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Performance Analysis of MANET Routing Protocols in Different Mobility Models

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Abstract— A mobile ad-hoc network (MANET) is basically called as a network without any central administration or fixed infrastructure. It consists of a number of mobile nodes that use to send data packets through a wireless medium. There is always a need of a good routing protocol in order to establish the connection between mobile nodes since they possess the property of dynamic changing topology. Further, in all the existing routing protocols, mobility of a node has always been one of the important characteristics in determining the overall performance of the ad hoc network. Thus, it is essential to know about various mobility models and their effect on the routing protocols. In this paper, we have made an attempt to compare different mobility models and provide an overview of their current research status. The main focus is on Random Mobility Models and Group Mobility Models. Firstly, we present a survey of the characteristics, drawbacks and research challenges of mobility modeling. At the last we present simulation results that illustrate the importance of choosing a mobility model in the simulation of an ad hoc network protocol. Also, we illustrate how the performance results of an ad hoc network protocol drastically change as a result of changing the mobility model simulated.

Index Terms— MANETs, Mobility Models, AODV, DSDV

I. Introduction

A mobile ad hoc network is a collection of wireless stations called nodes which are free to move and communicate with each other in the absence of any fixed infrastructure [1, 33]. There is lack of central administration. Any node within the transmission range of other node can directly communicate with it. In this paper we explore several mobility models and compare their effects on an ad hoc network. The final outcome of this study is to provide suggestions to the researchers and illustrate them the importance in carefully selecting and implementing a mobility model when evaluating ad hoc network protocols. A Mobility model (MM) is used to describe the movement of a mobile node, its location and speed variation over time while the simulation of a routing protocol. It is one of the key parameters that researchers have to consider before analyzing and simulating the performance of the routing protocols. We have studied how different mobility model scan influence the performance of routing protocols. Thus, it becomes necessary to choose a right mobility model when evaluating a MANET protocol. The goal of this paper is to present a number of mobility models for the researchers to decide a perfect mobility model for performing simulations.

1.1 Review of Mobility Models

The most important characteristic of a mobility model is the degree of realism with respect to the movement of real life users. More realistic models enable more accurate simulation and evaluation of network performance parameters. There exists no single comprehensive mobility model that does mimic the movement patterns expected in the real life environment. The incorrect selection of an inappropriate model leads to incorrect observations and results [3]. Sanchez and Manzoni [5] categorized the mobility models into two types: traces and synthetic models. Traces are those that deal with real life systems. However, traces provide accurate information but the ad hoc networks are not easily modeled if proper traces have not been created. In these networks synthetic models are rather used as they attempt to realistically represent the behaviors of MNs without the use of traces and other unknown statistics [28]. There exists a large variety of synthetic mobility models that are categorized into two broad classes based upon their mobility characteristics. Figure 1 shows the classification of different mobility models.

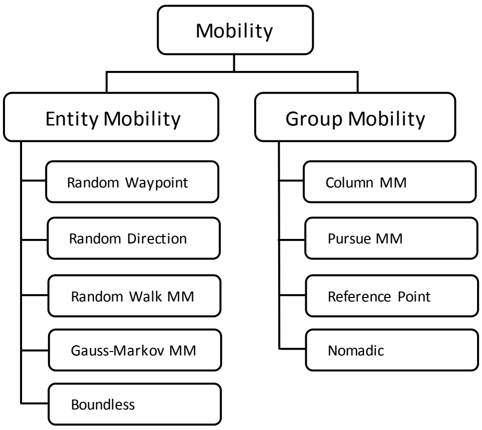

Fig. 1: Classification of Mobility Models

First class is Entity Mobility Models and second one is Group Mobility Models. One of the characteristics features of every mobility model is to ensure that none of the mobile nodes can travel outside the network simulation area [29]. Since there are a large number of MMs as mentioned above, we have chosen a few of the important models for our study. We have discussed and compared the entity mobility models based on Random Mobility in Section 2 and some of the Group MMs such as Column, Pursue and Reference Point Group MM in Section 3. One frequently used model in simulation of MANET routing protocols is Random Waypoint Model which is first discussed in next section.

