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A Study of MANET Mobility Models

Satveer Kour, Jagpal Singh Ubhi

***Abstract*— A Mobile Ad Hoc Network (MANET) is a collection of wireless mobile nodes forming a self-configuring network without using any existing infrastructure. In mobile ad hoc network, simulation plays an important role in determining the network characteristics and measuring performance. On the other hand, unrealistic simulation conditions may be misleading, instead of being explanatory. Mobility model is the foundation of the simulation study of various routing protocols in the MANET. Movement behavior of mobile entities is one of the most important concepts for the realistic simulation scenarios in mobile ad hoc networks. In this study, we provide a survey and classification of existing mobility models in the literature. In this paper, we survey and examine different mobility models proposed in the recent research literature. We also discuss various models that exhibit the characteristics of temporal dependency, spatial dependency and geographic constraints. Hence, we attempt to provide an overview of the current research status of mobility modeling and analysis.**

***Index Terms*— Mobile Ad hoc Network, Mobility Models.**

I. Introduction

Wireless and mobile ad hoc networks turn out to be the first option for a wide range of application areas, such as military, environmental, health, home automation and security. In general, a Mobile Ad hoc NETwork (MANET) is a collection of wireless nodes communicating with each other in the absence of any infrastructure. The idea behind networking wireless nodes in ad hoc manner dates back to the DARPA packet radio network research. From those days to nowadays, there had been numerous research on mobile ad hoc networks including working groups. The nodes in an ad hoc network move according to various patterns are needed in simulation in order to evaluate system and protocol performance. Unlike the wiring networks, the unique characteristics of mobile ad hoc networks pose a number of nontrivial challenges to security design, such as open peer-to-peer network architecture, shared wireless medium, stringent resource constraints and highly dynamic network topology [1]. Most of the earlier research on mobility patterns was based on cellular networks. Mobility patterns have been used to derive traffic and mobility prediction models in the study of various problems in cellular systems, such as handoff, location management, paging, registration, calling time, traffic load. Thus, when evaluating MANET protocols, it is necessary to choose the proper underlying mobility model. For example, the nodes in Random Waypoint model behave quite differently as compared to nodes moving in groups. It is not appropriate to evaluate the applications [2] where nodes tends to move together using Random Waypoint model. Therefore, there is a real need for developing a deeper understanding of mobility models and their impact on protocol performance. In the previous studies on mobile patterns in wireless cellular networks, researchers mainly focus on the movement of users relative to a particular area(i.e. a cell) at macroscopic level, such as cell change rate, handover traffic and blocking probability. However, to model and analyze the mobility models in MANET, we are interested in the movement of individual nodes at the microscopic level, including node location and velocity relative to other nodes, because these factors directly determine when the links are formed and broken since communication is peer-to-peer. MANET also introduces several challenges that must be studied carefully before a wide commercial deployment can be expected. These include dynamic topologies, routing, device discovery, bandwidth-constrained-variable capacity links, power-constrained and operation, security and reliability, Quality of Service (QoS), Inter-networking, Multicast, IP-Layer Mobile Routing and Diffusion hole problem [3].

Satveer Kour, Assistant Professor, Dept. of CSE, GNDU Regional Campus, Sathiala, Distt. Amritsar (Punjab), Contact No. 01652-251450, 8054754961
Jagpal Singh Ubhi, Associate Professor, Dept. of ECE, SLIET,Longowal, Distt.Sangrur (Punjab), Contact No. 9463068009

