

# 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 inaccuracy in evaluations, it has been widely used in the literature for the sake of its intrinsic simplicity. Here, we tried to improve the RWP in velocity selection aspect without losing simplicity. Traditional RWP assumes a bounded random velocity value independent of the length of the movement trajectory which may lead to inaccurate evaluations. To relax this assumption, some approaches are proposed and the time-based RWP model is introduced. This model eliminates the "instantaneous average of velocity" problem of RWP. Simulation experiments show that the time-based RWP can approximate RWP with accelerated motions in some extent. Moreover, it can approximate multi-level velocity selection paradigm which is used as a model for mobility and is more appropriate and realistic in most environments with physical constraints.

**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. Thus, performance analysis of such systems in the presence of different factors is an important issue. One of the factors that has a great impact on the design and analysis of such networks is the *mobility* [1][2][3]. Many different models have been proposed by researchers including *random waypoint* (RWP) model [4], *random direction model* [5], *Brownian motion* [6], and *map based mobility* [9][7][8]. Based on these models many different studies on different aspects of wireless networks have been conducted by researchers [10][11].

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

again with a new velocity. This pattern is repeated by all mobile nodes.

Traditional RWP considers some assumptions which are not realistic in many 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 independent of the length of the selected trajectory.

To relax the first assumption, some models have been proposed in the literature [12],[13]. In this paper, we try to relax the third assumption while partially eliminating the problem with the second assumption. Indeed, the third assumption is unrealistic in several cases. For example, it is rare that an object passes a 2 meter path with a velocity of 50 km/h and traverses a 20 km trajectory at a speed of 2 km/h.

Our results show that this assumption has a noticeable impact on the resultant location probability density function (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 of the network [14][15][16][17]. In the real world ruled by physical constraints, objects often choose their speed with respect to the length of the current trajectory. For example, human beings decide how to travel (by foot, by bicycle, by car, or by airplane) based on their journey length. In [18] urban, suburban, and rural regions are modeled. Obtained results confirm that considering traditional distributions used in the literature (like uniform distribution) with RWP model is not a proper assumption.

Another problem that arises by this assumption is "instantaneous average of velocity" (or "average node velocity") problem which is not a desirable property for the RWP, when used as a model for performance evaluation of ad hoc networks [19][20][21]. Before explanation of this problem, two definitions are clarified: the velocity value selected by each node for its current travel is referred to as

"motion step velocity" while the sample mean of velocity values (sampled instantaneously from all the nodes in the network) is referred to as "average node velocity" (also called steady-state velocity in the literature). In RWP, motion steps with lower speeds endure more in the network. Hence, the average node velocity is lower than the expected value of motion step velocity. The major problem addressed in [19],[20], and [21] is that instantaneous average of velocity decays over time which results in a longer simulation warm up time. In [20], authors addressed this problem for different mobility models and suggested applying steady-state average velocity as the initial velocity to diminish this decaying property. The authors considered velocity-time and velocity-distance independence to analyze the decaying property of the average velocity. In [21], two similar modifications are proposed and studied.

In the above-mentioned studies, no solution is provided for the steady state version of the problem. Indeed, average node velocity has a noticeable impact on the performance of ad hoc network protocols [22]. However, this important parameter is dependent to the velocity distribution of each motion step in the steady state, e.g. applying velocity ranges (0,20) and [1,19] with uniform distribution to RWP model, makes a noticeable difference in the average node velocity (Figure 1) and consequently on the simulated performance results, in spite of equal expected values (Figure 2). Our simulation results also confirm the effect of distribution of motion step velocity on the average node velocity for exponential and uniform distributions of the motion step velocity with equal expected values (Figure 3). Therefore, average node velocity and consequently evaluated performance measures in traditional RWP are highly sensitive to the changes in distribution of motion step velocity. Hence, detailed information about distribution of motion step velocity 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 environments, which is therefore a drawback for a simulation model. In this paper, we propose a model that addresses both "average node velocity" problems.

