This paper is organised as follows. Section 2 reviews the main properties of the Random Waypoint Model. In section 3 we propose a framework to study the simulation times that are needed when this model is employed. Section 4 comments the results that have been obtained with the simulation of different mobility scenarios. Finally Section 5 summarizes the main conclusions of the paper.

2. THE RANDOM WAYPOINT MOBILITY MODEL

According to the Random Waypoint (RWP) mobility model, the nodes of an ad hoc network move along a straight line from two destination points (waypoints) situated in a limited space. In the literature this space is normally bi-dimensional and restricted to a rectangular area of dimensions x_{max} and y_{max}. Once a node reaches a destination point, a new one is uniformly selected from this region. The speed for a movement is also chosen from a uniform distribution in the interval $[v_{min}, v_{max}]$. Both speeds and waypoints are generated with independently of all previous destinations and speeds. In addition, the model allows nodes to pause between two consecutive trips for a certain period of time. This period (Pause Time) is habitually fixed to a constant value (T_{pause}).

As a process to characterise the mobility of an actual MANET, the RWP model presents many limitations that derive from its own simplicity. To overcome these drawbacks a set of new mobility models has appeared in the literature (see, for example, [3]). These models refine the mobility patterns by incorporating individual or group correlations or considering the effects of the existence of obstacles. These improvements are achieved at the cost of a remarkable increase in the complexity and the number of parameters of the models. Oppositely, RWP model offers a high parsimony, that is to say, a low need of parametrisation. This simplicity has facilitated the possibilities of being analytically studied, which is not always feasible with other models. Furthermore, as long as it is not focused on any particular application, its high degree of abstraction converts RWP in an adequate process to evaluate new proposals on ad hoc protocols in a generic way. These advantages, together with its ease of software implementation and the fact that it has been incorporated to popular network simulation environments (especially NS-2), have made RWP a widely utilised model in the literature on ad hoc networks.

3. A FRAMEWORK TO STUDY THE SIMULATION TIME

3.1 Time between movements.

Considerable research efforts have been devoted in recent years to study the statistical properties of RWP. These papers have analytically demonstrated that the simulations with RWP can experience stability problems if the model parameters are not adequately elected. These problems have been associated to the long transient that can be required to stabilise the measurements of mobility metrics such as the speed [5] [7] [9] or the node position [1] [4] [8]. The main repercussion of these transients is that the measurements of the network performance may present an intolerable bias and be very dependent on the simulation time. In spite of the aforementioned studies, neither analytical nor empirical rule has been formulated to define the recommendable timing to simulate a particular mobility scenario. In fact the literature on ad hoc networks does not follow any specific procedure to select the simulation time for the experiments and the existence of these transients is neglected or just heuristically reduced by discarding an initial sequence of observations. Moreover, due to the high computational costs of simulating ad hoc networks on a per-packet basis, simulated times in the literature are normally very short (in the range from 100 to 2000 s). Thus the actual problem of bias is aggravated. Similarly, the simulation time (here T_{sim}) is normally defined with independence of the mobility conditions of the nodes. So, different mobility scenarios

topology of the network. Most works in the bibliography change the mobility conditions in the simulation of an ad hoc network by assigning different values to the pause time (T_{pause}) and the maximum admitted speed v_{max} of the RWP process which governs the node movements. So, the usual way to analyse the impact of the mobility is to directly plot the estimation of the parameters which describe the network performance (packet losses, delay, throughput, routing overhead, etc) versus the speed or the pause times of the nodes. However, neither the pause times nor the node speed by themselves can properly describe the impact of mobility on the link connectivity of an ad hoc network. Actually, the link connectivity depends not only on the interaction of these two factors but also on other parameters which are external to the mobility model such as the transmission range or the dimensions of the simulation area. So, two simulations that set the same values for the speed and the pauses but consider different transmission ranges can strongly diverge in their estimations of network performance.

Boleng et al. compare in [2] the ability of different metrics to represent the effects of mobility on the communication potential of an ad hoc network. The study concludes that the best way to characterise the mobility is by means of the estimated link duration. This parameter is a good indicator of the changes in the network topology induced by the movements of the nodes. It does not depend on the utilised routing protocol and its significance does not rely on the employed mobility model. Additionally, in a real scenario, it can be easily computed by the nodes in a distributed way.

