Realistic Individual Mobility Markovian Models for Mobile Ad hoc Networks

Carlos Alberto V. Campos, Daniel C. Otero, Luis Felipe M. de Moraes
Laboratório de Redes de Alta Velocidade – RAVEL
COPPE / Universidade Federal do Rio de Janeiro – UFRJ
Rio de Janeiro, RJ, Brasil
Email: {beto, daniel, moraes}@ravel.ufrj.br

Abstract— **Mobility Models try to represent the movement behavior of devices in Mobile Ad hoc Networks. These models are used in performance evaluation of applications and communication systems, allowing the analysis of the mobility's impact. In this context, two individual mobility models for Mobile Ad hoc Networks are proposed in this paper. These models were based in [1] and intend to represent a wider movement capability. Using the proposed models it is possible to move in the same direction, in adjacent directions, to accelerate and to stop, avoiding sharp turns and sudden stops. This way, it is tried a closer representation to the real movement of the users in urban enviroments and roads. In this paper, the models are described analytically by Markov Chains. Besides that, some comparisions between the proposed models, the Waypoint model and the Random Walk model are presented through the use of simulations.***

Keywords—**Ad hoc networks, mobility models, modeling and simulation, performance evaluation.**

I. Introduction

Mobile Ad hoc Networks are wireless communication technologies, where mobile devices can exchange information directly between each other or through multiple hops without the need of a communication infrastructure [2], [3]. This way, the computational devices can act as routers, data devices or even both simultaneously, giving the network an auto-configuration characteristic. These networks are recommended for situations where it isn't possible to deploy a fixed network or an infrastructured wireless network, as battlefields, businessmen sharing information in meetings, sallesmen communicating downtown and rescues teams in desaster situations as hurricanes, earthquakes and floodings. In this work, the computational devices are called mobile nodes (MNs).

A route between two MNs in an ad hoc network can be made through one or multiple hops. One of the main problems in ad hoc networks is to choose and to keep the routes, as the mobility of the MNs usually cause many changes in the network topology. For this reason, many routing protocols have been developed, trying to accomplish this task efficiently.

To evaluate the performance of a routing protocol [3], [4] there are many analysis that must be made, including the range of transmission of the MNs, traffic pattern, size of the buffer for the messages and the movement pattern of the users. This paper is mainly concerned with the movement pattern of the users.

Currently there are two ways of representing the movement pattern of the users in mobile networks [3]. One of them is through the use of traces, and the other one is through the use of mobility models. Despite representing the reality, the use of traces is not common because to keep track of the movement of the nodes is not an easy task in ad hoc networks, and even when this data exists usually it is confidential. In these situations the use of mobility models is required. These models can be divided in two categories [3], [4]: models for celular networks and models for ad hoc networks. This paper address mobility models for ad hoc networks.

In section II some mobility models used in Ad Hoc networks are briefly described. In section III two mobility models are proposed and described analitically. In section IV a performance evaluation of one of the proposed models is made. Section V concludes this paper.

II. Mobility Models for Ad hoc Networks

As has been mentioned before, mobility models are used to represent the mobility pattern of the MNs. These models are used in the performance evaluation of applications and communication systems, allowing the analysis of the impact caused by the mobility on the functioning of those, and can be applied in many environments, such as the management of the distribution of criptographic keys, evaluation of packet losses [5], traffic management, performance evaluation of routing potocols [3], [6], partition prediction [7], service discovery in partitionable networks [8] and medium access protocols for ad hoc networks. These models can be further classified in two types: individual mobility models and group mobility models.

A. Individual Mobility Models

Individual mobility models represent the movement pattern of a MN independently of the other MNs, and are the most used models in the performance evaluation of ad hoc networks [3]. In this section some of the individual mobility models will be briefly described.

One of the most used models in ad hoc networks is the random walk mobility model [9]. In this model, the direction and speed of movement at some point in time has no relationship with the direction and speed at previous points, making

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this model memoryless, and also generating a nonrealistic movement for each MN, with sharp turns, sudden stops and sudden accelerations. Some other models based on the random walk mobility model have also been proposed [10], [11].