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

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

## II. IMPROVING VELOCITY SELECTION IN RWP

As described above, independence of the velocity value and the trajectory length is an inappropriate assumption in the RWP model. In order to be able to pick velocity values closer to those observed in realistic situations, one may use the empirical

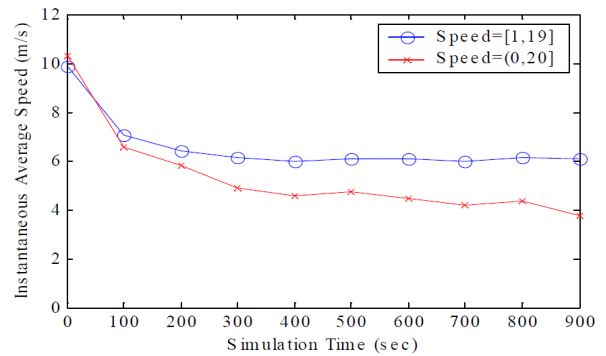


Figure 3. Decaying average node velocity in RWP and the effect of distribution of motion step velocity [19].

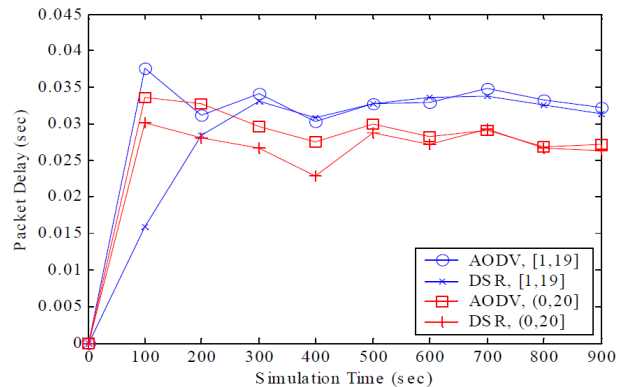


Figure 3. The effect of distribution of motion step velocity on an evaluated performance metric of the ad hoc network through simulation [19].

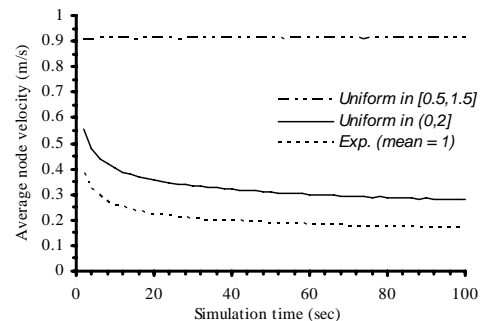


Figure 3. The effect of distribution of motion step velocity on the average node velocity in transient and steady state in RWP (simulated with 100000 nodes)

PDF of motion step velocity conditioned on the trajectory length obtained from extensive statistical study (it will be referred to as velocity selection function later on). This method is accurate but such statistical information is not easily available for several fields. Moreover, the obtained model can not be analyzed easily. Another approach that is a special case of the earlier one and needs less information of the field is the use of multi-level (piecewise) density functions. For example, we can model the velocity of human beings' travels in a plant as a density function in which people move by foot at

deterministic speed of 1 m/s when the trajectory length is below 150 meters and move by car at a speed of 14 m/s, otherwise (just as a simple example).

Another approach is considering a *linear relation* between velocity ( $V$ ) and trajectory length ( $l$ ) random variables:

$$V = V_0 \cdot l \quad (1)$$

Random variable  $V_0$  is independent of the trajectory length and is called the *base velocity* later on. The time duration of the motion step is obtained by:

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

Since  $V_0$  is independent of the trajectory length, so is the motion time ( $T_m$ ). If  $V_0$  is in  $[V_{\min}, V_{\max}]$ , then the corresponding motion time will be in  $[1/V_{\max}, 1/V_{\min}]$ . Hence, this model can be defined in an equivalent manner as 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 (TBRWP) later on.

