Journal of the Nigerian Association of Mathematical Physics
***Volume* 18 (May, 2011), pp 407 – 412**
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Modelling Mobility in Mobile AD-HOC Network Environments.

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Abstract

In the simulation of mobile ad-hoc networks (MANETs), the probability distribution governing the movement of nodes typically varies over time and converges to a steady state distribution, known as the stationary distribution. This paper presents and evaluates the stationary distribution for location, speed and pause time of a random waypoint mobility case. We show how to implement the random waypoint mobility model for ad-hoc networks without pausing, through a more efficient and reliable computer simulation, using MATrix LABoratory 7.5.0 (R2007b). Simulation results obtained verify the correctness of the model.

Keywords : Stationary, random waypoint, simulation, wireless channel, mobility pattern.

1. Introduction:

The nature of mobile ad-hoc networks makes modeling and simulation an invaluable tool for understanding the behaviour of these networks. Wireless channels experience high variability in quality due to a variety of phenomenon, such as multi-path propagation, fading, atmospheric effects and obstacles [1]. The advantages of simulating ad-hoc networks as opposed to real world scenarios include repeated events, parameters isolation and matrices exploration. Repeated events enable the development and refinement of network protocols by allowing protocol developers to test different protocols within same scenario. This gives the developer an in-depth understanding of how these changes impact on the overall performance of the system. Isolation of the parameters permits a detail study of a single parameter, such as mobility, data-traffic or transmission range. This is made possible by keeping all other performance parameters (matrices) constant.

An important component of network simulation is the mobility model. Once nodes are initially placed, the mobility model dictates the movement of the nodes within the network. A variety of models have been proposed for ad-hoc networks mobility [2, 3, 4, 5, 6] and a survey of many available in [7, 8]. These models widely vary in their movement characteristics. For instance, in the random walk mobility model used in [9], nodes select a direction to move (between 0 and 2π) with a speed from a given distribution and travel in the speed direction for a specified number of steps or time period. At the end of the period, the nodes repeat the process. Another mobility model is the random direction model [6] which operation is similar to the random walk, except that the nodes continue movement until they reach some location ε in the simulation boundary. Once in this area, they select a new direction to walk.

Mobility significantly affects the performance of MANET protocols. It also affects connectivity and consequently the performance of its mechanisms. This effect is illustrated in Figure 1:

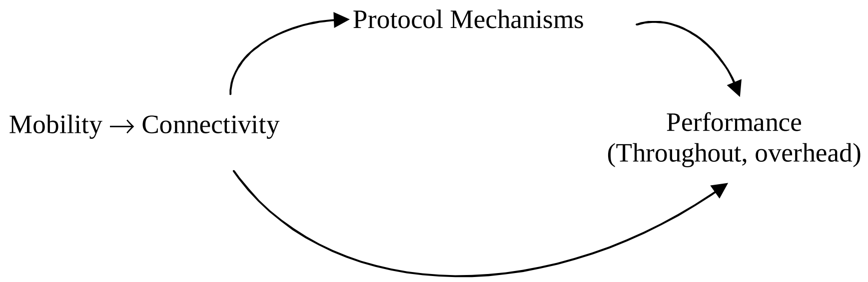

Figure 1. Diagrammatic illustration of mobility effect

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Variety of environments exists where the deployment of ad-hoc networks is expected. Examples of these include cities, highways, conference venues, campuses and battle fields. These environments have in common the presence of obstacles that obstruct the movement of nodes and hinder the propagation of wireless signals. Obstacles may be buildings, vehicles, people, mountains, hills, etc. The problem for this paper is on how to implement scenarios that include the presence of buildings. For instance, in real scenarios, the transmission quality through a building is affected by the composition of the building, as well as walls thickness.

Real world environment models have been proposed in [1] with empirical results for the evaluation of mobile networks. Here, they create a fully developed real-world model by augmenting their previous work in [10] but considered distributions with pauses. Our paper improves on [1] by simulating the mobility model using a more robust language for technical computing and consider distributions without pausing with alternative motion heuristics that improves the speed of mobile nodes.