II. Related Work

2.1 Entity Mobility Models

In Entity Mobility Models mobile nodes move independently within the simulation area. They include Random Walk MM, Random Waypoint MM, Random Direction MM, Boundless Simulation Area MM, Gauss-Markov MM, Probabilistic version of Random Waypoint MM, City Area and Street Section MM. Out of these all the Random MM belong to Ad-hoc MM and the remaining belong to Cellular MM.

2.1.1 Random Waypoint Mobility Model (RWPMM)

The Random Waypoint Mobility Model used by Johnson [12] and Lee [25] includes pause times between changes in direction and/or speed. In all the random based mobility models, the mobile nodes are set free to move randomly in any direction within the simulation area. We can say that a node is free to select its destination, speed and direction independent of the neighbor nodes. RWPMM is the only model that is widely implemented & analyzed in simulation of routing protocols because of its simplicity and availability. It was first proposed by Johnson and Maltz [16]. At the start of the simulation each mobile node waits for a specified time called pause time, t_p and randomly selects one location. A MN chooses a new random destination after staying at its previous position for a time period of t_p till its expiry. A node travels across the area at a random speed distributed uniformly from v_0 to v_{max} where v_0 and v_{max} represent the minimum and maximum node velocities. This process of choosing random destination at random velocity is repeated again and again until the simulation is finished. If υ_{max} is small and t_p is long then the network is stable and in reverse case it is dynamic. When $t_p = 0$, it represents a continuous mobility. This concept was proposed by Perkins & Royer [4], Nesargi & Prakash [11]. They modified the existing RWPMM to let a MN travel at a uniform speed throughout the simulation by setting pause time to zero. In this case the RWPMM behaves similar to Random Walk Mobility Model.

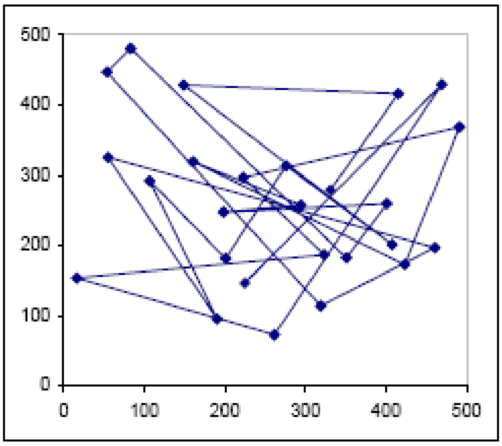

Fig. 2: Traveling pattern of an MN using the Random Waypoint Mobility Model

Figure 2 shows the movement trace of mobile nodes in RWPMM. Despite of so many characteristics, there are certain shortcomings in RWPMM. Firstly, the probability of choosing a new destination is very high. Secondly it can generate different mobility scenarios with different speed levels. According to Euros W. Navidi, nodes moving with RWPMM cause the generation of dense waves (i.e. clustering of nodes in one part of the simulation area), thus they appear to converge, disperse and again converge [18]. To eliminate this problem Random Direction MM was developed.

Advantages

- The most common use mobility model, because of its simplicity.
- A building block for developing a variety of mobility models.

Disadvantages

- Lack of regular movement modeling.
- Exhibits speed decay.
- Generates density waves.
- Memory-less movement behaviors (a common problem for all random waypoint variations) [8, 9].

2.1.2 Random Direction Mobility Model (RDMM)

The Random Direction Mobility Model [22] was created in order to overcome a flaw discovered in the Random Waypoint Mobility Model. In this model, MNs choose a random direction instead of a random destination. A MN tends to travel to the middle of the simulation area up to the boundary or nest intermediate location in that direction. It was mainly designed to curb the density waves generated in Random Waypoint Mobility Model. All the MNs are placed randomly in the network area and are assigned an angular direction in the range from 0 to 2π at a uniform random velocity between t_0 and t_{max}. On reaching the border of simulation area, MN pauses for a specific time and a new angle of movement and new velocity are assigned to the node. This process is continued till simulation ends. Since MNs used to travel to and pause at the boundary for some time, the average hop count for packets is much high as compared to other mobility models. Figure 3 shows the movement trace of a mobile node in RDMM.