#### A. Time-based RWP model

In this model, there are  $N$  points distributed in a bounded region that move and pause independently. After every motion step, each node goes to a pause state for  $t_p$  time units, and then chooses a new random destination point and repeats this movement pattern. 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 motion time,  $T_m$ , 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, it is sufficient to investigate motion of a single node to achieve asymptotical location distribution.

#### B. Average node velocity

As mentioned before, the TBRWP model eliminates the problems of steady state average node velocity. Considering the independency of  $T$  and  $l$ , the average node velocity can be obtained as:

$$E[S] = E[l] / E[T] \quad (3)$$

where,  $S$  is the steady state node velocity. This means that the average node velocity depends only on the average motion time and average trajectory length. That is, as stated earlier, in traditional RWP the average node velocity depends on the exact distribution of motion velocity, which needs detailed field-dependent information. But TBRWP needs only the average of the *motion time*.

### III. EXPERIMENTAL RESULTS

To study the properties of TBRWP model, we have conducted extensive simulation experiments by XMulator [23] (which is designed and extended by the authors to support mobility models). The simulation method to obtain asymptotical PDF is based on dividing the region into small square slices (20 slices in each axis), moving the node according to the model, observing the node position in different time instances, and counting the number of times the node is seen in each slice and finally normalizing the result.

#### A. Comparing with the traditional RWP

Long trajectories would cross the central region of the network more probably than the short ones. On the other hand, long trajectories have higher velocity values in TBRWP in comparison with traditional RWP. Thus, the average node velocity in the central region must be higher than that of the traditional RWP. Hence, the location PDF of nodes in the central region is lower than that of RWP; it is however vice versa at the corners. Figure 4 compares the location PDF of the RWP and TBRWP in one-dimensional space. The two-dimensional case is depicted in parts of Figure 6 and Figure 7.

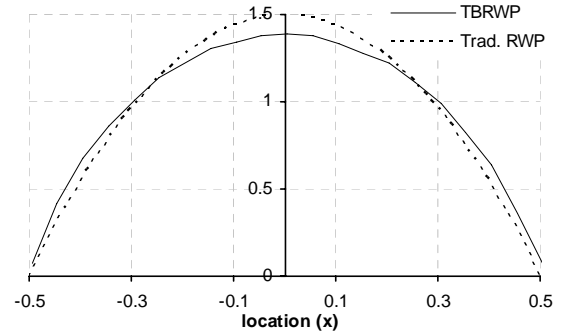


Figure 4. Asymptotical PDF of traditional RWP and TBRWP with uniform waypoint distribution in one-dimensional region.

#### B. Average node velocity problem

The decaying problem of average node velocity in RWP is eliminated in TBRWP. Comparing Figure 5 and Figure 3 makes it clear that TBRWP has no decaying problem and is not sensitive to the distribution of motion step velocity when expected value of motion step velocity is constant.

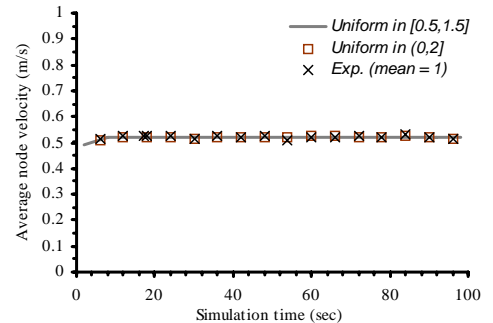


Figure 5. Average node velocity of TBRWP with different distributions of motion step time and equal expected value.