The Waypoint Mobility Model, described in [12], divides the course taken by the MN in two periods, the movement period and the pause period. The MN stays at some place for a random amount of time and then moves to a new place chosen at random with a speed that follows an exponential distribution between [minspeed, maxspeed], as shown in figure 1. This model is also memoryless, and has the same drawbacks of the random mobility model. In [13], is presented a study about the harmful behavior of waypoint model.

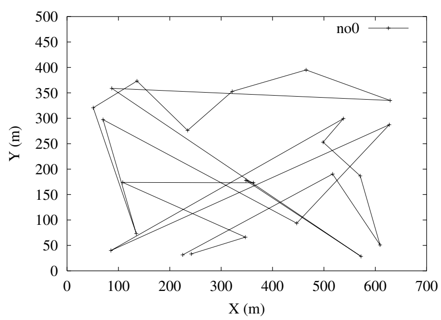


Fig. 1. Course taken by the MN (no0) using the Waypoint Model.

The Markovian Random Path Model (MRP) was proposed by Chiang in [1], and uses a markov chain to model the movement, introducing memory in the movement behavior. This model has three states to represent the movement coordinates x and y. The state zero (0) represents the current position of the MN, while state one (1) represents its previous position and state two (2) represents its next position. Figure 2 shows the markov chains for the movement coordinates x and y.

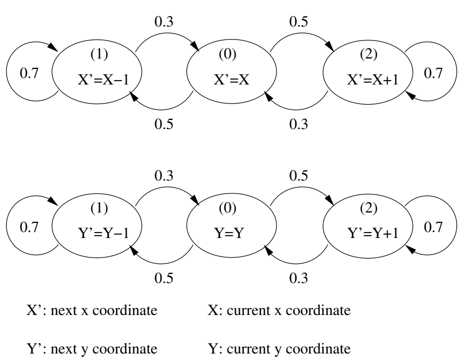


Fig. 2. MRP Mobility Model.

In this model, movements in the horizontal and vertical directions as well as stops are not possible for an interval of time greater than one step. Besides that, once the MN starts to move it is likely to remain in the same direction, because the probability that it stays in states (1) or (2) of the markov chain is greater than the probability that it goes back to state (0). Another property of this model is that it doesn't allow sudden changes of the way of the movement, because there aren't one step transitions between states (1) and (2), that is, before changing the way the MN first has to stop.

There are also other individual mobility models proposed in the literature. In [3] it is presented a boundless simulation area model. The work [4] describes the *Gauss-Markov* mobility model. The *City Section* mobility model is proposed in [3] and tries to represent the movement of a MN in urban environments. In [14], is proposed the smooth model, that represents motion smoother than randon walk and waypoint models.

B. Group Mobility Models

Group Mobility Models are used to represent the movement of a group of MNs. These models have recently been used to predict the partitioning of ad hoc networks, which is defined as a wide-scale topology change [7], caused mainly by the group movement behavior of the MNs.

A group mobility model developed by Hong *et al.* in [4] is the Group Point Reference Mobility Model (GPRM). For each MN there is an associated reference point which states the group movement. The MNs are initially placed randomly around the reference point within some geographical area. Each reference point has a group movement vector, which is summed with the random movement vector of each MN to determine the next position of the respective MN. The GPRM model defines the group movement explicitly, determining a movement path for each group.

III. Proposed Individual Mobility Models

As mentioned in section II-A, compared to the Random Walk and the Waypoint, the MRP model tries to describe a more realistic movement. However, it still has some drawbacks. Besides doesn't allowing stops and movements in the vertical and horizontal directions for an interval of time greater than one step, this model doesn't support speed changes while moving in some direction.

The proposed modeling address the problems mentioned above and are recommended to represent urban environments and roads. These models were based in [1], being also markovian processes [15]. This section describes these models.