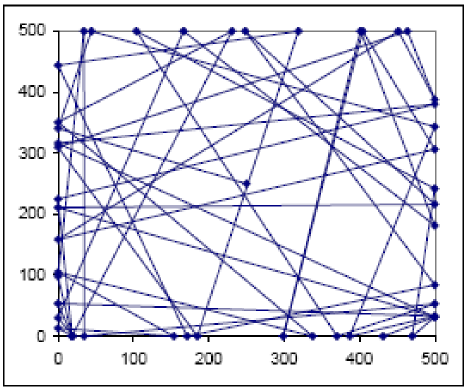

Fig. 3: Traveling pattern of an MN using the Random Direction Mobility Model

Advantages

- A variation of the random waypoint without drawback of density wave.
- Uniform distribution of chosen routes.

Disadvantages

- Unrealistic movement pattern.
- Average distances between mobile nodes are much higher than other models, leading to incorrect results for routing protocols evaluation.

2.1.3 Random Walk Mobility Model (RWMM)

The Random Walk model was first described mathematically by Einstein in 1926 [6]. It has proven to be one of the most widely used mobility models because it describes individual movements relative to cells [23]. It is a memory-less mobility process which retains no information about the previous status the node while moving to future decision [14]. A MN randomly and uniformly chooses a direction $\theta(t)$ in the predefined range from 0 to 2π and speed v_t between 0 and v_{max} to move to a new location. After a constant time interval t, a new direction and speed are calculated and assigned to MN. If the MN reaches the network area border, it is bounced back at an angle of $\theta(t)$ or π-$\theta(t)$ [15]. In RWMM the current speed is not dependent on the previous speed of the MN. This discrepancy can be eradicated in Random Gauss-Markov Mobility Model discussed in next section. Figure 4 shows the movement trace of a mobile node in RWMM.

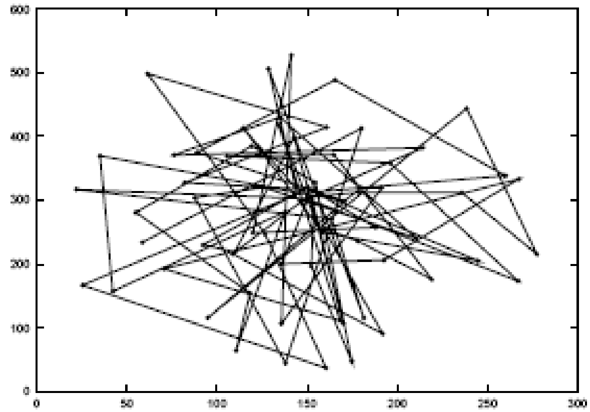

Fig. 4: Traveling pattern of an MN using the 2-D Random Walk Mobility Model

Advantages

- The simplest model to implement.
- Generates unpredictable movements, enabling a long-running simulation to consider all locations and node interactions.

Disadvantages

- Unrealistic movement patterns
- Sharp and sudden turns.
- Wrapping not observed in real applications.