### C. Comparing with multi-level velocity selection model

Two multi-level velocity selection functions are compared with TBRWP. Figure 6 compares the PDF of TBRWP and multi-level velocity RWP using the simple velocity selection function as

$$V = \begin{cases} 1 \text{ m/s} & 0 \leq l \leq 150 \text{ m} \\ 14 \text{ m/s} & l > 150 \text{ m} \end{cases} \quad (4)$$

where,  $V$  is motion step velocity and  $l$  is the length of the trajectory. Simulated plant is a  $1 \text{ km} \times 1 \text{ km}$  area. The result shows that the location PDF for the TBRWP and multi-level velocity RWP are close together. Another simulated velocity function is

$$V = \begin{cases} 1 \text{ m/s} & 0 \leq l \leq 150 \text{ m} \\ 14 \text{ m/s} & 150 \text{ m} \leq l \leq 1000 \text{ m} \\ 35 \text{ m/s} & l > 1000 \text{ m} \end{cases} \quad (5)$$

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 in length, the resultant PDF is close to the one for TBRWP and when it is increased to 7km the PDF tends to one of the RWP case. That is, when the area becomes larger the effect of this velocity selection function is less noticeable.

Another model that is compared with TBRWP is the *accelerated RWP*. Intuitively, when the motion is accelerated, long trajectories have larger average velocity than the shorter ones. In the accelerated RWP model simulated here, 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 point of the trajectory, acceleration value is negated to  $-a$ . Figure 8 compares the RWP, TBRWP, the pure accelerated RWP ( $v_0=0$ ), and above-mentioned accelerated RWP with different values of  $a$  and fixed  $v_0$  at 14m/s in a  $1 \text{ km} \times 1 \text{ km}$  field. As shown in the figure, when there is an initial velocity and no acceleration (or small acceleration), model tends to the traditional RWP and as the acceleration increases the model tends to the TBRWP and pass it toward the pure accelerated model. Hence, the TBRWP can approximate the accelerated

RWP for some acceleration range.

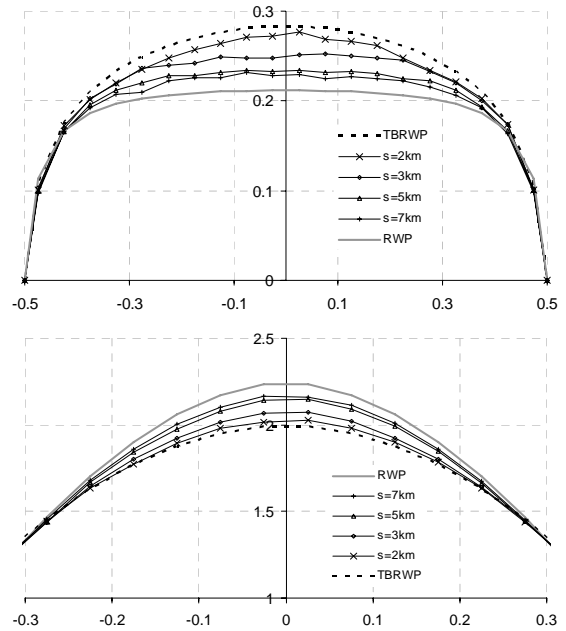


Figure 7. Comparison of normalized PDF of RWP, TBRWP, and multi-level velocity model of a square shaped town. 's' is side length of the town. Top figure is a cut at  $y=0.475$  and bottom one is a cut at  $y=0.025$  normalized distances. (bottom figure is truncated into range  $[-0.3, 0.3]$ )

## IV. CONCLUSIONS

In this paper, the RWP model is investigated from the velocity selection viewpoint. It is revealed in previous studies that the average node velocity has a noticeable impact on the evaluated performance of mobile networks. In RWP model, this important parameter is very sensitive to the distribution of motion step velocity, which is hard to obtain for several fields in real environments. Another problem of RWP is the decaying average node velocity, which leads to a longer simulation warm up time. Moreover, velocity selection in RWP is not realistic in several scenarios in which objects usually tend to select their velocities according to the trajectory length. Despite such problems, simplicity and availability of RWP has made it as a popular mobility model used widely in the literature.

