LD (sec)	FC	CT
1	90	2	0.11
2	45	1	
3	180	1	
4	72	4	
5	120	1	
6	88	3	
7	80	1	
8	240	2	
9	140	2	
10	60	1	

TABLE II.  
CONNECTION THRESHOLD FOR NODE 2

Interacting Nodes	LD (sec)	FC	CT
1	540	3	0.49
2	30	1	
3	600	4	
4	180	2	
5	445	1	
6	110	4	

Now, we determine the relationship of a node with each of its neighbors individually. For this, we construct a row matrix for each node in the mobile network, where each element designates the inter-relationship between the node and one of its neighbors. We denote the generic element of our matrix by *k<sub>ij</sub>*. Thus, for a node ‘*i*’, *k<sub>ij</sub>* represents the interaction of the node ‘*i*’ with node ‘*j*’. It is evident that the value of *k<sub>ij</sub>* lies between 0 and 1. It is worthwhile to mention that, while constructing the matrix, we consider only those neighbors who have a reasonable social interaction with the node, i.e. all the *k<sub>ij</sub>* in the matrix must lie above the threshold value of CT for the node ‘*i*’.

Till now, we have considered only a single network topology. A property that is common to many networks is the community structure, the division of network nodes into groups within which the network connections are dense but between which they are sparser [17]. This is shown in Figure 2. Here the node in bold mark moves from one community to another and sets up different social ties with different nodes present over there. The numbers in the Figure 2 indicate how the position of the node changes with time in a community structure.

The social behavior of a node essentially depends on its community behavior i.e. the involvement of the node to different social scenarios. The degree of interaction of a node within its original community is much more than,

when it enters a newer community. For example, a node from a university campus may visit a disaster relief camp. The pedestrian mobility pattern for these two locations

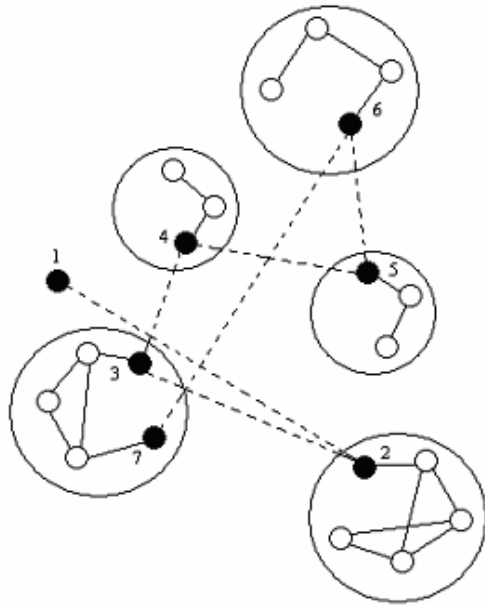


Figure 2. Movement of a node in a Community Structure.

will be different and will also influence its social behavior. In this context, we define another parameter called Community Factor (CF):

$$CF = \frac{\sum_i C_i * NNC}{\sum_i C_i} \quad (2)$$

where, NNC = New Network Coefficient whose value is either 0 or 1 and  $C_i$  = Specific grade assigned to a particular social network e.g. battlefield, cafeteria etc.

Here, the term NNC indicates whether it is exposed to a new network or not. Clearly, for a new network, its value is 0, since we do not consider the contribution of a new network to the value of CF. Thus for the said example, the social behavior of the node in the disaster relief camp will depend on the previous exposure of the node to this new community.

With the help of these factors, we now try to find out an indicator of the attitude of a node towards the interaction with others. To this end, we introduce Social Factor ( $\Psi_F$ ), which gives a measure of the degree of interaction between a node and others present in the ad-hoc network. For a node  $i$ , the social factor ( $\Psi_F$ ) is given as:

$$\Psi_{Fi} = \frac{\sum_{\substack{j=1 \\ j \neq i}}^N k_{ij} * CF_i * CF_j}{N} \quad (3)$$

where,  $N$  = Total no. of social neighbors above the CT level in a social network of 'i' which is equal to the number of elements of the row interaction matrix for the node 'i'.