2.1.4 Random Gauss-Markov Mobility Model (RGMM)

The Gauss-Markov Mobility Model was originally introduced by Liang and Haas [5] for simulation of Personal Communication System networks which was later on widely used for simulating Ad hoc Networks. It works on timeslot basis where the speed of a MN is correlated over time i.e. the speed and direction of n location is calculated using speed and direction of n-1 location and a random variable as shown below.

$$V_n = \beta V_{n-1} + (1-\beta)\Omega + \sqrt{(1-\beta)^2}\, x_{n-1} \quad (1)$$

where β ($0 \le \beta \le 1$) is tuning parameter for varying randomness, Ω is a constant representing the mean value of speed and direction as $n \to \infty$, x_{n-1} is a random variable from a Gaussian distribution. Totally random values are obtained when β = 1. Gauss-Markov model is a temporally dependent model as the degree of dependency is determined by the tuning parameter β [21]. According to Liang and Haas [5], there are three different kinds of mobility behaviors in various scenarios:

1. When β=0 i.e. GMM is memoryless. So the equation 1 is: $V_n = \Omega + x_{n-1}$. This is Random Walk Model.
2. When β=1 i.e. GMM has a strong memory. The equation 1 is: $V_n = V_{n-1}$. This is Fluid Flow Model.
3. When $0 \le \beta \le 1$ i.e. GMM has some memory. The current speed is dependent on previous speed V_{n-1} and Gaussian random variable x_{n-1}.

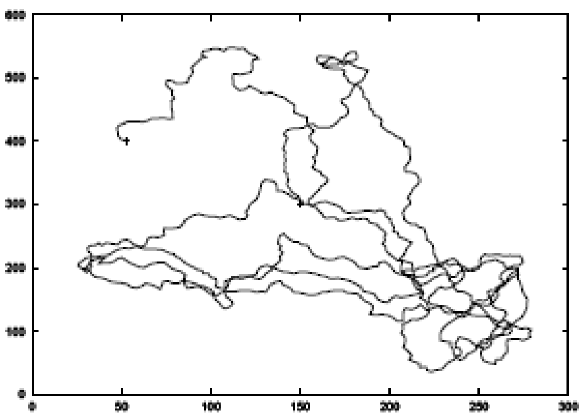

Fig. 5: Traveling pattern of an MN using the Gauss-Markov Mobility Model

Figure 5 shows the movement trace of a mobile node in RGMM. Thus by allowing previous speed and direction to influence current and future speed and direction, The Random Gauss-Markov Mobility Model eliminates the sudden stops and sharp turns encountered in Random Walk Mobility Model [19].

2.1.5 Boundless Simulation Area Mobility Model (BSAMM)

As proposed by Haas [17], it is based upon the relationship between the previous speed and direction of an MN with its current speed and direction. A speed vector v = (v,θ) is used to describe an MN's speed v as well as its direction θ while its position is represented by (x,y). Both the speed vector and position are updated at every Δt according to following formulas [5]:

$$v(t+\Delta t) = \min[\max(v(t)+\Delta v, 0), v_{max}]$$

$$\theta(t+\Delta t) = \theta(t) + \Delta\theta$$

$$x(t+\Delta t) = x(t) + v(t) * \cos\theta(t)$$

$$y(t+\Delta t) = y(t) + v(t) * \sin\theta(t)$$

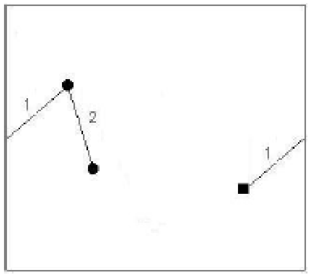

Fig. 6: Traveling pattern of an MN using the Boundless Simulation Area Mobility Model

where v_{max} is the maximum velocity defined in the simulation, Δv is the change in velocity which is uniformly distributed between $[-A_{max} * \Delta t, A_{max} * \Delta t]$, A_{max} is the maximum acceleration of a given MN, Δθ is the change in direction which is uniformly distributed between $[-\alpha * \Delta t, \alpha * \Delta t]$, and α is the maximum angular change in the direction an MN is traveling. In the Haas model, when a mobile node reaches one side of the simulation area, it continues moving and reappears on the opposite side of the area as shown in figure 6. Initial position of MN is represented by a square. It begins moving along path 1 towards rightmost boundary. After reaching the border, it appears on the opposite side and continues moving with the same angle and speed. When Δt time steps finish, the MN chooses a new direction and speed denote by path 2 and begins moving again. This process creates a torus-shaped simulation area as shown below. It is formed by first folding the simulation area such that top border lies against the bottom border i.e. $y = y_{max}$ and y=0, then fold the cylinder formed in such a manner that both circular ends connect each other.

