A comprehensive view of mobility models in Wireless Ad hoc Networks

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Abstract-- A Mobile Ad hoc Network (MANET) is a collection of wireless mobile nodes forming a self-configuring network without using any existing infrastructure. Since MANETs are not currently deployed on a large scale, research in this area is mostly simulation based. Among other simulation parameters, the mobility model plays a very important role in determining the protocol performance in MANET. Thus, it is essential to study and analyze various mobility models and their effect on MANET protocols. In this paper, the survey and examine different mobility models is proposed. Beside the commonly used Random Waypoint model and its variants, it is also discussed various models that exhibit the characteristics of temporal dependency, spatial dependency and geographic constraint. Here a comprehensive view of the mobility can significantly affect the protocol performance.

***Keywords*— Mobility model; Mobile Ad hoc Network; Random Waypoint Model**

I. INTRODUCTION

In general, a Mobile Ad hoc Network (MANET) is a collection of wireless nodes communicating with each other in the absence of any infrastructure. Due to the availability of small and inexpensive wireless communicating devices, the MANET research field has attracted a lot of attention from academia and industry in the recent years. In the near future, MANETs could potentially be used in various applications such as mobile classrooms, battlefield communication and disaster relief applications. To thoroughly and systematically study a new Mobile Ad hoc Network protocol, it is important to simulate this protocol and evaluate its protocol performance. Protocol simulation has several key parameters, including mobility model and communicating traffic pattern, among others. In this paper the main focus on the analysis and modeling of mobility models. The mobility model is designed to describe the movement pattern of mobile users, and how their location, velocity and acceleration change over time. Since mobility patterns may play a significant role in determining the protocol performance, it is desirable for mobility models to emulate the movement pattern of targeted real life applications in a reasonable way. Otherwise, the observations made and the conclusions drawn from the simulation studies may be misleading. 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 [1]. It is not appropriate to evaluate the applications where nodes tend 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. One intuitive method to create realistic mobility patterns would be to construct trace-based mobility models, in which accurate information about the mobility traces of users could be provided. However, since MANETs have not been implemented and deployed on a wide scale, obtaining real mobility traces becomes a major challenge.

Therefore, various researchers proposed different kinds of mobility models, attempting to capture various characteristics of mobility and represent mobility in a somewhat 'realistic' fashion. Much of the current research has focused on the so-called *synthetic* mobility models [2] that are not trace-driven. In the previous studies on mobility patterns in wireless cellular networks [3][4], researchers mainly focus on the movement of users relative to a particular area (i.e., a cell) at a macroscopic level, such as cell change rate, handover traffic and blocking probability. However, to model and analyze the mobility models in MANET, we are more 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.

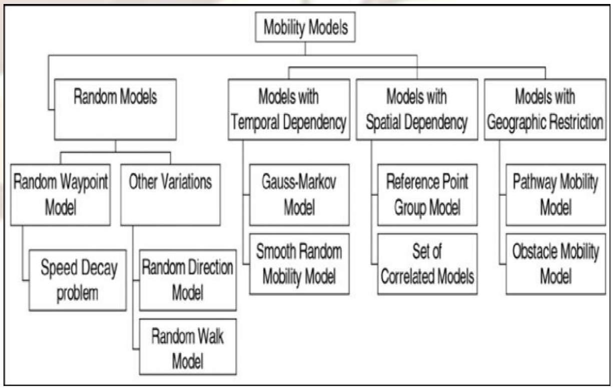

Fig 1-1. The categories of mobility models in Mobile Ad hoc Network

One frequently used mobility model in MANET simulations is the Random Waypoint model[5], 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. However, MANETs may be used in different applications where complex mobility patterns exist. Hence, recent research has started to focus on the alternative mobility models with different mobility characteristics. In these models, the movement of a node is more or less restricted by its history, or other nodes in the neighborhood or the environment. In Fig.1-1 it is 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. It is refer to this type of mobility model as *mobility model with temporal dependency*. In some mobility scenarios, the mobile nodes tend to travel in a correlated manner. We refer to such models as *mobility models with spatial dependency*. Another class is the *mobility model with geographic restriction*, where the movement of nodes is bounded by streets, freeways or obstacles.

II. RANDOM-BASED MOBILITY MODELS

A. Theory of Random Waypoint model

In random- based mobility models, the mobile nodes move randomly and freely without restrictions. To be more specific, the destination, speed and direction are all chosen randomly and independently of other nodes. This kind of model has been used in many simulation studies. One frequently used mobility model, the Random Waypoint model, and some of its stochastic properties. Then, two variants of the Random Waypoint model, namely the Random Walk model and the Random Direction model, finally, point out some limitations of the random-based models and their potential impact on the accuracy of the simulations.