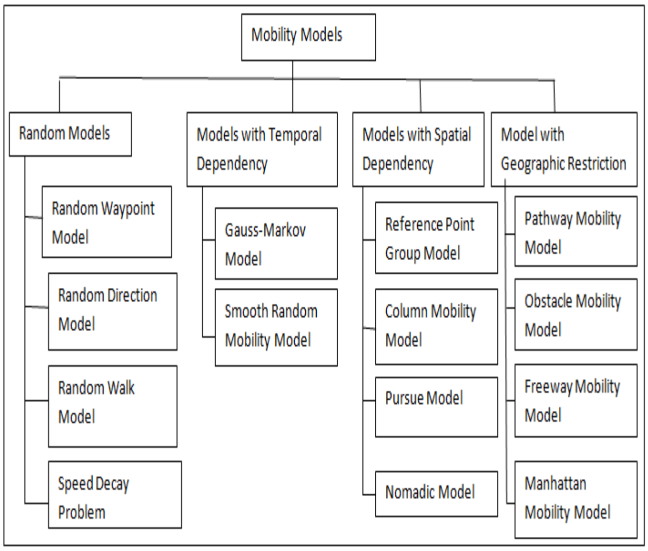

Figure 1: Categorization of Mobility Models

We provide a categorization for various mobility models into several classes based on their specific mobility characteristics. For some mobility models, the movement of a mobile node is likely to be affected by its movement history, called mobility with temporal dependency. In some mobility scenarios, the mobile nodes tend to travel in a correlated manner, called mobility nodes with spatial dependency. In some cases, the movements of nodes are bounded by streets, freeways or obstacles, this class deals with mobility models with geographic restrictions. One frequently used mobility model in MANET simulations is the Random Waypoint model, in which nodes move independently to a randomly chosen destination with a randomly selected velocity. The simplicity of Random Waypoint model may have been one reason for its widespread use in simulations. Further variations of Random Waypoint model are: Random

Direction Model, Random Walk Model. The remainder of this paper is organized as follows. In section 2, we describe the commonly used Random Waypoint Model, some of its stochastic properties and two of its variations. In section 3, we discuss two mobility models with temporal dependency, the Gauss-Markov Mobility Model and the Smooth Random Mobility Model. In section 4, several mobility models with spatial dependency are discussed. The mobility models with geographic restriction are discussed in section 5. We conclude this paper in section 6.

II. Random-Based Mobility Models

In random-based mobility models, the mobile nodes move randomly and freely without restrictions. For all the nodes, the destination, speed and direction are all chosen randomly and independently of other nodes [4].

2.1 The Random Waypoint Model

RWP (Random Waypoint) Mobility Model includes pauses between changes in direction and/or speed. A mobile node takes some period of time by staying in one location. After expiring this time period, the mobile nodes chooses a random speed and a random direction in the simulation area. The speed is uniformly distributed in min-speed and max-speed. The mobile node travels in the selected newly direction with the selected speed. Upon arrival, the mobile node pauses for a specified period of time repeating same process again [5].

2.2 Random Walk Model

RW (Random Walk) mobility model was originally proposed to emulate the unpredictable movement of particles in physics. It is also called Brownian Motion. In this mobility model, a mobile node moves from its current location to a new location by randomly choosing a direction and speed in which to travel. The new direction and speed are both chosen from predefined ranges, [0, 2*pi] and [min-speed, max-speed] respectively. Each movement in the Random Walk Mobility Model occurs in either a constant time t or a constant traveled d distance, at the end of which a new direction and speed are calculated. The Random walk model has similarities with the Random Waypoint model because the node movement has strong randomness in both models [6]. We can think the Random Walk model as the specific Random Waypoint model with Zero pause time.

2.3 Random Direction Model

RD (Random Direction) mobility model was created to overcome density waves in the average neighbors produced by RWP model. In this model, the node randomly chooses a direction and then travels to the border of the simulation area in this direction. Once the boundary is reached, the node pauses for a specified time, chooses another angular direction between 0 and 180 degrees and repeats the process [7].

III. Mobility Models with Temporal Dependency

Node mobility may be limited and constrained by acceleration, velocity and rate of change of direction. Next velocity of moving node may depend upon previous velocity. So, almost all velocities of moving nodes are ‘correlated’. This mobility characteristic is called *Temporal Dependency* of velocity.

3.1 Gauss-Markov Mobility Model

The Gauss-Markov Mobility Model was first introduced by Liang and Haas and widely utilized. In this model, the velocity of mobile node is assumed to be correlated over time and modeled as Gauss-Markov stochastic process. It was designed to adapt to different levels of randomness via tuning parameters. Initially each mobile node is assigned a current speed and direction [8]. At each fixed intervals of time n a movement occurs by updating the speed and direction of each mobile node. Specifically, the value of speed and direction at the nth instance is calculated based on the basis of the value of speed and direction at the $(n-1)^{st}$ instance and a random variable using the following equations:

Sn= alpha * Sn-1 + (1+ alpha)*S + sqrt (1-alpha 2)*SXn-1 ………Eq. (1)

Dn= alpha * Sn-1 + (1+alpha)*D + sqrt (1-alpha 2)*DXn-1 ………Eq. (2)

Where Sn and Dn are the new speed and direction of the mobile node at the time interval n, where 0 < alpha <1, is the tuning parameter used to vary the randomness s and d are constants representing the mean value of speed and direction as n-> infinity and SXn-1 and DXn-1 are random variables from a Gaussian distribution. Speed and Direction are calculated by using Eq. (1) and Eq. (2) respectively. Random values can be obtained by setting alpha=0 and linear motion can be obtained by setting alpha=1.The value of alpha between 0 and 1, intermediate levels of randomness are obtained. The next location is calculated on the basis of the current location, speed and direction of the movement. At time interval t, position of mobile nodes is calculated by equations:

Xt=Xt-1+St-1 Cos (Dt-1) ……… Eq. (3)

Yt=Yt-1+St-1 Sin (Dt-1) ……….Eq. (4)

Xt and Yt are the nest X-dimesion and Y-dimension of node at time interval, t. These parameters are calculated by using Eq. (3) and Eq. (4) respectively and completely based upon the previous calculated parameters Sn and Dn (Speed and Direction).

