Time-based Random Waypoint Mobility Model for Wireless Mobile Networks

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Abstract— **In this paper velocity of objects in well-known random waypoint mobility model is investigated and some improvements are introduced and analyzed. Although, traditional RWP model has some shortcomings which lead to noticeable errors in evaluations, it has been widely used in the literature in sake of its intrinsic simplicity and availability. Here, we tried to improve the RWP in velocity selection aspect without losing the simplicity. Traditional RWP assumes a bounded random velocity value independently of the length of the movement trajectory which leads to inaccurate evaluations. To eliminate this assumption, some approaches are proposed and time-based RWP model is introduced. This model eliminates the "instantaneous average of velocity" problem of RWP. Performed simulations show that time-based RWP can approximate RWP with accelerated motions in some extent and approximate multi-level velocity selection paradigm which is used as a model for mobility of human beings in a plant or a town.**

Keywords- Random waypoint model, mobility model, time-based RWP, wireless networks, velocity distribution.

I. INTRODUCTION

Wireless networks are growing rapidly and will have much effect in our future life, so, performance analysis in the presence of different factors is an important issue. One of these factors that influences the design and analysis of those networks is mobility [14][15][16]. Many different models have been proposed by researchers such as random waypoint (RWP) model [1], random direction model [2], Brownian motion [3], and map based mobility [4][12][13].Based on these models many different results have been extracted for various network architectures [5][6].

RWP is one of the most common models for mobile networks. In this model, each node chooses uniformly at random a destination point within the deployment region R, and moves toward it along a straight line. Node velocity is chosen uniformly at random in the interval [v_{min}, v_{max}]. When the node arrives at destination, it remains stationary for a predefined pause time, and then starts moving again according to the same pattern.

Traditional RWP considers some assumptions which are not realistic in several scenarios, some of these assumptions are:

- Moving in straight lines and considering no obstacles in the region.
- Assuming constant velocity during the motion, without positive or negative acceleration.
- Selection of the velocity value independently of the length of the selected trajectory.

To eliminate the first assumption, several models have been proposed in the literature [20],[21]. In this paper we try to diminish or eliminate the third assumption especially and second one partially. Indeed, the third assumption is unrealistic in several cases. For example it is rare in several scenarios that an object traverses a 2 meter trajectory at velocity of 50 km/h and traverses a 20 km trajectory at velocity of 2 km/h.

Our results, which are presented later on, show that this assumption has a noticeable impact on the resultant location PDF. The asymptotic location PDF of a mobility model is an important aspect of it which is used to evaluate the performance or the connectivity properties [25]. In the real world, objects often choose their velocities according to the length of the trajectory. For example, human beings decide how to travel (by foot, by bicycle, by car, or by airplane) according to their travel length.

Another problem that arises by this assumption is "instantaneous average of velocity" (or "average nodal velocity") problem which is attributed as a harmful property of RWP as a model for performance evaluation of ad hoc networks[22],[23],[24]. Indeed, in RWP, motion steps with lower velocity values endure more in the network. Hence, the instantaneous average of the velocity of the nodes is lower than the expected value of the velocity of each motion step. The major problem addressed in [22],[23], and [24] is that instantaneous average of velocity decays over time which results in a longer simulation warm up time. In [23] authors addressed this problem for different mobility models and suggested applying steady-state average velocity as initial velocity to diminish this decaying property. The authors considered velocity-time and velocity-distance independence to analyze the decaying property of average velocity. In [24] two similar modifications are proposed.

In the previously mentioned papers no solution is provided for the steady state version of the problem. Indeed, average node velocity has an impact on the performance of ad hoc network protocols [19]. However, this important parameter is dependent on the velocity distribution of each motion step in steady state (Figure 1), i.e. applying (0,20] and [1,19] velocity ranges with uniform distribution to RWP, makes a noticeable difference in the average nodal velocity and consequently on the simulated performance results, in spite of equal expected values (Figure 2). Our simulations confirm the effect of motion step velocity distribution on the average nodal velocity for exponential and uniform motion step velocity distributions with equal expected values, too (Figure 3). Therefore, average nodal velocity and consequently evaluated performance measures in traditional RWP are highly sensitive to the velocity distribution changes. Hence, detailed information about velocity distribution is essential to have an accurate performance evaluation in case of traditional RWP. This type of information is not easily available for several fields and depending on this information is a drawback for a simulation model. Here, we propose a model which eliminates both of the problems substantially.

