Project 13: Mobility Study in Wireless Networks

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Abstract

Mobile ad-hoc Network (MANET) plays a crucial role in modern wireless communication. In order to support realistic and accurate protocol simulations, a proper mobility model is desired. In this report we have shown several notable models proposed in the past few years; analysis of the pros and cons of these models are provided. We also give out a model based on our understanding and use Palm Calculus, a well-known but not widely used technique, to explore the model in detail.

1. Introduction

1.1. Classic Models

Mobility models need to meet two goals: (1) they need to be broad enough to accomodate a large variety of examples, and (2) simulation of the models can be practically mastered. A series of Models, based on ideal or practical situations, have been developed by researchers such as Babak Pazand [3] and Jean-Yves Le Boudec [5] in recent years. Among these models:

- *Random Walk* [3]

  The random walk mobility model is the simplest mobility model, generating completely random movement patterns. It was designed for simulations in which the movement patterns of mobile nodes are completely unpredictable. In this model a mobile node is initially placed in a random location in the simulation area, and then moved in a randomly chosen direction between $[0, 2\pi]$ at a random speed between $[V_{min}, V_{max}]$. The movement proceeds for a specific amount of time or distance, and the process is repeated a predetermined number of times. Figure 1 shows the result of a single node executing the random walk mobility model with a constant travel time.

  Two variations of the random walk mobility model were proposed by Nain et al to address the problem experienced when mobile nodes reach the boundary of their simulation area. In the random walk with wrapping approach, when a mobile node reaches an edge, it wraps to the opposite edge and continues its movement with the same direction and speed. Figure 2 demonstrates this process.

  In a further approach, random walk with reflection, when a mobile node reaches any edge of the simulation area, the node changes its angle of movement to $\alpha + \pi/2$ and its velocity remains constant (Figure 3).

  The approach employing reflection clearly generates more accurate movement patterns, simply because real life mobile nodes are more likely to reflect their movement when reaching an obstacle.

  This model simulates the movement unrealistically, and doesn't do so well in sharp and sudden turns, and is also hard to observe the wrapping in reality.