3.2 Smooth Random Mobility Model

As a result, unrealistic movement behavior of mobile nodes occurs, because of memoryless nature of Random Mobility Model. It does not seem natural the sharp turn and sudden acceleration or deceleration of moving nodes. So, Bettstetter proposes a model to change the speed and direction of node movement smoothly and incrementally. The mobile nodes in real life tend to move at certain speeds $\{V^1_{pref}, V^2_{pref}, \ldots, V^n_{pref}\}$, rather than at speeds purely uniformly distributed in the range $[0, V_{max}]$. The probability distribution of node velocity is as follows: the speed within the set of preferred speed values has a high probability, while a uniform distribution is assumed on the remaining part of entire interval $[0, V_{max}]$. The frequency of speed change is assumed to be a Poisson process in Smooth random Mobility Model [7].

IV. Mobility Models with Spatial Dependency

The location, speed and movement direction of mobile node are not affected by other nodes in the neighborhood in case of Random Waypoint model and other random models. Above said models do not capture many realistic scenarios of mobility. Some MANET applications like team collaboration among users, battlefield and disaster relief areas exists and users likely to follow the team leader. So, velocities of different nodes are ‘correlated’ in space, thus we call this characteristic as the *Spatial Dependency* of velocity.

4.1 Reference Point Group Mobility Model (RPGM)

In RPGM model, the mobile nodes in MANET move together in a group or platoon. Each group has a centre, which is either a logical centre or group leader node. We assume that the centre is the group leader. So, each group has composed of one leader and a number of members. The movement of group leader at time t can be represented by motion vector V^t_{group}. The motion vector V^t_{group} can be randomly chosen or carefully designed based on certain predefined paths. Same as, the movement of group members are also affected by the movement of its group leader. Here, mobility is assigned with a *reference point* that follows the group movement. Upon this predefined reference point, each mobile node could be randomly placed in the neighborhood. The motion vector of group member *i* at time *t*, V_i^t, can be described as

$$V_i^t = V^t_{group} + RM_i^t \quad \text{…………Eq. (5)}$$

Where the motion vector RM_i^t is a random vector decided by group member *i* from its own reference point. In Eq. (5), the motion vector of i^th^ member is calculated by adding up the motion vector of group, V^t_{group}, and Random vector of member *i*, at time interval, *t*. Many realistic scenarios could be modeled and generated with this framework, by properly choosing the checkpoints along the preferred motion path of group leader [9].

4.2 Column Mobility Model (CMM)

The column mobility model represents a set of mobile nodes that move in a certain fixed direction. The research area in which column mobility model used is destroying mines by military robots. It is derived from RPGM with the main difference being that groups in CMM move in columns and not in random fashion. Let $P_i^t=(X_i^t, Y_i^t)$ be the position of node *i* at time *t* and $RP_i^t= (X_i^t, Y_i^t)$ be the reference point of node *i* at time *t*. At time slot t, the mobile node *i* is to update its reference point RP_i^t by adding an advance vector α_i^t to its previous reference point RP_i^{t-1}. So,

$$RP_i^t= RP_i^{t-1} + \alpha_i^t \quad \text{……… ……Eq. (6)}$$

where the advance vector α_i^t is the predefined offset used to move the reference grid of node *i* at time *t*. After the reference point is updated, the new position of mobile node *i* is to randomly deviate from the updated reference point by random vector w_i^t. So,

$$P_i^t = RP_i^t+ w_i^t \quad \text{…………….. Eq. (7)}$$

In Eq. 6, reference point has been calculated on the basis of advance vector, which is further used in calculation of finding next position of moving node shown in Eq. 7. If the mobile node goes beyond the boundary of a simulation field, it flipped to 180 degree. Thus the mobile node is able to move towards the center of simulation field in the new direction [13].

V. Mobility Model with Geographic Restriction

Another limitation of Random Waypoint mobility model is its unconstrained motion of mobile nodes. In the natural scenarios, mobile nodes have the freedom to move freely and randomly everywhere in the environment. Same as, the motion of vehicles is bounded to freeways or local streets in the urban area and on campus, the pedestrians may be blocked by the buildings and other obstacles. So, movement of nodes must be in pseudo-random fashion on predefined pathway in the simulation field. This kind of mobility model is called a *mobility model with geographic restriction.*

5.1 Pathway Mobility Model

This mobility model is generated in the form of a graph denoted by G, having buildings in the form of vertices, V and set of edges, E, model the streets and freeways between those buildings.