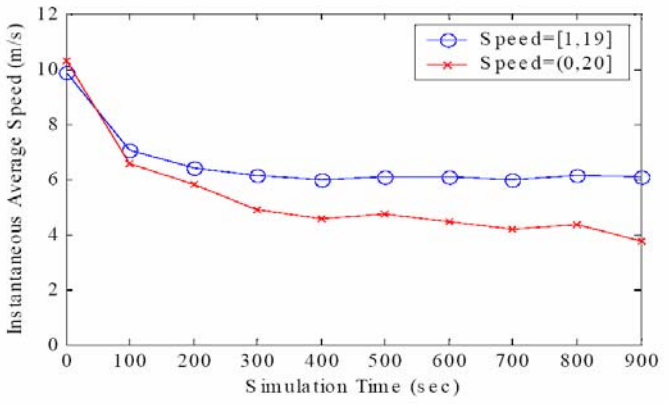

Figure 1 Decaying average nodal velocity in RWP and the effect of motion step velocity distribution. (from [22]) .

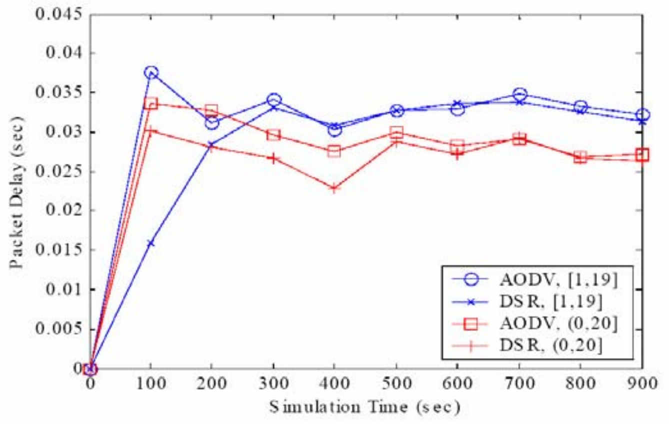

Figure 2 The effect of motion step velocity distribution on an evaluated performance metric of the ad hoc network through simulation (from [22]).

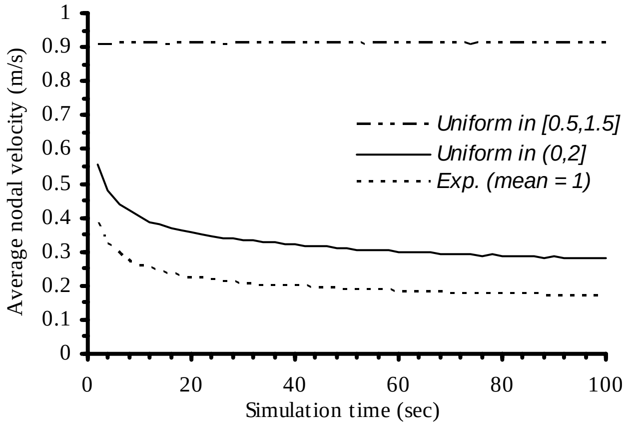

Figure 3 The effect of motion step velocity distribution on the average nodal velocity in transient and steady state in RWP (simulated with 100000 nodes)

However, considering the exact and accurate relation between the velocity and the trajectory length is ideal but it leads to a complicated model. In this paper, a few preliminary approaches to solve the problem are proposed and then time-based RWP (TBRWP) is introduced as a simplified yet useful model. Considering acceleration in RWP motion steps is another issue which is addressed here through simulation. Obtained results show that the location PDF of TBRWP can approximate accelerated RWP in some range of acceleration.

In the next section we will introduce our approaches to improve velocity selection in RWP and introduce the TBRWP model precisely. In Section III experimental results are reported, and finally the paper is concluded.

II. IMPROVING VELOCITY SELECTION IN RWP

As described before, assuming a velocity value independently of the trajectory length is an improper assumption in RWP model. In order to choose velocity values closer to the real ones in different scenarios, one may use the PDF of motion step velocity conditioned on the trajectory length obtained from extensive statistical field study and will be referred to as velocity selection function later on. This method is accurate but this statistical information is not easily available for several fields and the model may not be analyzed easily. Another approach which is a special case of the earlier one and needs lesser field information is using multi-level (piecewise) density function. For example, we can model the velocity of traveling human beings in a plant as a density function in which human beings move by foot at the deterministic speed of 1 m/s when the trajectory length is below 150 meters and move by car at the speed of 14 m/s, otherwise.