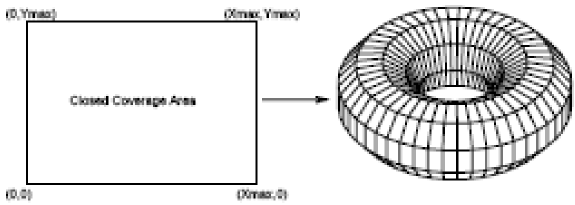

Fig. 7: Rectangular simulation area mapped to a torus in the Boundless Simulation Area Mobility Model.

2.1.6 Freeway Mobility Model

It can be used in exchanging traffic status or tracking a vehicle on a freeway [3]. There are several freeways on the map and each freeway has lanes in both directions [26]. The Freeway mobility pattern is expected to have spatial dependence and high temporal dependence. The differences between Random Waypoint and Freeway are the following:

- Each mobile node is restricted to its lane on the freeway.
- The velocity of mobile node is temporally dependent on its previous velocity.
- If two mobile nodes on the same freeway lane are within the safety distance, (SD), the velocity of the following node cannot exceed the velocity of preceding node [21].

Figure 8 shows the movement trace of mobile nodes in Freeway MM.

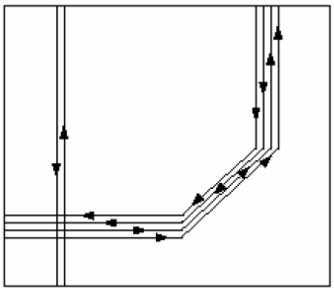

Fig. 8: Movement pattern of MNs in Freeway MM

2.1.7 Manhattan Mobility Model

Manhattan model was introduced to emulate the movement pattern of mobile nodes on streets defined by maps [21, 26]. It can be useful in modeling movement in an urban area where a pervasive computing service between portable devices is provided. The map is composed of a number of horizontal and vertical streets. Each street has two lanes for each direction (north and south direction for vertical streets, east and west for horizontal streets). The mobile node is allowed to move along the grid of horizontal and vertical streets on the map. At an intersection of a horizontal and a vertical street, the mobile node can turn left, right or go straight. This choice is probabilistic: the probability of moving on the same street is 0.5, the probability of turning left is 0.25 and the probability of turning right is 0.25.

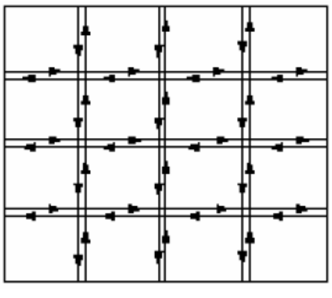

Fig. 9: Movement pattern of MNs in Manhattan MM

However, it differs from the Freeway model in giving a node some freedom to change its direction. Figure 9 shows the movement trace of mobile nodes in Manhattan MM. The Manhattan mobility model is also expected to have high spatial dependence and high temporal dependence.

Limitations of Random Mobility Models

The Random mobility models are widely accepted mainly due to their simplicity of implementation and analysis. However, according to the authors of [21], they fail to capture mobility characteristics in case of Temporal (i.e. the current velocity is dependent on the previous velocity), Spatial (i.e. each mobile node moves independently of others) & Geographic Dependency (i.e. the movement of a mobile node may be restricted along the street or a freeway). To overcome this failure, Group mobility models were proposed which are discussed in next section.