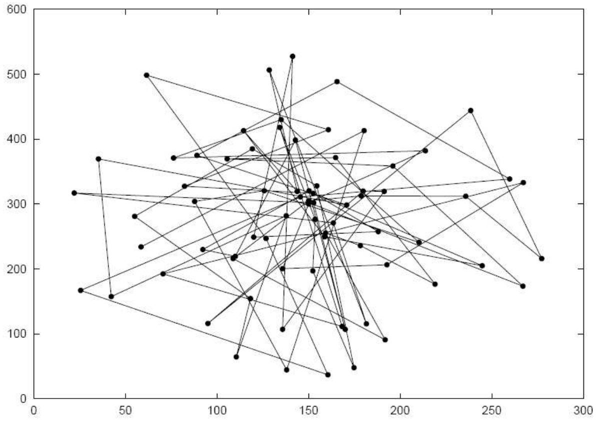

Figure 1: The random walk mobility model employing constant time

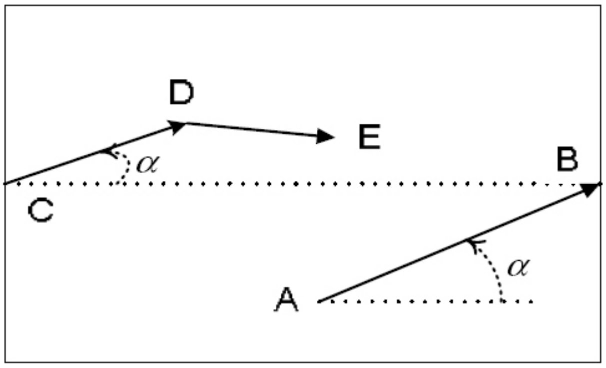

Figure 2: Wrapping approach in the random walk mobility model

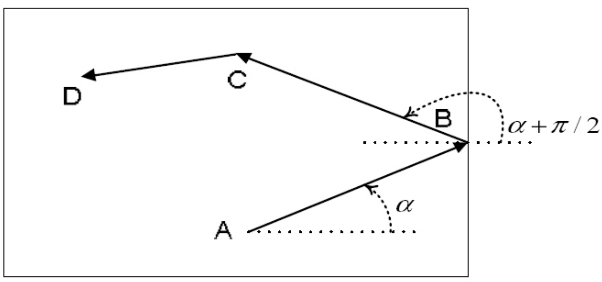

Figure 3: Reflection approach in Random Walk mobility model

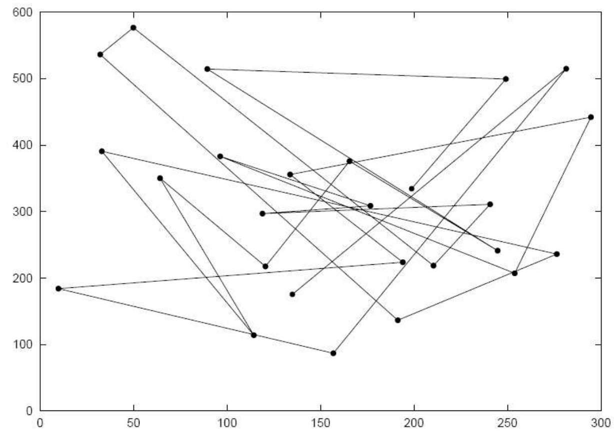

Figure 4: Movement pattern by using the random waypoint mobility model

- *Random Waypoint* [3]
  The random waypoint mobility model introduces specific pause times between movements, and was first proposed by Broch et al. The random waypoint model is the most popular mobility model employed in contemporary research, and can be considered a foundation for building other mobility models. In this model, each node starts its movement from an initial point in the simulation area by selecting a random destination, the waypoint, and a random speed from a predefined range of $[V_{min}, V_{max}]$. Once the mobile node reaches its waypoint, it pauses for a specific amount of time, after which the above process repeats. The movement pattern of a mobile node employing this mobility model is illustrated in Figure 4. Although there is widespread use of the random waypoint model, some major drawbacks affecting simulation results have been reported.

  This model lacks of the regular movement models, and introduces sudden stops, and it shows speed decay and density wave problems. Even worse, it is unable to reach a steady state and has memory-less movement behaviors.

- *Random Direction* [3]
  In order to eliminate the density wave phenomenon the random direction mobility model has been developed by Royer et al. In the random direction model, each mobile node chooses a random direction between $[0, 2\pi]$ and starts its movement in that direction from the center, towards the boundary of the simulation area. When the node reaches the boundary, it pauses for a constant time and selects another movement direction between $[0, \pi]$. This procedure is repeated a predetermined number of times. Figure 5 shows the movement pattern of a mobile node employing the random direction model.

  The same as Random Walk, there is no realistic movement pattern in this model. Moreover, errors may be introduced into the routing protocols evaluation, because its average distances between mobile nodes are much higher than other models.

- *Swiss Flag* [3]
  Le Boudec has defined a novel modification to the basic random waypoint model, in order to obtain a uniform distribution of average speeds throughout a simulation and to overcome the drawback of speed decay inherent in the standard random waypoint model. In this model, the simulation area is considered as a combination of connected areas forming the shape of the Swiss flag. Each mobile node starts its movement from a random location and travels to a random destination through the shortest path between two points.