2. THEORETICAL FRAMEWORK

Mobility models are designed to describe the movement pattern of mobile users and how their location, velocity and acceleration change over time. Mobility models has important role to play in the determination of protocol performance. The model emulates the movement patterns of real life applications in a reasonable way. Two types of mobility models are used in simulations of ad-hoc networks: traces and synthetic models [11]. Mobility patterns observed in real life systems are referred to as traces. Traces provide exact information about mobility when a large number of nodes are observed for a long period of time. Synthetic models attempt to represent realistically, the behaviour of mobile nodes (MNs) without using traces and other possibly unknown statistics. These models are extensively dealt with in [3, 5, 12, 13, 14, 15, 16, 17] and allows for the representation of the positions of individual mobile nodes.

Simulation of the random waypoint is not trivial a task. They pose numerous challenges such as speed decay, change in location distribution and the simulation progression speed [18, 19, 20, 21]. The observation of these parameters is related to the existence of a stationary regime.

3. THE SYSTEM MODEL

The random waypoint model can formally be defined as a stochastic process

$$\{D_i.\tau_{p.i},V_i\}_{i\in N} = \{(D_1.\tau_{p.1}.V_1).(D_2.\tau_{p.2}.V_2)...\} \qquad (1)$$

where

D_i is the point of destination in its α-dimensional coordinates

$\tau_{p.i}$ denotes the pause time in D_i.

V_i is the velocity of the node during i time period

The movement vector from d_{i-1} to d_i is denoted as a trajectory τ_i. Therefore, the complete movement trace of a node can be described as

$$\{\tau_1.\tau_2...\tau_i...\} = \{d_1 - d_0.d_2 - d_1...d_i.d_{i-1}...\} \qquad (2)$$

The resulting node distribution function $f_x(x)$ is composed of three distinct components namely the static (s), pause (p) and mobility (m) components and is represented as:

$$f_x(x) = f_s(x) + f_p(x) + f_m(x) \qquad (3)$$

These components can be described as probability distribution functions (*pdfs*). Put differently, they represent likelihood functions.

3.1. Stationary Distributions without Pausing

To derive the stationary distributions for both speed and location without pausing, we consider the condition where all nodes are mobile and set the pause time to zero. A node moves according to the random waypoint model in the line segment [0, α]. Now let *x* denote a node's location and S and D denote the starting and destination points of a randomly chosen movement period respectively. Then

$$f_S(s) = f_D(d) = \begin{cases} \dfrac{1}{\alpha} & for\ 0 \le s, d \le \alpha \\ 0 & otherwise \end{cases} \qquad (4)$$

Now, without loss of generalization, we could also treat speed and location as independent entities. Considering speed, if a node is travelling at a speed *s*, the time spent on a path of length 1, is *1/s*. Therefore *f(s)* is proportional to *1/s*. Since $\int_{v_0}^{v_1} f(s)ds = 1$ [22], then

$$f(s) = \begin{cases} \dfrac{1}{s\log(v_1/v_0)} & v_0 < s < v_1 \\ 0 & otherwise \end{cases} \tag{5}$$

Notice that equation (5) only holds when the minimum speed v_0 is greater than 0. To obtain the pdf for location, we observe that at any time *t*, the node travels on a straight line path between two points. Since the speed is constant along the path, the position of the node is uniformly chosen from among the points on the path (x_1, y_1), and (x_2, y_2). Conditional on the endpoints of this path, the probability density of the *x*-coordinate of the node's location is

$$g(x \mid x_1, x_2) \;=\; \begin{cases} \dfrac{x}{|x_2 - x_1|} & x_1 < x < x_2 \\ 0 & othewise \end{cases} \tag{6}$$

3.2. Alternative Distributions for Speed

If speeds are chosen from a uniform distribution with a low minimum speed, then, at any given time, a large proportion of nodes will start slowing down in movement. From [22] we observe that if the speed is chosen uniformly on (*0.01, 20*), with zero pause time, it is trivial to compute from the stationary density in equation (5) that on the average, half of the nodes will be moving at speeds less than 0.45, and 25% of the nodes will be moving at speeds less than 0.07. This can create a nearly stable backbone that can make network performance seem unrealistically good. For this reason, [22] suggest that it may be desirable to choose node speeds in a way that avoids having large numbers of slow moving nodes, hence, resulting in a network with fewer slow-moving nodes. An easy solution to this problem is to increase the minimum speed. A method for choosing speeds from any desired stationary distribution as presented in [22, 23] shows that since a node travelling at speed *s*, spends time *1/s* on a path of length 1, any stationary density can be achieved through an appropriate choice of *p(s)*. For instance, if

$$p(s) = \frac{2s}{v_1^2 - v_0^2} \quad for\;\; v_0 < s < v_1 \tag{7}$$

then, the stationary density (or speed) will be uniform on (v_0, v_1), since *p(s)/s* is constant. To select uniformly distributed speeds on (v_0, v_1) throughout the simulation, the initial speed should be selected from a uniform distribution on (v_0, v_1): the stationary distribution. All subsequent speeds should be selected from the density in equation (7). It is permissible to set $v_0 = 0$, so that arbitrarily slow speeds can be attained.