G= (V, E)

This corresponding graph can be either randomly generated or carefully defined based on the real map of a city in which simulation has to be done. On the edges of the graph, mobile nodes are placed. For each node, a destination is randomly chosen and node moves towards this destination through the shortest path along with the edges. At the arrival on the destination, node pauses for a pause time, T_{pause} time and then chooses the next destination for the next movement. This process continues until the simulation ends. In this model, the mobile nodes are only allowed to move on pathways. The nodes are traveling in a pseudo-random fashion on the pathways due to certain level of randomness exists. In the Freeway and Manhattan Mobility models, mobile nodes are restricted to the pathway in the simulation field [10].

5.2 Obstacle Mobility Model

Because geographic constraint plays an important role in mobility models, there may be the provision of obstacles existing in the simulation field. If obstacles come in the path of moving node, node has to change its trajectory. Obstacles also affect the speed of moving nodes. The common example is radio propagation. Whereas, radio signals behave well in outdoor environment and behave poorly with some attenuation in outdoor environment. Johansson, Larsson and Hedman et al. [11] develop three realistic mobility scenarios to depict the movement of mobile users in real life, including

1. **Conference scenario**consisted of 50 people attending a conference, having some people with very low mobility and most of them are static.
2. **Event Coverage scenario** where a group of highly mobile people or vehicles are modeled. Those mobile nodes are frequently changing their positions.
3. **Disaster Relief scenarios**where some nodes move very fast and others move very slowly.

Obstacles are placed in the form of rectangular boxes in random fashion manner on the simulation field. A proper movement trajectory is chosen by the mobile node to avoid running such obstacles. The signal is fully absorbed by the obstacle when the radio signal propagates. Jardosh, Belding-Royer and Almeroth et al. [12] also investigate the impact of obstacles on mobility modeling in depth. Here, the movement trajectories and the radio propagation of mobile nodes are restricted somewhere. They analyzed very clearly that people in daily life usually follow the predefined paths between buildings instead of nodes moving randomly.

VI. Conclusion

Here, we examined the mobility models with its properties and exhibit different mobility characteristics. We expected that these mobility models behave differently and influence the protocol performance in different ways. Each model has its own unique and specific mobility characteristics. On the basis of characteristics, these are the comparative features of mobility models in its own category:

Table 1: Comparison of Random Mobility Models

Characteristics	Random Waypoint Model	Random Walk Model	Random Direction Model
Proposed By	Proposed by Johnson and Maltz [14].	Proposed by Karl Pearson [21].	Proposed by Royer, Melliar-Smith & Moser [15].
Key Features	Vmax, Tpause are the key factors, where Vmax is the maximum speed and Tpause is the stop time upon reaching the destination.	It is the specific type of Random Waypoint model with Tpause time=0.	Vmax, Tpause is there, node randomly chooses a direction and moves direction between 0 and 180 degrees.
Node Distribution Method	Uniform	Uniform	Uniform
Memory/Memoryless	Memory less	Memory less	Memory less
Average Speed	Nodes move at average relative speed between (0, Vmax).	At each interval t, node moves θ(t) from (0,2π)	Node moves (-π/4, π/4) with probability of 61.4%.
Distribution Method	Method used is Probability Distribution	Uniform or Gaussian Distribution	Non-uniform spatial node or density wave method is used.
Border Effect	It has mean-ergodic property.	It has border-effect property.	It affects from border-effect property but also deals with directional affect.
Entity/Group Mobility Model	It comes under in Entity mobility model.	It comes under in Entity mobility model.	It comes under in Entity mobility model.
Temporal Dependency	It restricts Temporal Dependency.	It restricts Temporal Dependency.	It restricts Temporal Dependency.
Spatial Dependency	No Spatial Dependency is there.	No Spatial Dependency is there.	No Spatial Dependency is there.
Geographic Restrictions	No Geographic Restrictions are there.	No Geographic Restrictions are there.	No Geographic Restrictions are there.