B. The Random Waypoint Model

The Random Waypoint Model was first proposed by Johnson and Maltz[5]. Soon, it became a 'benchmark' mobility model to evaluate the MANET routing protocols, because of its simplicity and wide availability. To generate the node trace of the Random Waypoint model the *setdest* tool from the CMU Monarch group may be used. This tool is included in the widely used network simulator *ns-2* [22]. In the network simulator *(ns-2)* distribution, the implementation of this mobility model is as follows: as the simulation starts, each mobile node randomly selects one location in the simulation field as the destination. It then travels towards this destination with constant velocity chosen uniformly and randomly from $[0, V_{max}]$, where the parameter V_{max} is the maximum allowable velocity for every mobile node[6]. The velocity and direction of a node are chosen independently of other nodes. Upon reaching the destination, the node stops for a duration defined by the 'pause time' parameter T_{pause} . If T_{pause} =0, this leads to continuous mobility. After this duration, it again chooses another random destination in the simulation field and moves towards it. The whole process is repeated again and again until the simulation ends. As an example, the movement trace of a node.

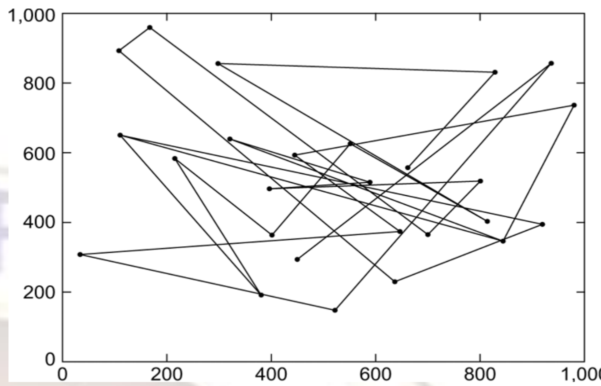

Fig 1-2.Nodes movement in the Random Waypoint Model.

In the Random Waypoint model, V_{max} and T_{pause} are the two key parameters that determine the mobility behavior of nodes. If the V_{max} is small and the pause time T_{pause} is long, the topology of Ad Hoc network becomes relatively stable. On the other hand, if the node moves fast (i.e., V_{max} is large) and the pause time T_{pause} is small, the topology is expected to be highly dynamic[1]. Varying these two parameters, especially the V_{max} parameter, the Random Waypoint model can generate various mobility scenarios with different levels of nodal speed. Therefore, it seems necessary to quantify the nodal speed. Intuitively, one such notion is average node speed. If we could assume that the pause time T_{pause} 0 , considering that V_{max} is uniformly and randomly chosen from $[0, V_{max}]$, it can easily find that the average nodal speed is $0.5V_{max}$ [2]. However, in general, the pause time parameter should not be ignored. In addition, it is the relative speed of two nodes that determines whether the link between them breaks or forms, rather than their individual speeds. Thus, average node speed seems not to be the appropriate metric to represent the notion of nodal speed. The Mobility metric to capture and quantify this nodal speed motion. The measure of $_{relative}$ speed $_b$etween node *i* and *j* at time *t* is

$$RS(i, j,t) \mid V_i (t) - V_j (t) \mid \quad (1)$$

Then, the Mobility metric *M* is calculated as the measure of relative speed averaged over all node pairs and over all time. The formal definition is as follow.

- However, to our best knowledge, until now, no work provides quantitative analysis for the impact of maximum allowed velocity and pause time on the network topology.
- Even if the T parameter is small, we can still claim that average nodal speed is approximated as 0.5V.

$$\overline{M} = \frac{1}{|i,j|}\sum_{i=1}^{N}\sum_{i=1}^{N}\frac{1}{T}\int_{0}^{T} RS(i,j,t)dt \qquad (2)$$

Where |i,j| is the number of distinct node pair (i,j), n is the total number of nodes in the simulation field (i.e., ad hoc network), and T is the simulation time.

Using this Mobility metric, we are able to roughly measure the level of nodal speed and differentiate the different mobility scenarios based on the level of mobility. In [1], Bain, Sadagopan and Helm define another mobility metrics Average Relative Speed in a similar way. The experiments show that the Average Relative Speed linearly and monotonically increases with the maximum allowable velocity.