From (1) and Tables I & II, we can say that CT approaches a steady state value less than 1. Since, for a highly social node the value of  $N$  is very high compared to the numerical values of CFs, in that case  $\Psi_{Fi}$  also tends to a steady value less than 1.

### B. Formulation of Pause Time

We explicitly define Pause Time (PT) for our mobility model as the time elapsed by a node when it meets a social neighbor over a wireless channel or in a geographic location in a MANET. As an example, we can say that the distribution of pause time in the classroom is a bell-shaped normal distribution [10], with the peak around the 60-120 minutes interval, which is the regular class duration. Basically, the distribution is based on Markov model of location transition of mobile nodes.

However, we try to develop an expression of pause time based on our social factors as given in Section IV.A. We do this because instead of taking a fixed value of pause time (as in the case of RWP) or simply some random value, we make pause time as a function of social network parameters.

Since geographic grouping is a different concept to social grouping, social attractiveness of different groups plays a key factor for controlling pause time. We define another quantity namely Previous Average Connectivity (PAC) which is the average time of connection of node  $i$  to a social group  $G_i$ . Thus, associating all the variables together (including  $\Psi_F$ ), we give an empirical relation connecting  $\Psi_F$  and PT:

$$PT = \Psi_F * GA_i * [1 + PAC(t)] \quad (4)$$

where  $GA_i$  is the individual group attraction force of the node  $i$  to the group  $G_i$  and has a value in the range  $[0, 1]$  i.e. a node may have no pause time at all. Here, the term PAC (t) also serves as a history parameter for different nodes. Table III gives some values of PT for the mobile nodes in an ad-hoc network.

Thus, instead of using random pause time for the mobile users scattered across a social gathering, we try to find out a node specific pause time.

TABLE III.  
SAMPLE VALUES OF PAUSE TIME (PT)

Node No.	$\Psi_F$	$GA_i$	PAC (t) (sec)	PT (sec)
1	0.34	0.5	529	90
2	0.68	0.85	265	154
3	0.83	0.3	1072	267
4	0.25	0.5	999	125

### C. Effect of Group Velocity on the Mobile Nodes

In this Section, we define the following terms:

- $V_n$  = Velocity of a node within a group
- $V_g$  = Velocity of a group

While  $V_n$  represents the individual node movement,  $V_g$  is indicative of the average node velocities within a social group.

The effect of the group velocity can be better understood if we consider clustering in a MANET. In a clustered network, a group of mobile nodes communicate with each other to perform a common task. Here, an analogy can be drawn with that of a social grouping in which there is a direct impact of the activity of the group leader on the movement of the nodes.

For the sake of clarity, we use the basic relationship between the group velocity and the position of the group members as in [16]. But, here we introduce a slight modification that instead of direct relationship between  $V_n$  and  $V_g$ , there is also an influence of GA, which is defined in section IV.B. Hence, the new position of a mobile node,  $N_n$  after unit time is given as:

$$N_n = N_p \pm \int_0^T \frac{\partial V_n}{\partial t} dt \pm \left[ \int_0^T \frac{\partial V_g}{\partial t} dt \right] * GA \quad (5)$$

where,  $N_p$  = Previous Node position and  $T$  = Total time elapsed by a node in the present group.

It is obvious from (5) that there will be a tendency for the mobile host to change its present group if a strong group attraction force is exerted on it from an outside group. This is an important issue. Since, joining a group or leaving a group is analogous to a new link set-up and link failure respectively, and this mobility pattern of nodes indicates a necessity for route update for the neighboring nodes. Using the same relation, we can also gather information about the social connectivity of the nodes after a period of time.