Table 2: Comparison of Mobility Models with Temporal Dependency

Characteristics	Gauss-Markov Mobility Model	Smooth Random Mobility Model
Proposed By	Proposed by Liang and Haas [16].	Proposed by Bettstetter [17].
Key Factor	Correlated velocity of mobile node Sn, direction Dn and variance Xt, Yt are the key factors.	Preferred speeds $\{V^1_{pref}, V^2_{pref}, \ldots, V^n_{pref}\}$ and maximum speed, V_{max} are the key factors.
Node Distribution Method	Uniform	Uniform
Memory/Memoryless	Memoryless, strong memory and some memory.	Memory
Average Speed	Nodes move at average relative speed between (0, Vmax) and flipped to 180 degree if reach to boundary line.	Both direction and speed are partly decided by previous values. Node flipped between [-π, π].
Distribution Method	Method used is Gaussian distribution.	It is the Poisson process followed by probability distribution.
Border Effect	It has border-effect property.	It has border-effect property.
Entity/Group Mobility Model	It comes under in Entity mobility model.	It comes under in Entity mobility model.
Temporal Dependency	It allows Temporal Dependency.	It allows Temporal Dependency.
Spatial dependency	No Spatial Dependency is there.	No Spatial Dependency is there.
Geographic Restrictions	No Geographic Restrictions are there.	No Geographic Restrictions are there.

Table 3: Comparison of Mobility Models with Spatial Dependency

Characteristics	Reference Point Group Mobility Model	Column Mobility Model
Proposed By	Proposed by X. Hong, G. Pei and C. C. Chiang [18].	Proposed by M. Sanchez and P. Manzoni [19].
Key Factors	Each group has a centre, a logical centre, a group leader and group members. The motion vector of group, V^t_{group} and motion vector of a group member i, at time t, named as reference point, RM_i^t are the key factors.	Same as RPGM, having set of mobile nodes, reference point RP_i^t, along with advance vector of each mobile node i, at time t, α_i^t for referencing the grid property.
Node Distribution Method	Uniform	Uniform
Memory/Memoryless	Memory	Memory
Average Speed	Nodes move at average relative speed between (0, r_{max}) and flipped to 0 to 2π degree if reach to boundary line.	Average relative speed is (0, r_{max}) and flipped to 180 degree if reach to boundary line.
Distribution Method	Method used is Uniform distribution.	It is the centralized distribution.
	Maximum allowed speed is r_{max} .	same.
Entity/Group Mobility Model	It comes under in Group mobility model.	It comes under in Group mobility model.
Temporal Dependency	It does not allow Temporal Dependency.	It does not allow Temporal Dependency.
Spatial Dependency	Spatial Dependency is there.	Spatial Dependency is there.
Geographic Restrictions	No Geographic Restrictions are there.	No Geographic Restrictions are there.

Table 4: Comparison of Mobility Models with Geographic Restrictions

Characteristics	Pathway Mobility Model	Obstacle Mobility Model
Proposed By	Proposed by Tian, Hahner & Becker [20]	Proposed by Johansson, Larsson and Hedman [11].
Key Factors	Simualtion area is built up in the form of graph, nodes as vertices and edges as paths, along with pause time, T_{pause}.	Simulation area is in the form of city map having obstacles also.
Node Distribution Method	Non-Uniform	Non-Uniform
Memory/Memoryless	Memoryless	Memoryless
Average Speed	Nodes move at average relative speed between (0, r_{max}) and choose the next destination after reaching the final destination.	Trajectory has been made and changes if obstacles come in the path.
Distribution Method/Shortest Path Algorithm	Nodes placed randomly and reach to destination by following the shortest path.	Voronoi graph is built up and Dijkstra algorithm is used to find the shortest path.
Property	Pseudo-Random fashion.	Pseudo random with obstacles.
Entity/Group Mobility Model	It comes under in Entity mobility model.	It comes under in Entity mobility model.
Temporal Dependency	It does not allow Temporal Dependency.	It does not allow Temporal Dependency.
Spatial Dependency	No Spatial Dependency is there.	No Spatial Dependency is there.
Geographic Restrictions	Geographic Restrictions are resolved.	Geographic Restrictions are resolved.

Table 1, Table 2, Table 3, Table 4 summarized the random mobility models (Random Waypoint Model, Random Walk Model and Random Direction Model), Temporal Dependency based Mobility Models (Guass-Markov, Smooth Random Mobility Model), Spatial Dependency Bases Mobility Models (Reference Point Group Mobility Model, Column Mobility Model), Mobility Models with Geographic Restrictions (Pathway Mobility Model, Obstacle Mobility Model), respectively on the basis of various characteristics. Among these characteristics, Node distribution method, Average mobility speed, Temporal Dependency, Spatial Dependency and Geographic Restrictions, Category of Mobility Model are compared. There is currently a large number of mobility models used in the literature. As discussed earlier, these models have different properties, each with its advantages and disadvantages. Further categorization of mobility models may include realism, diversification and complexity.

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