3.3. Model Implementation

We implement the system model using MATLAB. MATLAB is a language for technical computing. It has a wide range of sophisticated solutions for simulations of this nature and is most flexible to use. The simulation program was run under ideal conditions with empirical data that depicts real-world settings and results were obtained. These results are represented graphically and discussed in the following section.

4. DISCUSSION OF SIMULATION RESULTS

Figure 2 shows a plot of cumulative distribution function and the speed of node distribution on the interval [*0.1, 5*]. We observe in this figure that the trend of average nodal speed decays exponentially over time. This shows that once a mobile node chooses a far away destination with a slow speed, it takes a long period for the node to reach its destination. During this period, the mobile node moves slowly.

Figure 3 shows the random time series distribution of node speed for two different node movements in a real-life setting within the simulation domain. We observe here that the speed distribution of the mobile nodes fluctuate without pausing (with a zero pause time). The graph also confirms that the average nodal speed keeps decreasing over time. Comparing the two random plots, we observe that though one of the plots increases at a slow but steady rate, both plots show inconsistency in movements, which is expected of two independent nodes, pursuing uncommon goals.

In Figures 4 and 5, the mobile nodes were identically distributed without pausing on the x-coordinate. We observe from these graphs that the proportion of time spent by a node on the path of a given direction is proportional to the path length of the direction. In Figure 5, we discover that both random independent nodes do not on the average exceed the cumulative distribution function, g(x).

Figures 6 and 7 show a modified version of the model used in Figures 2 and 3 (i.e. equation (7)). Here, we choose a desired random distribution of mobile nodes travelling at speed *s* and spend time $\frac{1}{s}$ on a path. It follows that if speeds are chosen according to a probability density *p(s)*, the stationarity will be proportional to *p(s)/s*. We observe from the graphs that the distribution of mobile nodes with respect to speed is preferably stable over time. This confirms that the model is able to overcome the non-uniform spatial distribution and density waypoint function.

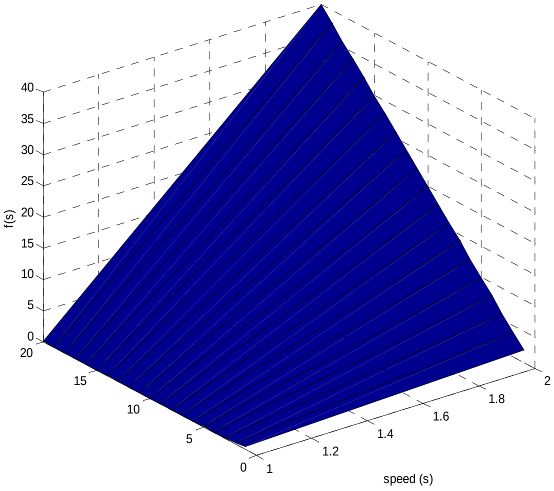

Figure 2. Graph of f(s) vs. speed (s)