III. RANDOM WALK MODEL

A. Random Walk mobility

The Random Walk model was originally proposed to emulate the unpredictable movement of particles in physics. It is also referred to as the Brownian motion. Because some mobile nodes are believed to move in an unexpected way, Random Walk mobility model is proposed to mimic their movement behavior [2]. The Random Walk model has similarities with the Random Waypoint model because the node movement has strong randomness in both models. We can think the Random Walk model as the specific Random Waypoint model with zero pause time. However, in the Random Walk model, the nodes change their speed and direction at each time interval. For every new interval t, each node randomly and uniformly chooses its new direction θt from (0, π2). In similar way, the new speed follows a uniform distribution or a Gaussian distribution from [0, Vmax]. Therefore, during time interval t, the node moves with the velocity vector (v(t) cosθ(t),v (t) sin θ(t)) . If the node moves according to the above rules and reaches the boundary of simulation field, the leaving node is bounced back to the simulation field with the angle of θ t or π−θ(t), respectively. This effect is called border effect [9]. The Random Walk model is a memory less mobility process where the information about the previous status is not used for the future decision. That is to say, the current velocity is independent with its previous velocity and the future velocity is also independent with its current velocity. However, we observe that is not the case of mobile nodes in many real life applications.

B. Non-uniform Spatial Distribution and Random Direction Model

The spatial node distribution of Random Waypoint model is transformed from uniform distribution to non-uniform distribution after the simulation starts. As the simulation time elapses, the unbalanced spatial node distribution becomes even worse. Finally, it reaches a steady state. In this state, the node density is maximum at the center region, whereas the node density is almost zero around the boundary of simulation area. This phenomenon is called non-uniform spatial distribution. Another similar pathology of Random Waypoint model called density wave phenomenon (i.e., the average number of neighbors for a particular node periodically fluctuates along with time) is observed [12].

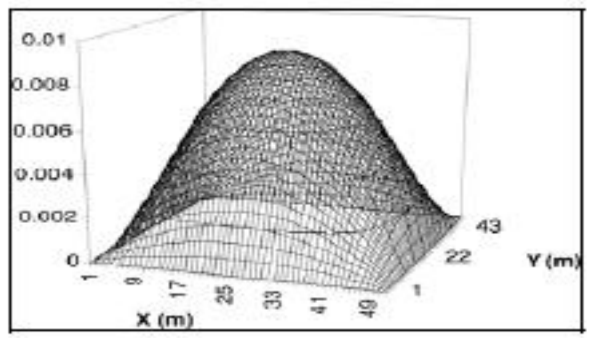

Fig 1-3. Node Spatial Distribution (Square Area)

This phenomenon results from the certain mobility behavior of Random Waypoint model. In Random Waypoint model, since the nodes are likely to either move towards the center of simulation field or choose a destination that requires movement through the middle, the nodes tend to cluster near the center region of simulation field and move away from the boundaries. Therefore, a non-uniform distribution is formed [9][11]. At the same time, the nodes appear to converge, disperse and converge at center region periodically, resulting in the fluctuation of the node density of neighbors (i.e., density wave)[12].

Following provide the analysis for the above phenomenon. Let the random variable P_i(t) = (X_i(t), Y_i(t), Y_i (t)) indicate the geographic location of the mobile node i at time t.

1. *Rectangular Area***:** In [9], to approximate the spatial node distribution in the square simulation field of size (a) by use the analytical expression.

f_p(P)= $f_{x,y}$(x,y) $\approx \frac{36}{a^6}(x^2 - \frac{a^2}{4})(y^2 - \frac{a^2}{4})$ (3)

2. *Circular Area***:** For a circular area with radius a, the analytical expression is

$f_{p(P)}$= $f_{r,\theta}$(r,θ) = f_r(r) = $\frac{2}{\pi a^2} - \frac{2}{\pi a^2} r^2$ (4)

For 0≤r≤ a. As r increases, the spatial node density also decreases.

Moreover, these two formulas imply that the node spatial distribution is not a function of node velocity. In other words, in Random Waypoint model, no matter how fast the nodes move, the spatial node distribution at a certain position is only determined by its Cartesian location.

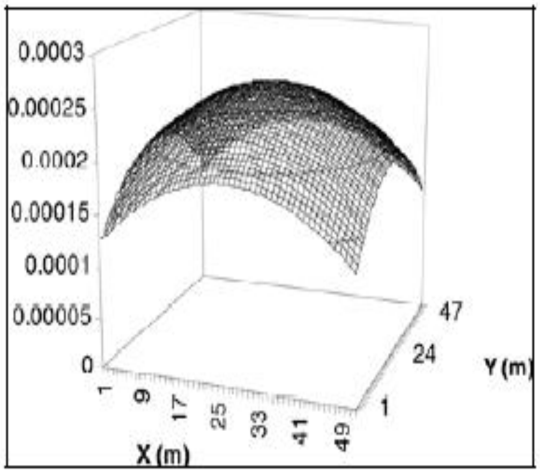

Fig 1-4. Node Spatial Distribution (Circular Area)

The probability distribution of movement angle.