A. Simple Individual Mobility Markovian Model - SIMM

The SIMM model uses a discrete-time Markov chain that allows horizontal and vertical movements, besides allowing stops. However, it doesn't support speed changes.

The Markov chains used in the SIMM model are shown in figure 3. This model is an extension of the MRP model, described in section II-A. As can be seen in the figure, the model introduces a transition from state (0) to the same state (0) with a probability $1 - 2p$, allowing the MN to remain at the same position in x or y during some interval of time.

Both the MRP model and the SIMM model have a markov chain for the x coordinate and another one for the y coordinate. It is possible to join the two markov chains and create another one with two state variables, one for each coordinate, as shown

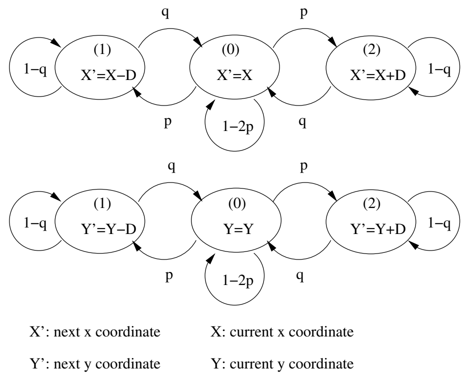


Fig. 3. State transition diagram for the SIMM model

in figure 4. In this chain, the movement is represented by the increment or decrement on the coordinates x and y by a value of D. This way, the speeds achieved in this model are D and $D\sqrt{2}$ unities, where $D \in \mathbb{R}$ and the speed can be measured in *m/s*, *Km/h*, or any other measure wished. The SIMM model can represent movements with only two speed values, being suitable for scenarios with low speed variation.

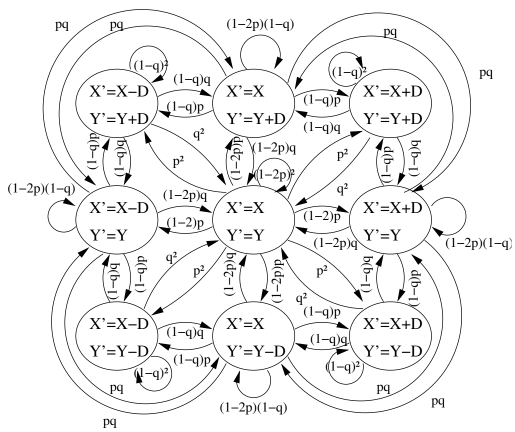


Fig. 4. Diagram with 2 state variables (x and y coordinates)

Figure 4 shows all the possible transitions in the SIMM model. Based on this figure, it is possible to observe the following characteristics:

1) The probability that a MN remains stopped at a point in time is given by $(1-2p)^2$. If p has a large value, this model will allow very few stops.
2) The probability that a MN remains moving in the same (vertical or horizontal) direction is given by $(1-2p)(1-q)$. If p has a very large value, the model will allow very few moves in these directions. Besides that, as q increases, fewer will be the moves in these directions.
3) The probability that a MN remains moving in the same (diagonal) direction is given by $(1-q)^2$. This way, the less is the value of q, the greater will be the move in this direction.

With this, by varying the values of p and q it is possible to obtain different movimentation patterns with the SIMM model. If the values $p = 0.4$ and $q = 0.3$ are chosen, the model generates severe movimentation in diagonals, as illustrated in figure 5.

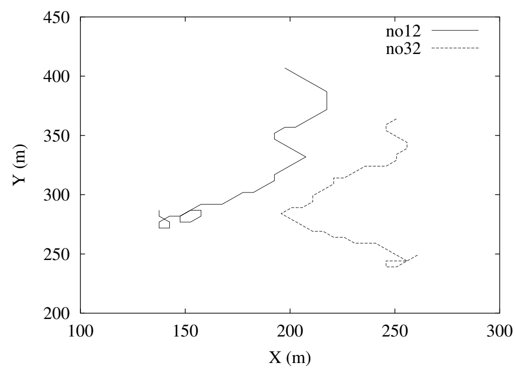


Fig. 5. Course of two nodes using the SIMM model.