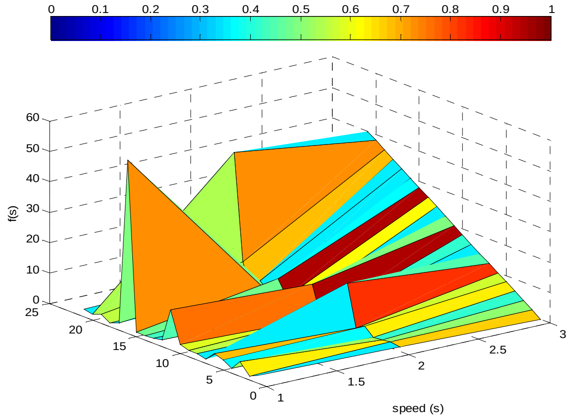

Figure 3. Graph of f(s) vs. speed (s), for random independent nodes

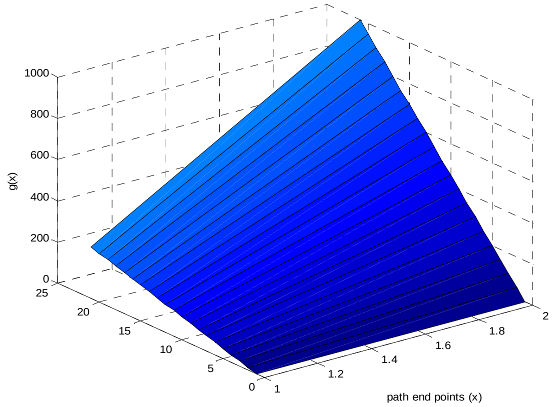

Figure 4. Graph of g(x) vs. path end points (x)

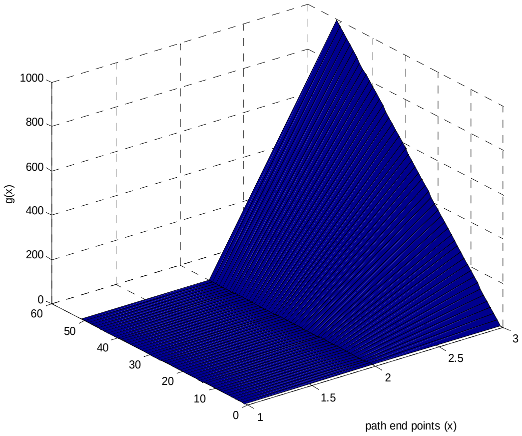

Figure 5. Graph of g(x) vs. path end points (x), for random independent nodes

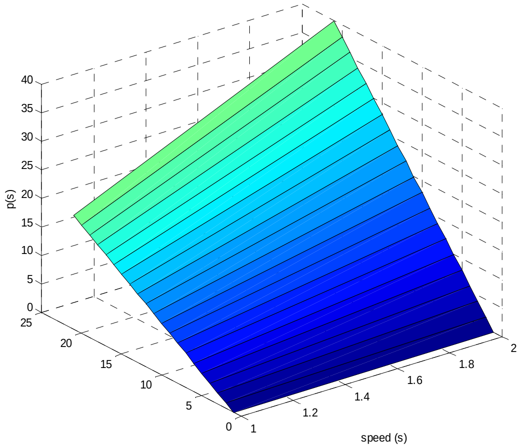

Figure 6. Graph of p(s) vs. speed (s)

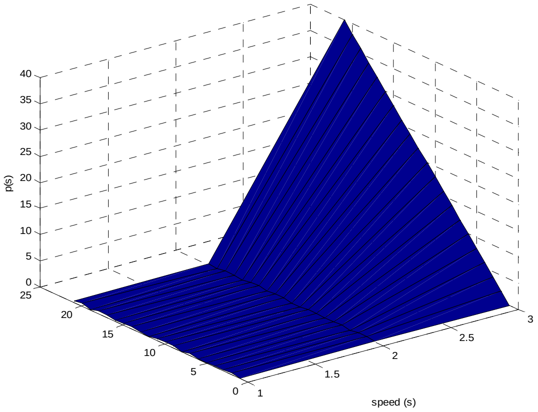

Figure 7. Graph of p(s) vs. speed (s), for random independent nodes

5. CONCLUSION

To thoroughly simulate a new protocol for an ad-hoc network, a mobility model that accurately represents movement pattern of the mobile nodes in a given network is required. To this end, the random waypoint mobility model was simulated in order to solve the problem of speed distribution of nodes of an ad-hoc network for a specified number of steps or time period.

This paper has provided solution to the problem of speed distribution of nodes through a real-world simulation, which provides a means for evaluating mobile nodes (in ad-hoc networks) in terms of efficiency and robustness. The problems that obstruct the movement of these nodes and hinder the propagation of wireless signals have been minimized with the help of the proposed system model, to allow these mobile nodes move freely without the use of a base station infrastructure. Simulation results show how the model parameters help in minimizing obstacles in the wireless ad-hoc network. Therefore, in the nearest future, MANETs would be potentially useful in various applications such as mobile classrooms and for disaster relief operations.

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