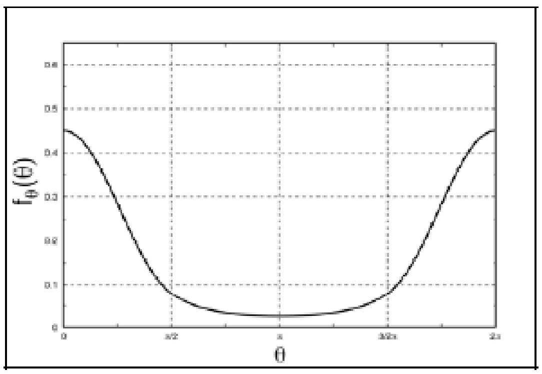

Fig 1-5. The probability distribution of movement direction.

Therefore, it seems that the non-uniform spatial node distribution and density wave problem is inherent to the Random Waypoint model. Hence, a modified version of the Random Waypoint model is required to achieve the uniform spatial node distribution.

IV. UNSTEADY STATE PROBLEM IN RANDOM WAYPOINT MODEL AND ITS SOLUTION.

A. Random Waypoint model with zero pause time.

Waypoint model with zero pause time is constantly decreasing over time. For the non-zero pause time Random Waypoint model, the general trend of average nodal speed also decays, even though the long pause time may result in the fluctuations. Intuitively, we know once the mobile node chooses a faraway destination with a slow speed; it takes a long period for the node to finish this trip. During this period, the mobile node moves slowly. As the simulation advances, on average more and more nodes are trapped in such long trip. Then such slow-motion mobility pattern will become the dominating behavior of Random Waypoint model. Therefore, the average nodal speed keeps decreasing over time. Based on following three reasonable assumptions made for Random Waypoint model,

1. The mobile node is supposed to uniformly choose a new destination from a circle of radius Rmax center at the current location and move towards it.
2. The pause time is set to 0.

3. The node travels with speed uniformly distributed in the interval [Vmin, Vmax].

Similar to the discussion it can get the expected travel distance of each movement epoch E [L] is

$$E\,[L]=\frac{2}{3}R_{max} \qquad (5)$$

Realizing the zero minimum speed is the key reason of non-steady state problem [22] proposes to limit the minimum speed of Random Waypoint model, in order to achieve the steady state. Through comparing the simple improved Random Waypoint model with the original one, they observe that the modified version significantly improves the stability of Random Waypoint model.

The speed decay problem is not an exclusive problem to Random Waypoint model. It seems to exist for all random mobility models that independently choose the destination and movement speed. However, if the speed for the initial trip is selected from a steady state distribution and the subsequent speeds are chosen from the original speed distribution, the speed decay problem can be completely removed. Thus, a stationary random mobility process could be generated for the simulations. The renewal theory to Random Waypoint model and also confirm the observations about the speed decay problem.

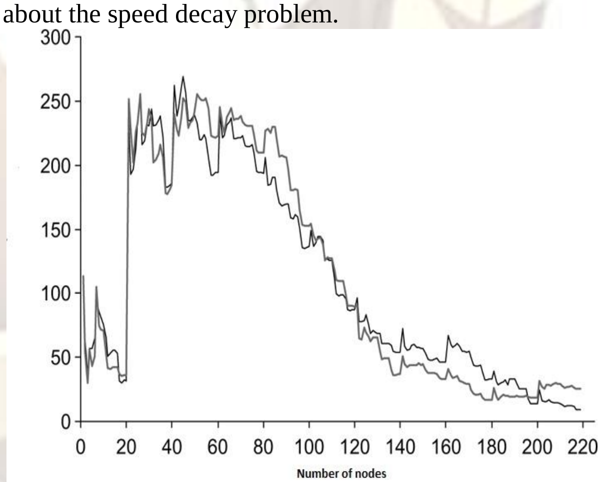

Fig 1-5 Random Waypoint is a mean-ergodic random process.

Thus, the time average speed for a given node over time is equal to the ensemble average nodal speed for all the nodes in a single epoch.

V. CONCLUSION

By studying various mobility models, we attempt to conduct a survey of the mobility modeling and analysis techniques in a thorough and systematic manner. Beside the Random Waypoint model and its variants, many other mobility models with unique characteristics such as temporal dependency, spatial dependency or geographic restriction are discussed and studied in this paper. I believe that the set of mobility models included herein reasonably reflect the state-of-art researches and technologies in this field. Having examined those mobility models, we observe that the mobility models may have various properties and exhibit different mobility characteristics. As a consequence, we expected that those mobility models behave differently and influence the protocol performance in different ways. Therefore, to thoroughly evaluate ad hoc protocol performance, it is imperative to use a rich set of mobility models instead of single Random Waypoint model. Each model in the set has its own unique and specific mobility characteristics. Hence, a method to choose a suitable set of mobility models is needed.

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