### D. Movement of Mobile Nodes in presence of Obstacles

In order to closely resemble real world situations, we introduce obstacles in the network area. Unobstructed terrains are unrealistic as real world scenarios contain various objects placed at various locations. The objects act as a barrier to both free movements of mobile nodes as well as wireless transmission between the nodes. These obstacles are used to model buildings and other structures present in an actual terrain like campus, battlefield etc. The obstacles can be of various shapes and sizes. For the sake of simplicity, in simulating our model, we consider regular rectangular shaped obstacles (using rectangles, various complex shapes like 'L', 'H' can also be constructed) as our simulation is carried out for a college campus where main obstacles are buildings which are usually of regular shapes.

The incorporation of obstacles, though takes us a step ahead towards accurate modeling of ad-hoc environments, does not provide a complete solution. The random

movement of nodes, bouncing off the walls of the obstacles, is unrealistic. People in college campuses or city terrains do not move about in this manner, reflecting off buildings. Thus the movement pattern of the nodes shown in Figure. 3 does not represent real world situations.

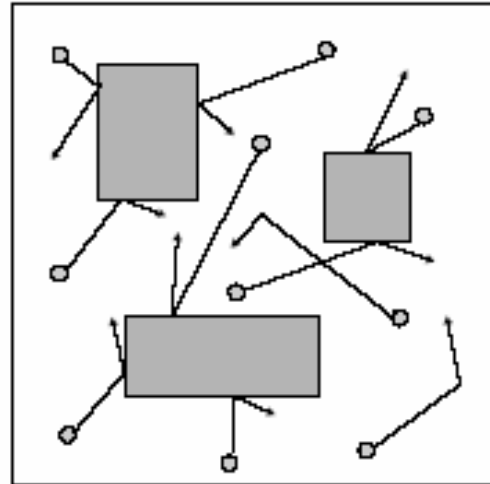


Figure 3. Random Obstacle-based Movement.

When a person traveling towards a destination experience an obstacle in his path, he travels along the edge of the obstacle and then again continues in his desired path. Moreover, people may select specific buildings as their destinations. Accordingly, in our simulations (the results of which have been provided in the next section), we have provided doors in the obstacles through which a node may enter or leave.

## V. SIMULATION RESULTS AND ANALYSIS

The primary objective of our simulation is to understand the impact of social network considerations and incorporation of obstacles on the mobility distribution of an ad-hoc network which in turn greatly affects the network performance. To obtain quantitative information about the proposed mobility model and compare it with the existing models, we have simulated our algorithm for an ad-hoc environment under certain constraints as given below.

We have considered an ad-hoc network deployed in a university campus. The simulation area is 1000m x 1000m. The maximum transmission range of the nodes is considered to be 250m. The simulation terrain along with the obstacles present is shown in Figure 4. The simulation area has been divided into four parts, as shown. Now, 40 mobile nodes are placed randomly within the area in the following manner: the nodes are divided into four groups of 10 nodes each, each group representing a specific community with its own particular community behavior; the nodes of each group are placed in the four regions of the terrain.

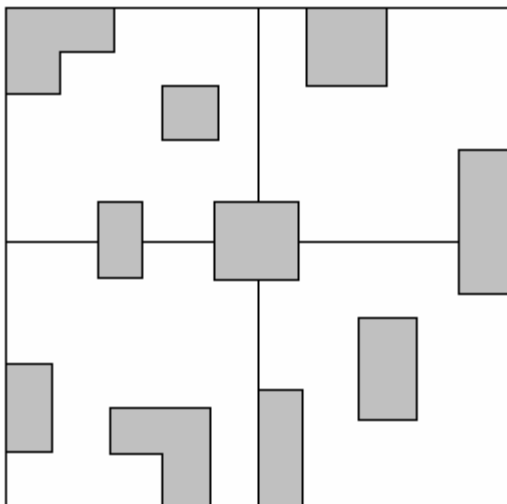


Figure 4. Simulated Terrain.

The nodes are then assigned with random velocities ranging from 1 to 4 m/s. The nodes then select their destinations, the members of a group tending to select the same common destination. The single row interaction matrices are formed for the various nodes and the different social parameters are calculated and after reaching their desired destinations, each mobile node takes a pause-time generated using (4). After pausing for this time, it again continues its motion towards some other destination. If a node encounters any obstacle in its path, it follows a path around the obstacle and then again continues its original path, as mentioned in section IV.D. The nodes may also select points inside the buildings as their destinations, and in that case, it has to enter the building through doors situated on all sides at the middle.