The problem with using the link duration as a mobility metric is that its estimation can be clearly affected by short simulations. In the following section, we try to evaluate which is the minimum value of the simulation time T_{sim} (in terms of T_{mov}) to achieve a stable estimation of the statistics of the link duration. We also compare the effects of this transient with those provoked by an uniformly distributed initialisation of the node speeds and positions.

4 SIMULATIONS AND RESULTS

At the present, no analytical model has related the statistical properties of the link duration with the parameters of the RWP model, the network dimensions and the transmission range. So the only way to study this metric is by means of Monte Carlo runs.

To analyse the influence of the simulation time on the bias of the measurement of the link duration, we performed a wide set of simulations using ns-2 and Matlab. Table 1 defines the parameters of the employed scenarios for the experiments. All the values of the simulation variables were selected from the typical ranges that are employed in the literature. Depending on the constant speed that is defined for the nodes, these experiments represent three generic application scenarios for an ad hoc network with mobile nodes:

- Scenario of low mobility: speeds of 1 m/s (typical velocity of a walking person)
- Scenario with a mean/high mobility: speeds of 5 m/s (representing the case of a person running or in a motorless vehicle).
- Scenario with a very high mobility: speeds of 20 m/s (which could be assimilated to scenarios in which the mobility is determined by motored vehicles).

As a first attempt to evaluate the importance of the simulation time, we compared the three previous scenarios with three different pause times (0, 25 and 50 s). For this initial experiment we utilised in all cases the same absolute values of T_{sim}, ranging from 50 to 4000 simulated seconds. This range is very representative of the typical simulation times that are employed by most studies in the literature on ad hoc networks. Figures 1, 2 and 3 show (for v_{min}=1 m/s, 5 m/s and 20 m/s respectively) the estimations of the mean and the median of the link durations for different pause times. In all simulations a link duration is considered as the uninterrupted time that two nodes stay within the transmission range of one another. In order

logarithmic scale. The figure also compares the fitting of several standard distributions, illustrating that distribution tail can be properly approximated by a Weibull distribution (other statistical tests, such as Kolmogorov-Smirnov or Chi2 were utilised with similar results).

Weibull probability density function (pdf) follows the expression:

$$f_W(x) = \frac{b}{a^b} \cdot \exp\left[(-\frac{x}{a})^b\right] \cdot x^{b-1} \quad if \quad 0 \le x \le \infty \tag{8}$$

where a and b are defined as the scale and shape parameters, respectively.

In the analysis of the figure, both parameters were designed to adjust both the estimated mean and the decay rate of the CDF of the link duration. From the curves we observe that a distribution with the same shape parameter (b=0.8938) properly matches the decay of the actual CDFs independently of the speed. The Weibull approximation can be utilised as an analytical tool to evaluate the probability than the duration link exceeds the simulation time. If this probability is too high the elected value for T_{sim} should be revised.

Table 2 shows the ability of the Weibull approximation as a estimator of this probability. The results prove that simulations of even 2000 s are clearly insufficient to obtain a reasonable estimation of the mean link duration as long as more than 2% of the samples would be expected to exceed the simulation time itself.