2.2 Group Mobility Models

The mobility models proposed so far in the literature assume some kind of permanent group affiliation. Also they require that each node belongs to a single group. In reality in a typical military scenario, a much more complex mobility behavior is observed. Some nodes move in groups; while others move individually and independently; a fraction of nodes are static. Moreover, the group affiliation is not permanent. The mobile groups can dynamically re-configure themselves triggering group partition and mergence. All these different mobility behaviors coexist in military scenarios. A good realistic mobility model must capture all these mobility dynamics in order to yield realistic performance evaluation results, which, unfortunately, is not satisfactorily captured in any of the existing models [31]. In Group Mobility Models all the mobile nodes are arranged in a group and the mobility of nodes depends upon the movement pattern of the whole group i.e. all the nodes move together collectively. This class includes Exponential Correlated Random MM, Column MM, Nomadic Community MM, Pursue MM, Reference Point Group MM [13, 26].

2.2.1 Column Mobility Model

It is mostly used for scanning and searching purposes. A set of MNs form a line and move uniformly in a particular direction. Each individual MN follows one another. According to Sanchez [6], in Column MM individual MNs are placed in a single-file line and move about their initial positions. The process begins by calculating a new reference position using:

$$new\_ref\_pos = old\_ref\_pos + advance\_vector$$

where old_ref_pos is the previous reference point and advance vector is a predefined offset. New position of MN is calculated as:

$$new\_pos = new\_ref\_pos + random\_vector$$

Figure 10 shows the movement of three MNs using Column MM.

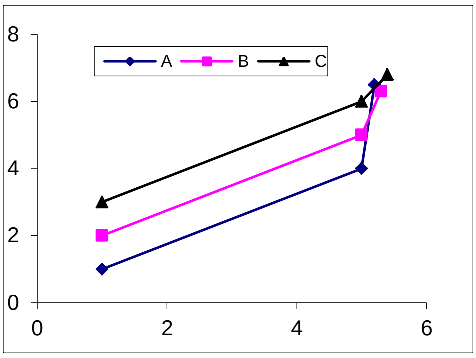

Fig. 10: Movement pattern of MNs in Column MM

All the MNs move around their respective reference points, i.e. they follow a particular reference point and move accordingly. As seen from the above figure, the MNs are initially lined up in bottom left corner and begin moving 4 units to the right and 3 units up as specified by their advance vector (4,3).The new positions can then be calculated using the above formulas.

2.2.2 Nomadic Community Mobility Model (NCMM)

In this model a group of MNs move collectively from one position to other within the simulation area. Within each group or community each node maintains its own personal spaces to move in randomly. E.g. a class of students can move together collectively in the campus but students within the class would move around a particular location individually. The new position is calculated as:

$$new\_pos = ref\_pos + random\_vector$$

Figure 11 shows the movement of MNs in NCMM. The reference point is black dot which moves from one location to another and all the MNs follow this point. As compared to Column MM where each column has its own reference point, Nomadic Community MM shares the same reference grid. Moreover movement in NCMM occurs sparsely while in CMM it is constant.

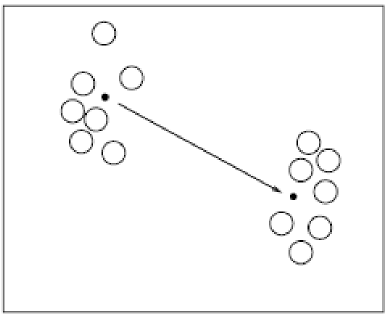

Fig. 11: Movements of seven MNs using the NCMM

2.2.3 Pursue Mobility Model (PMM)

In this model, several nodes attempt to capture a single MN ahead. The node being pursued i.e. target node, moves freely according to the Random Waypoint MM. According to Sanchez and Manzoni [6], this model attempts to represent MNs attacking a particular target. The new position of MN at any given time t is calculated as:

$$position_t = position_{t-1} + v_t(posiiton_{target}\text{-}position_{t-1}) + random\_vector$$

where v_t acceleration function is used to allow only a limited maximum step in each movement of a MN being pursued. The random vector is calculated from Random Walk MM to offset the movement of MN. Figure 12cshows the movement of MNs in Pursue MM where the white node is the target node or pursed node and black ones are being pursued.