Another approach is considering linear relation between the velocity and the trajectory length random variables. Random variable V_0 is defined as the velocity value of a moving object when the trajectory length is one unit and is called base velocity later on. It is important to assume that V_0 is independent of the trajectory length. The velocity value of a moving object with a trajectory length l is defined as:

$$V = V_0 . l \qquad (1)$$

Hence, the time of motion is obtained by:

$$T_m = \frac{l}{V} = \frac{l}{V_0 l} = \frac{1}{V_0} \qquad (2)$$

In other words, motion time is independent of the trajectory length. If V_0 is in $[V_{\min}, V_{\max}]$ corresponding motion time is in $[1/V_{\max}, 1/V_{\min}]$. Hence, this model can be defined in an equivalent manner too: consider a variety of RWP mobility model in which motion time is a bounded random variable and is independent of the trajectory length. This model is referred to as time-based RWP later on.

A. *Time-based RWP definition*

In this model there are N points distributed in the region which move and pause independently. After every motion step, each node goes to paused state for t_p time units then chooses a new random destination point and repeats as above. Motion time is a random variable bounded in [T_{min}, T_{max}], with a well-defined expected value E[T_m]. It is important to assume that the start time of each node motion is independent of the other ones. In other words, considering the motion time as a random process, sample paths must be mutually independent. In case of fixed T_m as motion time, an iid initial pause time with uniform distribution in [0, T_m] may be considered to achieve motion start time independence. Since each node moves and pauses independently of the others, it is sufficient to investigate motion of a single node to achieve asymptotical distributions.

B. *Average nodal velocity*

As mentioned before, TBRWP solves the problems of steady state average nodal velocity. Considering equation (1) and independency of V_0 and l, average nodal velocity is obtained through:

$$E[V] = E[V_0 l] = E[V_0]E[l] \qquad (3)$$

This means that average nodal velocity depends only on the average base velocity V_0 and average trajectory length. In other words, as mentioned before, in traditional RWP the average nodal velocity is dependent on the exact distribution of motion velocity which needs detailed field-dependent information. But TBRWP needs only the average of base velocity.

III. EXPERIMENTAL RESULTS

To probe the properties of TBRWP, an extensive simulation has been performed by Xmulator [7] (which is designed and extended to support mobility models by the authors). The simulation method to obtain asymptotical PDF is based on dividing the region into small square parts, moving the node according to the model, observing the node position in time slices, and counting the number of times the node is seen in each square part and normalizing the result.

A. *Comparing with traditional RWP*

In comparison with traditional RWP, average velocity of long trajectories is less than average velocity of short trajectories in TBRWP. On the other hand, long trajectories are more probable to cross the region. Therefore, the average nodal velocity in center of the network is higher than the corners and hence, location PDF of nodes in the center of network is lower than the PDF of RWP and reverse at the corners. Figure 4 compares the location PDF of RWP and TBRWP in one-dimensional case. Two-dimensional case is depicted in parts of Figure 6 and 7.

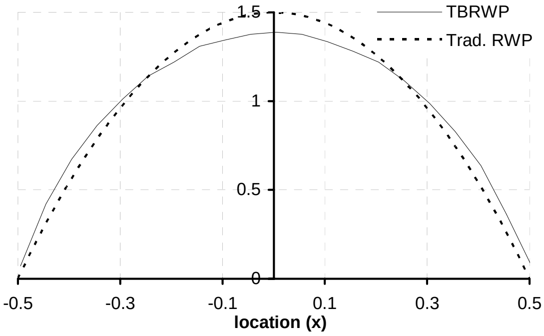

Figure 4 Asymptotical PDF of traditional RWP and TBRWP with uniform waypoint distribution in one-dimensional region.

The decaying problem of average nodal velocity in RWP is eliminated in TBRWP. Figure 5 depicts the average nodal velocity of TBRWP which could be compared with Figure 3. As depicted in the figure, TBRWP has no decaying problem and is not sensitive to the distribution of motion step velocity when expected value is constant.

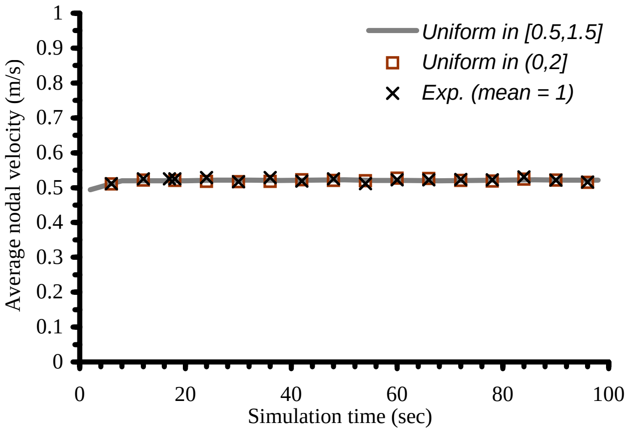

Figure 5 Average nodal velocity of TBRWP with different motion step velocity distribution and equal expected value.