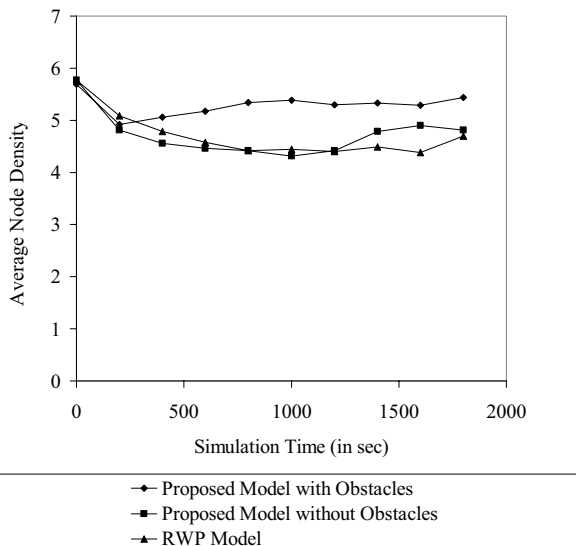


Figure 5. Average Node Density Vs Simulation Time for the campus terrain.

Now, each node is considered and the number of neighbors present within its range is calculated. For this purpose, we use an indicator variable  $I_{vj}$  defined as:

$$I_{vj} = 0, \text{ if the node } j \text{ is within the range}$$

$$I_{vj} = 1, \text{ if the node } j \text{ is out of range.}$$

The indicator variable for a node is calculated with all other nodes. The sum of the indicator variables is equal to the number of neighbors. The average number of neighbors per node is calculated. The simulation is carried out for half an hour and readings are taken at regular intervals of 5 seconds.

Further, the exact scenario is duplicated and simulated – once under our proposed model in absence of obstacles and again under the Random Way-Point model.

The above results show that the introduction of obstacles in the simulation terrain largely affects the mobility distribution pattern.

Simulations were also carried out in different scenarios using the proposed model and also the Random Way-Point Model in unbounded areas (i.e. areas with no boundaries).

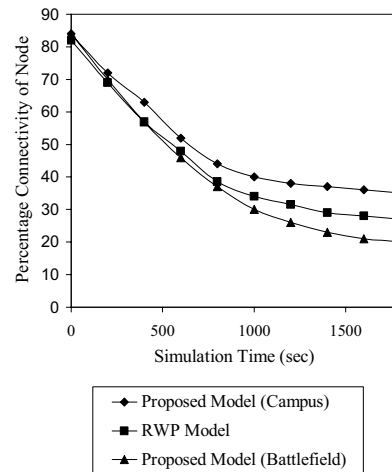


Figure 6. Percentage node connectivity Vs Simulation Time for different scenarios.

Figure.6 shows a comparison of the proposed model for two scenarios (campus and battlefield) with the RWP model. It is evident from the graph that unlike RWP model, our proposed model is able to capture the time location dependence of mobility distribution for different social scenarios since it does not assume random pause time. Moreover, the degree of connectivity of mobile nodes will suffer a major change for different communities. Thus, our model reflects the near actual pattern of pedestrian mobility distribution.

## VI. CONCLUSION

In this paper, we have presented a theoretical framework for the mobility distribution of the nodes in a MANET. Here, we have considered the effect of social behavior on the movement of a node which is basically a move and pause type of motion. Instead of assuming random pause-time distribution for the mobile hosts, we have designed a theoretical background for the pause-time formulation. The simulation result of our model shows a marked improvement over the existing RWP model regarding the connectivity of nodes. Further, we

have considered obstacles in the simulation terrain which greatly affect node distribution pattern. Moreover, our model has fewer assumptions over the RWP model, thus making it more realistic. Finally, we plan to refine our model by determining the pathways between obstacles and also the transmission characteristics in the presence of obstacles, which are left as future works.

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