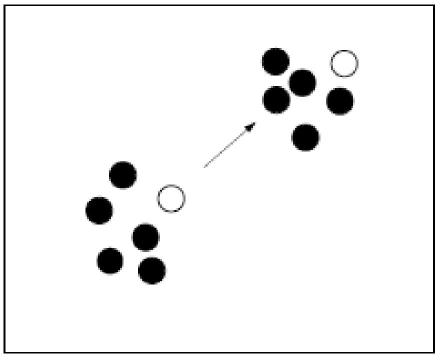

Fig. 12: Movements of MNs using the Pursue MM

2.2.4 Reference Point Group Mobility Model (RPGMM)

According to Hong et al. in [15], this model represents a random motion of a group of MNs as well as a random motion of each individual MN within the group. All the group movements are based upon the path traveled by a logical center, which may be pre-defined or completely random. This group motion is represented with a group motion vector. The motion of the group center completely characterizes the movement of its corresponding group of MNs, including their direction and speed. Individual MNs randomly move about their own pre-defined reference points, whose movements depend on the group movement. Figure below shows the movements of MNs using RPGMM. As the individual reference points RP move from time *t* to*t*+1, their locations are updated according to the group's logical center. Once the updated reference points RP (t+1) are calculated they are combined with a random motion vector to represent the random motion of each MN about its individual reference point. Figure 13 shows the movement trace of mobile nodes in RPGMM.

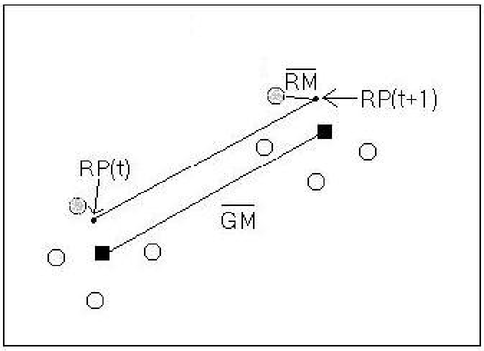

Fig. 13: Traveling pattern of five groups using the RPGMM

Applications of Group mobility models

- Group mobility can be used in military battle field communications where the commander and soldiers form a logical group.

III. Importance of Choosing a Mobility Model

In this section, we illustrate that the choice of a mobility model can have a significant effect on the performance investigation of an ad hoc network protocol. The results presented illustrate the importance of choosing an appropriate mobility model for the performance evaluation of a given ad hoc network protocol. There are three techniques to evaluate the performance; analytical modeling, simulation and measurement. In this paper, simulation technique had being chosen because it is the most suitable technique to get more details that can be incorporated and less assumption is required in comparison to analytical modeling. We use ns-2 [2, 7] to compare the performance of the Random Waypoint Mobility Model, the Reference Point Group Mobility (RPGM) model and Freeway Mobility Model using simulation parameters shown in Table 1 below. To evaluate the performance of these mobility models, we tested on AODV [4, 34] and DSDV [27] routing protocols on the basis of throughput. However, the same simulations can be performed on other performance metrics also [24], which is left for future work.

Table 1: Simulation parameters for comparison of mobility models on different flat routing protocols

Parameter	Value
Number of Nodes	50
Transmitter Range	250 m
Simulation time	900 sec
Pause time	0.1 sec
Simulation area	1000x1000
Packet size	64 bytes
Traffic type	CBR
CBR sources	20
Packet rate	4 pkts/sec

IV. Simulation Results for Different Mobility Models

The simulation results are focusing in analyzing the performance based on throughput. It can also be called as message delivery ratio, i.e., the total number of messages received at their intended destination divided by the total number of generated messages.