B. *Comparing with multi-level velocity selection*

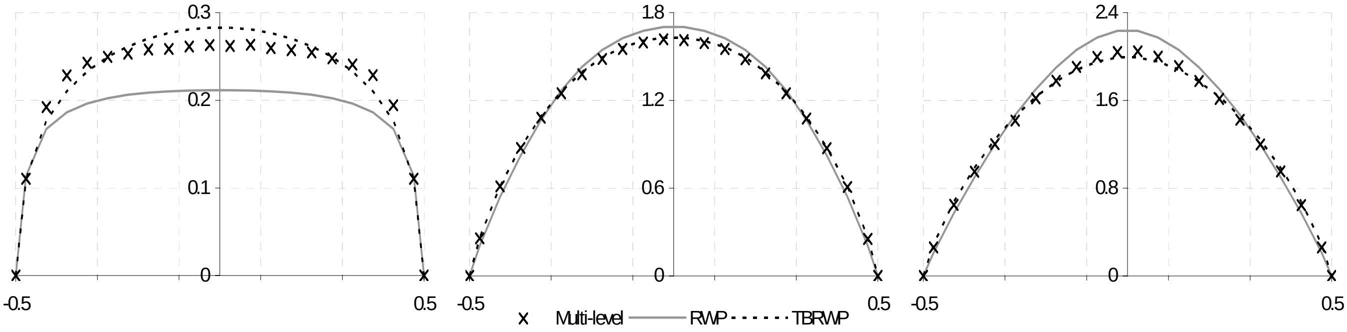

Figure 6 Asymptotical PDF of traditional RWP, TBRWP, and multi-level mobility in a plant with uniform waypoint distribution in two-dimensional region at y=0.475 (left), y=0.225 (middle), and y=0.025 (right).

Two multi-level velocity selection functions are used here to compare with TBRWP. Figure 6 compares the PDF of TBRWP and multi-level velocity RWP with the below function which is a sample velocity function for a plant:

$$V = \begin{cases} 1\ m/s & 0 \le l \le 150\,m \\ 14\,m/s & l > 150\,m \end{cases} \tag{4}$$

Where, V is the velocity of motion step and l is the length of the trajectory. Simulated plant is a 1km × 1km area. The result shows that the resultant PDF of TBRWP is close to one of multi-level velocity RWP. Another simulated velocity function is:

$$V = \begin{cases} 1\ m/s & 0 \le l \le 150\,m \\ 14\,m/s & 150\,m \le l \le 1000\,m \\ 35\,m/s & l > 1000\,m \end{cases} \tag{5}$$

It is a sample velocity function for a square shaped town. Figure 7 depicts the normalized location PDF for various side length of the town. As depicted in the figure, when side is about 2km the PDF is close to the PDF of TBRWP and when the side is increased to 7km the PDF tends to one of RWP. Indeed, when the area becomes larger the effect of velocity selection function is diminished.

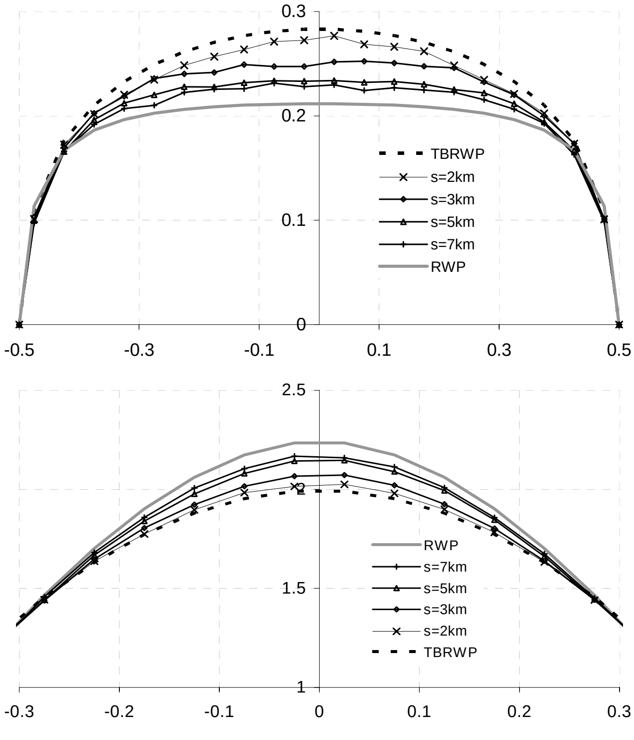

Figure 7 Comparison of normalized PDF of RWP,TBRWP, and multi-level velocity model of a square shaped town. 's' is side of the town. Top is at y=0.475 and bottom is at y=0.025.normalized distances.