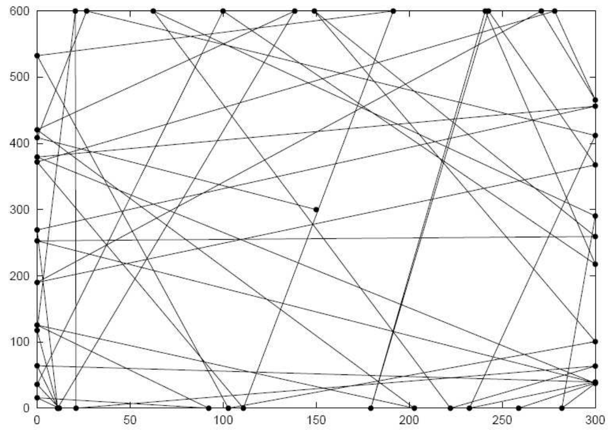

Figure 5: Movement pattern by using the random direction mobility model

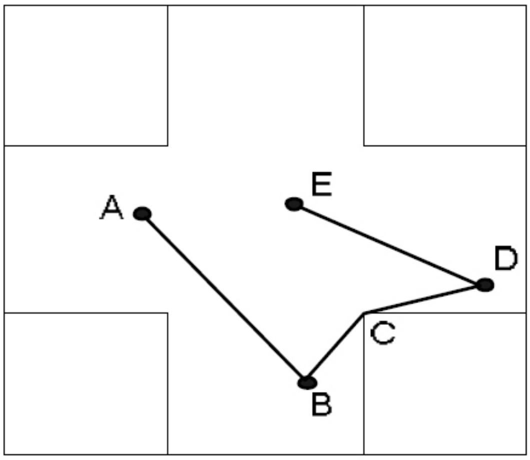

Figure 6: The Swiss Flag mobility model

Sometimes these routes consist of a breakpoint, resulting in an actual path with two segments. The node shown in Figure 6 commences its movement from A, travels to B, and pauses for a specific time. Location D is then chosen randomly, which results in the shortest path to it including two segments with one breakpoint.

As the Random Waypoint, it also lacks the regular movement model. And the nodes are always concentrating in the center and corners.

- *Restricted Random Waypoint* [3]
  In a very large area network, it is unlikely that a mobile node moves between random points located far from each other. In reality, a mobile node more likely travels within small part of a network and, after some movements in a specific area, may choose a distant location. To model this movement behaviour, the restricted random waypoint mobility model was proposed by Blazevic et al. The main characteristic of this model is its coverage of a large geographic area. The model may be considered as representing a small number of towns directly connected by highways. Two types of mobile node are considered, ordinary nodes and commuter nodes. An ordinary node commences its movement by randomly selecting a town,

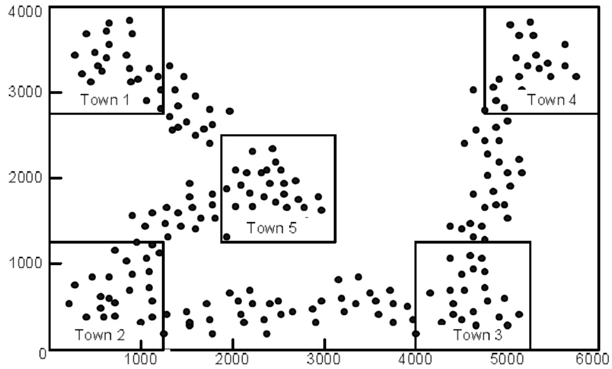

Figure 7: Movement pattern the restricted random waypoint mobility model

and then moving within the town according to the random waypoint model. After a number of movements specified by a stay-in-town parameter, the node chooses a random destination in another town and travels there through a specific highway connecting the two towns. Commuter nodes perform the above process with their stay-in-town parameter equal to 1. Figure 7 shows an example of this model with 5 towns and 4 highways connecting towns 1 and 5, towns 5 and 2, towns 2 and 3, and towns 3 and 4.

Long journey are need to all mobile nodes. And it is both lack of scalability and consideration of the constraints of the real movement.

- *Gauss-Markov* [3]
  Liang and Haas first proposed the Gauss-Markov mobility model and an implementation of this model has been presented by Camp et al. The main disadvantage of random mobility models is their sudden and sharp turns, which are unrepresentative of real user movements. To address this problem, a nodes speed and direction at time n should be a function of speed and direction at time n-1, which is:

$$V_n = f(V_{n-1})$$

and

$$D_n = f(D_{n-1})$$

This assumption is the fundamental basis of the Gauss-Markov model, which provides more realistic movement behaviors. A nodes speed and direction are calculated at each time interval using the formulae:

$$V_n = \alpha V_{n-1} + (1-\alpha)\overline{V} + \sqrt{(1-\alpha^2)}V_{x_{n-1}}$$
$$D_n = \alpha D_{n-1} + (1-\alpha)\overline{D} + \sqrt{(1-\alpha^2)}D_{x_{n-1}}$$

Here, α is a parameter and $0 \leq \alpha \leq 1$, used for changing the degree of randomness of the model. When α is closer to 0, the randomness will increase, resulting in sharper turns; when α is closer to 1, the model tends to a linear movement pattern. $V_{x_{n-1}}$ and $D_{x_{n-1}}$ are random variables chosen from a Gaussian distribution, with S and D the mean speed and direction of the movement, respectively. At each time interval, the next coordinate of the mobile node is calculated using the equations: $X_n = X_{n-1} + V_{n-1}\cos D_{n-1}$ $Yn = Y_{n-1} + V_{n-1}\sin D_{n-1}$