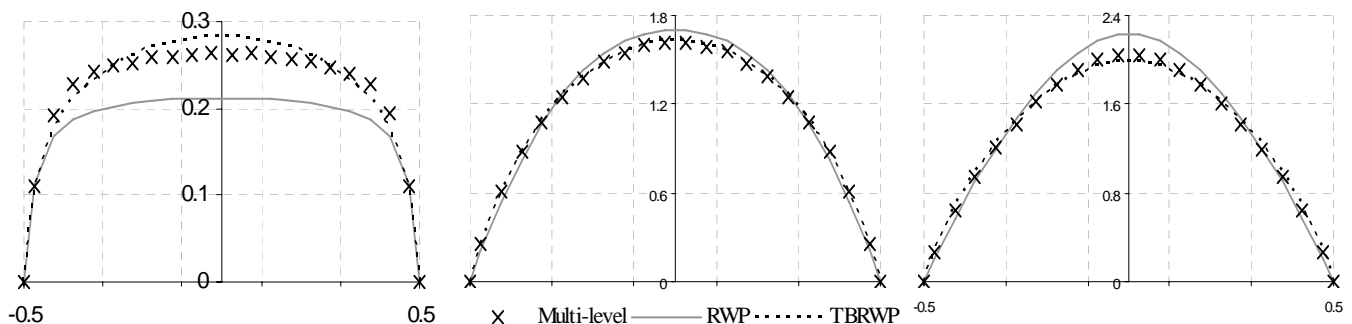


Figure 6. Asymptotical PDF of traditional RWP, TBRWP, and multi-level velocity selection model in a plant with uniform waypoint distribution in two-dimensional region viewed at  $y=0.475$  (left),  $y=0.225$  (middle), and  $y=0.025$  (right).

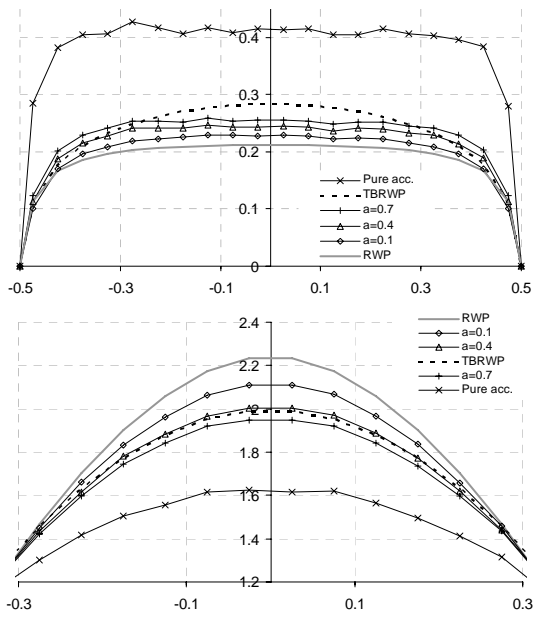


Figure 8. Comparison of normalized PDF of RWP, TBRWP, and accelerated RWP with acceleration 'a' in  $m/s^2$  and initial velocity of  $14m/s$  in a  $1km \times 1km$  region. Top figure is a cut at  $y=0.475$  and bottom one is a cut at  $y=0.025$  normalized distances.

In this paper, the time-based RWP (TBRWP) is introduced as a variation of RWP without making the model complicated. In TBRWP, velocity of each motion step is determined by multiplying the trajectory length and a base velocity random variable. This base random variable could be considered as the inverse of motion step time. Average node velocity of TBRWP model is dependent only to the expected value of motion step time which is easier to obtain than the exact distribution of motion step velocity. Moreover, the average node velocity of TBRWP has diminished the 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 velocity selection function. As simulation experiments confirmed, the PDF of TBRWP can approximately match these models. Accelerated motion with initial velocity is also modeled and simulated. Obtained results show that the PDF of accelerated model (for some typical values of acceleration) can be approximated by TBRWP.

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