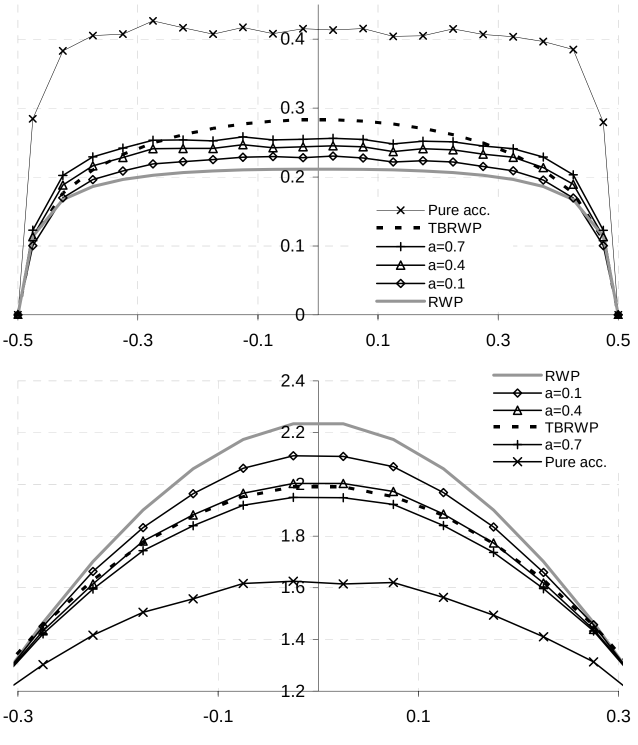

Figure 8 Comparison of normalized PDF of RWP,TBRWP, and accelerated RWP with acceleration 'a'.and initial velocity of 14m/s in a 1000m ×1000m region. Top is at y=0.475 and bottom is at y=0.025 normaized distances.

Another model which is compared to TBRWP is accelerated RWP. Intuitively, when the motion is accelerated, long trajectories have larger average velocity than the shorter ones. In our simulated accelerated RWP model, each mobile node starts its motion with an initial velocity of v_0 and positive acceleration of a. When the node reaches to the half of the trajectory, acceleration value is negated to $-a$. Figure 8 compares the RWP, TBRWP, the pure accelerated RWP ($v_0 = 0$), and accelerated RWP with different vales of a and fixed v_0 at 14m/s in a 1km × 1km region. As depicted in the figure, when there is an initial velocity and no or small acceleration, model tends to traditional RWP and as the acceleration increases the model tends to TBRWP and pass it toward pure accelerated model as acceleration dominates the initial velocity. Hence, TBRWP can approximate accelerated RWP in some range of acceleration value.

IV. CONCLUSIONS

In this paper, RWP model is investigated from viewpoint of velocity selection. It is revealed in previous work that average nodal velocity has a noticeable impact on the performance of ad hoc networks. In RWP average nodal velocity is strongly dependent on the velocity distribution which is hard to obtain exactly for several fields. Another problem of RWP is decaying average nodal velocity, which leads to a longer simulation warm up time. Moreover, RWP velocity selection is not realistic in several scenarios in which objects tend to select their velocities according to the trajectory length. Although RWP has theses problems, its simplicity and availability made it the dominated mobility model in the literature.

In this paper time-based RWP (TBRWP) is introduced as a variation of RWP without making the model complicated. In TBRWP, velocity of each motion step is product of the trajectory length and a base velocity random variable. This base random variable could be considered as inverse of motion time. Average nodal velocity obtained from applying TBRWP is depends only on the expected value of each motion velocity which is a more available parameter than the exact distribution of each motion velocity. Moreover, average nodal velocity of TBRWP has no decaying property of RWP substantially.

Mobility of human beings in a plant or a town is modeled through a variation of RWP with multi-level mobility selection function. As simulations confirmed, PDF of TBRWP can match these models approximately. Accelerated motion with initial velocity is also modeled and simulated. Obtained results show that the PDF of accelerated model in some range of acceleration value could be approximated by TBRWP.

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