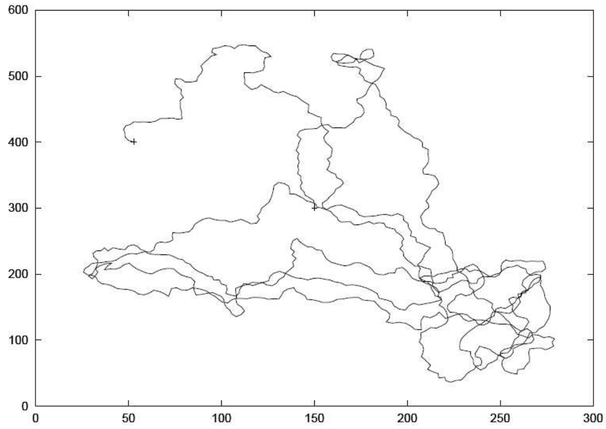

Figure 8: Movement pattern of the Gauss-Markov mobility model

The movement pattern of a mobile node employing the Gauss-Markov mobility model with parameters α =0.75, $\overline{V} = 10$, $\overline{D}$ = 90, n=1 with 1000 movements, is illustrated in Figure 8.

Though it avoids many problems that other models may incur, it still does not have enough consideration on obstacles and users' travel decisions.

- *Smooth Random* [3]
  Another mobility model, that addresses unrealistic movement patterns, is the smooth random mobility model, described by Bettstetter. As its name indicates, changes to the current direction and speed are smoothed, eliminating both sharp and sudden turns, as well as sudden stops. In this model, instead of employing a uniform distribution of speeds between $[0, V_{max}]$, a preferred set of speeds is defined and a high probability is assigned to each of them. As an example, the set may be $0, 1/2V_{max}, V_{max}$and the probability distribution employed is:

$$P(V) = \begin{cases} P(V=0)\delta(V) & V=0 \\ P(V=1/2V_{max})\delta(V-1/2V_{max}) & V=1/2V_{max} \\ P(V=V_{max})\delta(P-V_{max}) & V=V_{max} \\ \frac{1-P(V=0)-P(V=1/2V_{max})-P(V-V_{max})}{V_{max}} & 0<V_{max}<1 \\ 0 & else \end{cases}$$

Employing a preferred set of speeds, each with high probabilities, corresponds to real world mobile nodes tending to travel at preferred speeds. Another feature of this model is the acceleration or deceleration parameter, resulting in changes from current to targeted speeds, occurring incrementally. If the current speed is less than the targeted speed, a random value is chosen from $[0, a_{max}]$, a to accelerate the node; otherwise, a random value is selected from$[a_{min}, 0]$. During the acceleration or deceleration, at each time interval the speed is calculated using $V(t) = V(t-\Delta t) + a(t)\Delta t$
When the direction change event occurs, a new movement direction is selected randomly from $[0, 2\pi]$. If the $\varphi^*(t^*)$ is the new direction at time t^* , and $\varphi(t^*)$ is the old direction, then the model sets the direction difference as:

$$\Delta\varphi(t^*) = \begin{cases} \varphi^*(t^*) - \varphi(t^*) + 2\pi & -2\pi < \varphi^*(t^*) - \varphi(t^*) \leq -\pi \\ \varphi^*(t^*) - \varphi(t^*) & -\pi < \varphi^*(t^*) - \varphi(t^*) \leq \pi \\ \varphi^*(t^*) - \varphi(t^*) - 2\pi & \pi < \varphi^*(t^*) - \varphi(t^*) \leq 2\pi \end{cases}$$

Simulation area	1000m*100m
Preferred set of speed	$\{0,13.9m/s\}$
Acceleration, Deceleration	$[0,2.5]$, $[-4,0]$
Probabilities	$p(v=0)=0.3 \quad p(v=v_{\max})=0.3$

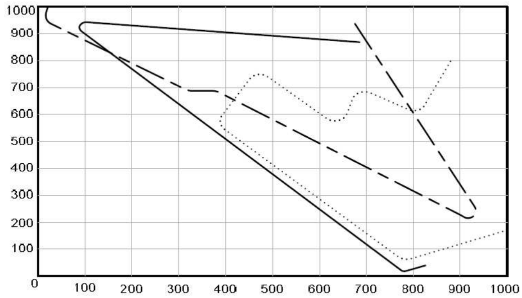

Figure 9: The movement pattern of three nodes with Smooth Random

In order to have smooth and incremental turns, each mobile node changes its direction by $\Delta\phi(t)$ degrees at each time slot. $\Delta\phi(t)$ is the maximum allowable direction change. During a loop repeated for $\frac{\Delta\varphi(t^*)}{\Delta\phi(t)}$ time intervals, the mobile node changes its current direction by $\Delta\phi(t)$ degrees until it reaches the targeted new direction.