B. Generic Individual Mobility Markovian Model - GIMM

In most of the scenarios where ad hoc networks are used, the MNs move changing their speed. To represent this scenarios, it is proposed a generic markovian model that supports different speeds, the GIMM model. In this model there is a set of values used for the increment on the initial position, chosen within $[1, n]$, that is, the increment corresponds to the speed of the MN moving from the current position X to the next position X'. To represent this new feature the following parameters need to be adjusted:

$m \rightarrow$ is the value that represents the sum of all the transition probabilities, from state (i), to states at the right-hand side. Is is also used for to represent the sum of all the changes to the left.

$b \rightarrow$ is the base of the exponent that represents the increment of the position.

The variation of the speed value follows a geometric distribution, where the initial value is 1 and the maximum value is n, so:

$n \rightarrow$ maximum number of increment on steps, where,

$$0 < n < \infty \quad | \quad n \in \mathbb{R} \text{ and is potency of } b \tag{1}$$

This way, n can be represented by:

$$n = b^{\log_b n} \quad | \quad b \in \mathbb{R} \tag{2}$$

The next position of the MN is calculated the following way:

$$\begin{aligned} X' = & X + s \cdot b^v, \quad 0 \leqslant v \leqslant \log_b n, \\ & s = \{-1, 0, 1\}, \quad v \in \mathbb{Z} \end{aligned} \tag{3}$$

Where s represents the way of the movement, with the values -1 for the opposite way, 0 for the same position and 1 for the same way. The value v represents the exponent of the increment given to the next position of the MN.

Each state of the chain shown in figure 6, except for the states $(-e, e)$, will have the following values for their transition probabilites:

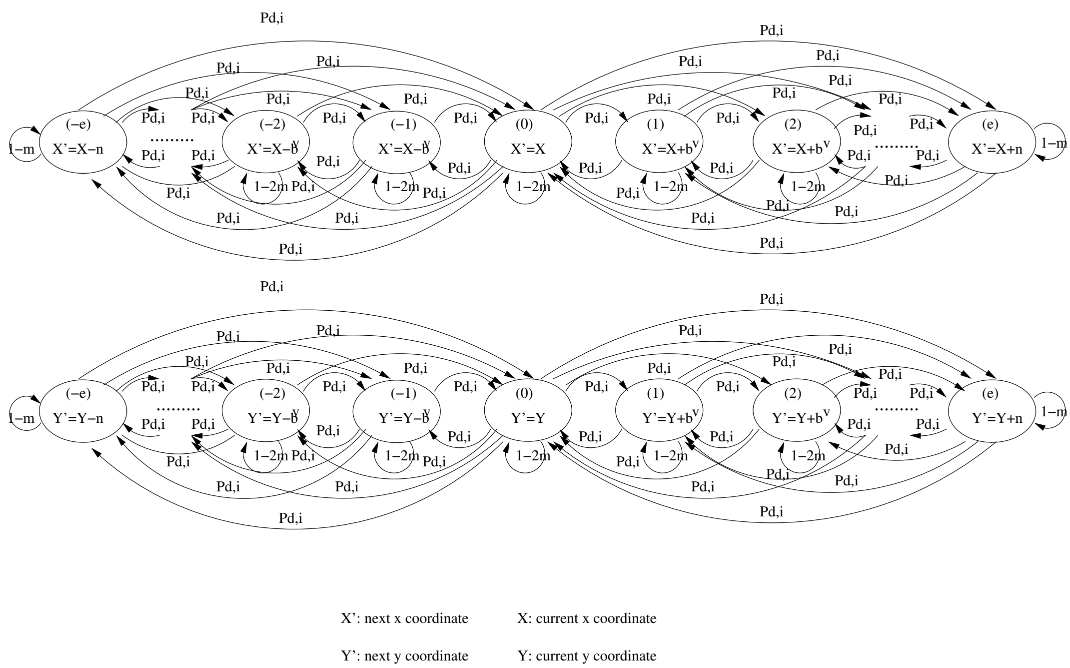


Fig. 6. State transition diagram for Model GIMM

- To stay at the current state the value is equal to $(1-2m)$, as defined in equation (4);
- The sum of all the transition probabilities to any state at the right-hand side of the current state is equal to m, as shown in figure 6. This value is defined in equation (5) for the state (0), in equation (6) for the positive states and in equation (7) for the negative states;
- The sum of all the transition probabilities to any state at the left-hand side of the current state is also equal to m, as shown in figure 6. This value is defined in equation (5) for the state (0), in equation (6) for the negative states and in equation (7) for the positive states.

$$\begin{aligned} &P(X'(t) = X(t) + s \cdot b^v | X'(t-1) = X(t-1) \\ &+ s \cdot b^v) = 1 - 2m, 0 \leqslant v < \log_b n, -1 \leqslant s \leqslant 1 \end{aligned} \tag{4}$$

$$\begin{aligned} &\sum_{v=0}^{\log_b n} P(X'(t) = X(t) + s \cdot b^v | X'(t-1) \\ &\qquad = X(t-1)) = m \quad s = \{-1, 1\} \end{aligned} \tag{5}$$

$$\begin{aligned} &\sum_{v=k+1}^{\log_b n} P(X'(t) = X(t) + s \cdot b^v | X'(t-1) \\ &\qquad = X(t-1) + s \cdot b^k) = m, \\ &\qquad 0 < k \leqslant \log_b n, \quad k \in \mathbb{Z} \end{aligned} \tag{6}$$

$$\begin{aligned} &(\sum_{v=0}^{k-1} P(X'(t) = X(t) + s \cdot b^v | X'(t-1) \\ &= X(t-1) + s \cdot b^k)) + (P(X'(t) = \\ &X(t) | X'(t-1) = X(t-1) + s.b^k)) = m \end{aligned} \tag{7}$$

As the states $(-e, e)$ are the edges of the markov chain, as shown in figure 6, they are different from the other states. Once in state $(-e)$ the only possible transition is to another state at its right-hand side, where the sum of all the possible probability values is equal to m, as defined in equation (7), or to itself, with the probability value of $1-m$, as defined in equation (8). In a symmetrical way, once in state (e), the only possible transition is to another state at its left-hand side, where the sum of all the possible probability values is also equal to m, as defined in equation (7), or to itself, with the probability value of $1-m$, as defined in equation (8).

$$\begin{aligned} &P(X'(t) = X(t) + s \cdot n | X'(t-1) = X(t-1) \\ &+ s \cdot n) = 1 - m, \quad s = \{-1, 1\} \end{aligned} \tag{8}$$

To obtain the state transition probability from a state (i) to any other state, as shown in figure 6, the following has to be done: $P_{d,i} \rightarrow$ is the probability of being in state (d) at the instant t, given that at instant $t-1$ it was in state (i);

The equation below has a general form and represents $P_{d,i}$ in function of $P_{i+1,i}$.

$$P_{d,i} = \frac{P_{i+1,i}}{b^{|d|-1}}, \tag{9}$$

$P_{i+1,i}$ can be obtained by the sum of all the transition probabilities to the left or right-hand side. This sum is given by a geometric series with ratio $\frac{1}{b}$ plus a residual probability. This way, in equation (10), the general form of $P_{i+1,i}$ is given in function of m, defined in equation (5), and n, defined in equation (1).

$$P_{i+1,i} = \frac{mn(b-1)}{nb + b^{i+2} - 2b^{i+1}}, \ b > 1 \tag{10}$$

As shown analytically in this section, the presented modeling has the following characteristics:

- The state transition probabilities from a state (i) to the following (or previous) states follows a geometric series with ratio $\frac{1}{2}$, that is, the value of $P_{\frac{|i|}{i}(|i|+2),i}$ is half of the value of $P_{\frac{|i|}{i}(|i|+1),i}$, $\quad |i| > 0$;
- The speed increases exponentially until the maximum value n;
- Once in a state $(i \rightarrow positive)$, it isn't possible to change to a state $(i \rightarrow negative)$ without passing through state (0) and vice-versa. With this, the GIMM model avoids sharp turns.