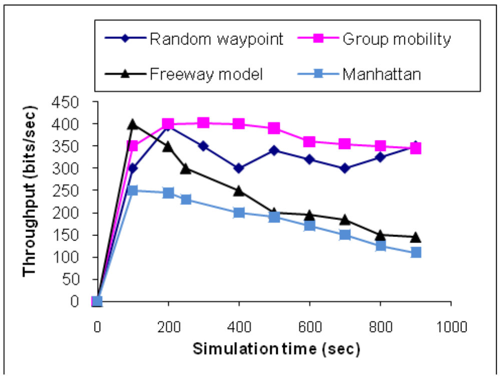

Fig. 14: Throughput of DSDV protocol in different mobility models

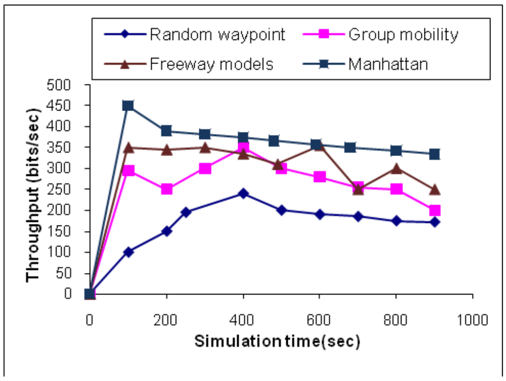

Fig. 15: Throughput in AODV with 50 nodes for different mobility models with 50 nodes

We have compared AODV and DSDV against four different mobility models. As seen from the above simulation graphs, AODV performs better than DSDV in all the models. One of the reasons being the average hop distance between the source and destination becomes high, this increases the packet overhead. Also the usage of fresh route information and quickly adapting nature of AODV are reasons for better results produced by AODV. However, DSDV gives a high throughput in case of Random waypoint mobility model, Group mobility model and Freeway mobility model. The overall performance of AODV is seen far better and it can be chosen as the routing protocol in this type of mobility conditions.

V. Summary

The above metric forms the basic subset of network parameters. In order to design realistic mathematical network models, additional metrics are required. A good description of novel mobility models and their parameters is proposed in [21]. The ns-2 results used in our simulations are obtained from [10]. A lot of publications have compared the performance of the routing protocols using the above metric. Some general conclusions are described hereafter. As seen from the above simulation graphs, In DSDV, each node maintains a list of all destinations, the control overhead is heavier comparing to AODV protocol [20, 32] which has a lower communication overhead as the roots are built only when required and there are no periodic updates required. Therefore, it does not incur substantial traffic and also consume less power. Generally, on-demand algorithms are reported to perform better for large number of nodes and modest traffic load due to their inclusion of the original message in the flooded route-discovery packets. The first packet delay is more (because the route is established, on demand) and the route to every other node in an ad hoc network is not available. The storage requirements of on-demand routing protocols are also usually lower than their table-driven counterparts. All these factors are indicative that they use a lesser resources such as power and storage, and hence can provide better scalability. It is amply clear that the mobility model chosen for simulation influences the behavior of a routing protocol provided other network parameters remain unchanged [10].

VI. Conclusions

We attempt to conduct a survey of mobility models. Each model has its own unique and specific mobility characteristics. Hence, while evaluating the performance of routing protocols for mobile ad hoc networks, the chosen mobility model is one of the key determinants in the success of an accurate simulation. The main role of a mobility model is to mimic the movement behaviors of actual users. Given the critical role of the mobility model in supporting realistic and accurate protocol simulations, its correct design and selection is essential. Different mobility models have different characteristics and serve different purposes. Therefore, instead of defaulting to a fixed Mobility Model for every simulation, or implementing a model that fails to model accurate MN behavior, the researchers should conduct a thorough analysis of appropriate mobility models before beginning their simulations. In a nutshell, if an entity mobility model is desired, we recommend using either the Random Waypoint Mobility Model or Group Mobility Model.

VII. Future work

In this paper, only two ad-hoc routing protocols are considered and their performance is analyzed under the Random waypoint and Group mobility models. The analysis of these two routing protocols can further be studied for other simulation based mobility models such as Random Walk, Random Direction, Gauss Markov, Column and Reference Point etc. Further study can be devoted to enhancement of other Ad hoc routing protocols under these real-world scenarios.

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