Figure 9 illustrates the movement pattern of three mobile nodes based on the following values:

The changes to the current direction and speed are smoothed, eliminate the sharp and sudden turns and stops.

It is somewhat similar to Gauss-Markov, and also lacks of consideration on obstacles, and does not focus on the regular elements of users' movement.

1.2. New Models

In the reality, there are a myriad of scenarios to be taken into considerations, some new models are in great need to solve the problems that the classical ones cannot address. These new models are:

- Denizhan N. Alparslan and Khosrow Sohraby propose a generalized random mobility model to capture sever mobility scenarios, and gave a mathematical analysis over one-dimensional [1] and two-dimensional[2] case.

  It assumed that $R = [0, a]$is a bound region on which mobile terminals operate,and $X_s \in R$ and $X_d \in R$,$V \in v_{min}, v_{max}$, T_p is the random variable in $[0, \infty]$
  $f_{X_d|X_s}$ is the conditional density function (pdf) of X_d given X_s;

  $f_{V|X_s,X_d}$ is the conditional pdf of V given X_s and X_d;

  $f_{T_p|T_d}$ is the conditional pdf of T_p given X_d.

  And the scenarios in both unidimensional and two-dimensional models are presented by the above pdf. Highway scenario, acceleration model can be found in this article.

- Ahmed E. Kamal and Jamal N. Al-Karaki introduce a new realistic mobility model for mobile ad hoc networks.[6]

It was found that if the initial speed, location, and pause time are sampled form the stationary distribution rather than the uniform distribution, convergence to stationarity is immediate and no data need be discarded.[6] The user mobility model needs to incorporate user behavioral patterns, link characteristics and the node association to reach accurate prediction.
The initialization of location, speed and direction are introduced, the One-step Markov path model is also used to solve the problem. And later the stationary distribution of the mobility state of the new model is also presented. It demonstrated that this model would be helpful when simulating user mobility in general mobile networks.

- Chih-Ping Chu, Hua-Wen Tsai introduce a novel mobility model which combines different mobile patterns to simulate people's complex movement behaviors in urban areas, including driving and walking.[7] In their new model, the mobile behaviors are divided into 3 categories, Destination-based, Random-based, and Route-based. And they have a very cool idea to distinct the mobile node, denoted a vehicle, by individual node, public vehicle and Taxi. Later, they compare the performance by ns2 in different condition of these models.

1.3. Problems with Models

One thing needed to be pointed out is: If handled inproperly, seemingly simple models (such as random waypoint) can bring strikingly hard challenges. As mentioned above, problems such as speed decay and a change in distribution of location and speed as simulation progresses [5] can be very disturbing, and it is related to whether the model has a stationary regime. To avoid such defects, we need to (1) make sure the model does have a stationary regime and (2) remove the beginning of all simulation runs. Besides, even if there exists a stationary regime, it may take too long (can be as long as 1000 seconds) to reach the steady state. Luckily, some methods such as *Perfect Simulation* can be used to eliminate the transient state, that is, to sample the initial simulation state from the stationary regime. This method is quite simple and effective in solving some certain models, e.g. random trip models, with the aid of Palm techniques, which will also be covered in this report.

2. Related Work

For the Random Mobility Models, Michele Garetto and Emilio Leonard gave an Partial differential equations explanations to Random Waypoint and Random Direction model [4]. They offer simple expressions, which relate the transient duration to the model parameters, they also contribute to the definition of generalized random direction model whose stationary distribution of mobiles in the physical space corresponds to an assigned distribution.
For the Random Direction model, the author develop the equations from unidimensional case to multidimensional case. The Random Waypoint model is also develop in the same way. Moreover, the steady state is also analyzed via exponential case and multidimensional case. Transient analysis is also issued in this article.

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