Moreover, the GIMM model still can represent movimentation patterns that only increment the position by one (as the SIMM model), and also that increment the position by arbitrary values within $[1, n]$ (for the coordinates x and y). This way, the GIMM model is generic, allowing the representation of many movement patterns.

IV. Evaluation of the Proposed Modeling

In this section the proposed modeling will be evaluated by simulations and compared to other existing models, described in section II-A. First the metrics will be defined, then the simulation parameters will be described, and finally the results will be presented.

A. Metrics

Four metrics were identified as suitable for the comparative evaluation of the modeling, sharp turns, sudden speed changes, sudden stops and sudden accelerations. Each of them will be defined next.

A sharp turn occurs whenever there is a change in direction with an angle within [90^o, 180^o] or [135^o, 180^o]. This metric translates the smoothness of the change in direction.

A sudden speed change is defined by the value of a MN's ΔV, which is calculated by subtracting v_t from v_{t+1}, where v_t and v_{t+1} represent the speed at the instants (t) and $(t+1)$, respectively. With this, the speed change is considered sudden when $|\Delta V|$ has a greater value than or equal to 50% of the maximum speed considered in the simulation environment.

A sudden stop is a sudden speed change where $v_{t+1} = 0$ and ΔV is negative.

A sudden acceleration is also a sudden speed change but with $v_t = 0$ and ΔV positive.

B. Simulation Parameters

The software Scengen [16] was used to generate the mobility scenarios. Model GIMM was developed in C++ and appended to the set of available models of this software. The models Waypoint, MRP and GIMM were evaluated and compared by simulations.

The simulation scenario includes a 700 x 500 meters area and 50 MNs, initially positioned at random. In the simulated modeling, n has been set to 1, resulting in the special case of the modeling denominated SIMM. There, p and q have been set to 0.4 and 0.3, respectively. For each model considered, a hundred simulations have been done. The confidence level was 0.95.

C. Achieved Results

As described in section II-A, the interval of time during which a MN is moving in the Waypoint model is of variable size and related to the value of its speed and the size of the simulation area. Being so, the number of direction and speed changes of a MN during an interval of time is not a constant value. Besides, the interval of time during which a MN is moving in the MRP model and also the proposed models is constant. This way, when comparing the number of direction and speed changes for each model, the simulation time will be kept sufficient so as to allow the occurence of exactly 1000 direction changes. This value was chosen so as to make the presentation and comparision of the results easier.

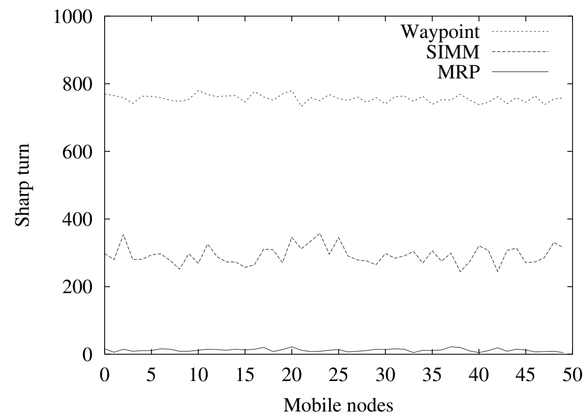


Fig. 7. Number of sharp turns with an angle $\geqslant 90^o$.

Figures 7 and 8 show the number of sharp turns with angles greater than or equal to 90^o and 135^o, respectively. It can be observed that for the Waypoint model, nearly 75% of the turns were considered sharp, 47% with angles greater than 135^o. This high value, in contrast to the expected of 50%, is explained by two reasons. First, as the simulation area is limited, the MN reaches the border of that area from time to time. By reaching the border, the current move is finalized and a new one is created with speed and direction chosen at random, what increases the probability of sharp turns. Second, the speed also affects this result, because as greater the speed is, the greater is the probability of reaching the border, which in turn increases the probability of turns and also sharp turns. For both the MRP and the SIMM model the results were below 5%, what was expected given the low probabilistic values associated with sharp turns in these models.

In the MRP model, the sharp turns were approximately 3%, a value already expected, considering that the model introduces memory on the move, and allows only very few stops and quite few movements in the horizontal and vertical directions, what makes the movement smooth and basicaly in diagonals. For the SIMM model the results ontained were also the ones expected. As shown in figure 8, approximately 30% of the turns were considered sharp. As the MRP model, the SIMM model has also memory in the movimentation. Moreover, model SIMM allows movements in the horizontal and vertical directions. These characteristics cause the probability of sharp turns to have a value between the ones in the MRP and Waypoint models.

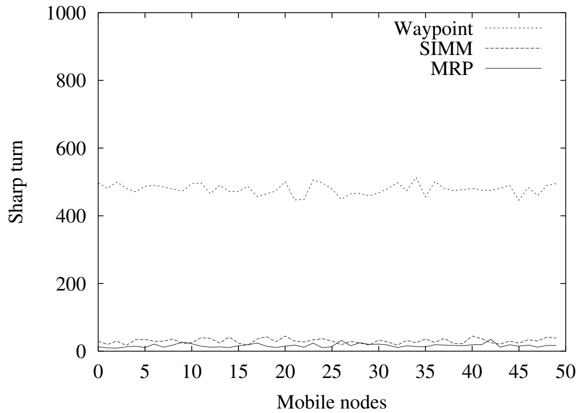
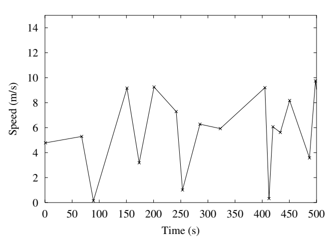
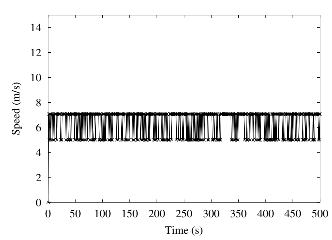


Fig. 8. Number of sharp turns with an angle $\geqslant 135^o$.

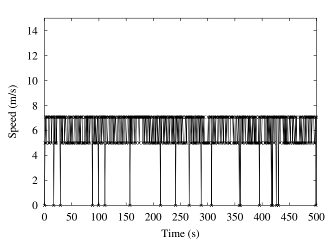
The measurement of changes in the speed is also important. Usually in a realistic movement pattern these changes are smooth most of the time. Figure 9 shows the average speed versus time. It can be seen that the Waypoint model has a considerable variation of speed, that is, within short intervals of time the speed have high peaks and drops. The MRP model has a different behavior, with v_t varying between 5 m/s and 7.07 m/s. The SIMM model is also smoother, as expected, and besides supporting the same speed values used in the MRP model, it also supports stops.



(a) Waypoint Model



(b) MRP Model



(c) Proposed Model

Fig. 9. Variation of the Average Speed.

V. Conclusions and Future Work

This paper describes the nonrealistic behavior of the most used mobility models in ad hoc networks, moreover, two mobility models are proposed. These models are based on markovian processes, that are suitable for the modeling of the movimentation of a MN independently of the others within nonuniform regions. They allow movements in the same and adjacent directions, speed changes and intervals of pause between consecutive movements. Besides, they avoid sharp turns and sudden stops, representing a more realistic movement in urban regions and roads, compared to the MRP and specially to the Waypoint model. The results obtained by simulation confirmed the characteristics mentioned above and modeled analiticaly, showing that the proposed models are more adequated than the Waypoint and MRP. As future works, the proposed models will be applied on the routing protocols AODV, DSDV and DSR, allowing the evaluation of the impact caused by the mobility models on those.

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