Table 2. Probability of having a link duration higher than T

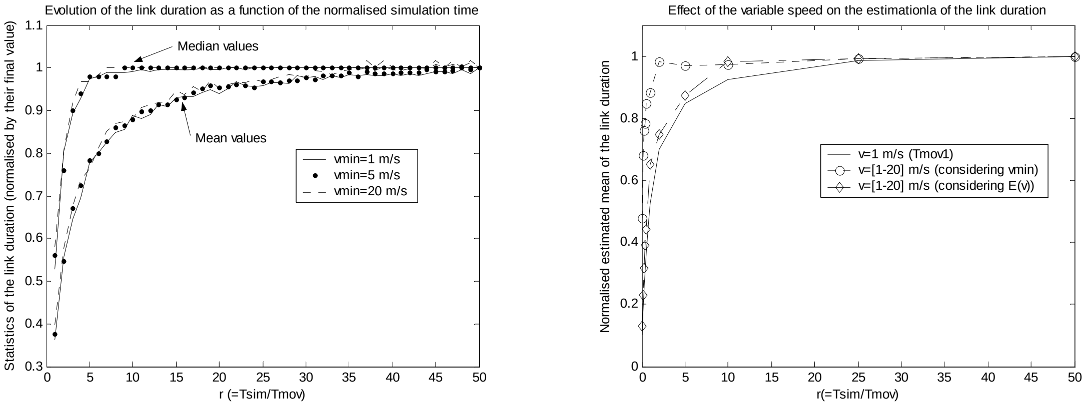
Estimated from actual traces (v_{min}=1 m/s, T_{pause}=0 s)			Estimated with Weibull fit (a=0.0046,b=0.8938)		
T=1000 s	T=1500 s	T=2000 s	T=1000 s	T=1500 s	T=2000 s
0.1076	0.0500	0.0245	0.1283	0.0523	0.02204

On the other hand, a value of the Weibull shape parameter under the unity indicates a slower tail decay than that of the exponential fit and, consequently, a higher variability in the link duration than that expected for the exponential model. Authors in [6] propose to model the link states by means of a two state On Off process (depending whether the nodes are within the transmission range or not). The markovian approximation of this model implicitly assumes than sojourn times in each state (including the link duration as the time of permanence in the On state) are exponential. Experimental results show that the exponential fit can be too optimistic for the case without pauses. However, as the pause probability increases, the relative variability of the link duration decreases, since the link duration tends to the constant value of T_{pause} when P_p tends to the unity. In this case Weibull approximation (with values of b over the unity) was also found to characterise the CDF tail of the estimated distribution properly.

These results illustrate that mean speed (here v_{min}) and pause times impose the time range for the dynamics of the simulations. Thus, it is clearly inadequate to establish the value of T_{sim} without taking into consideration the values of v_{min} and T_{pause}.

Figure 5(a) depicts again the estimated mean and median of the link duration for the three scenarios without pauses (T_{pause}=0). In this experiment the simulation times differ for each scenario as they were made proportional to the particular value of T_{mov}. So, the figure plots the evolution of the statistics against a proportion parameter (r), defined as the ratio between the employed value of T_{sim} and the calculated T_{mov} of the scenario.

The curves, which are normalised by their ‘stationary’ values (those estimated with a simulation of 1000 T_{mov}) do not show any significant difference between the three scenarios. As a consequence, we can conclude that if T_{sim} is established as a function of T_{mov} (by fixing a common value of the parameter r for all the simulations) the bias of the measurements will be independent of the node mobility. The results also show that, with independence of the node speed, the estimated medians of the link duration stabilise after a period of $5 \cdot T_{mov}$ (r=5).



a) Constant speed

b) Comparison with variable speed

Figure 5. Evolution of the statistics of the link duration as a function of the normalised simulation time

4.1. Effects of the transients provoked by initial uniform distributions

As it has been already remarked, numerous studies on the literature [1] [4] [7] [8] have proved that both the stationary distribution for node positions and speeds in the RWP model do not follow the uniform distributions that are utilised to generate destination points and the speeds. So, if the initial values for these variables are also generated from an uniform distribution, a transient period will be required to reach a stationary behaviour of the speed and the distribution of nodes in the simulation area.

To provoke a stationary uniform distribution of the nodes within the area, authors in [1] propose to modify the RWP model, by selecting the destination points of the trajectories only from the perimeter of the area. In [4] this variation, which is named RWPB (*Random Waypoint on the Border*) is also analytically studied.

A possible solution which does not alter the original RWP model is examined in [7]. This study suggests selecting the initial values of the speeds and the x and y coordinates of the nodes from their stationary distributions. The study shows with different simulations that with this procedure the need for a transient to stabilise these parameters is almost eliminated. This strategy has been followed in the experiments of the previous section. However, as literature usually does not take into account these transients, we can investigate which is its importance when compared with the times that are demanded for a stable estimation of the statistics of the link duration. Aiming at this comparison, we repeated the experiments using uniform distributions for the random variables of the RWP model.

In the cases of constant velocity the only possible problem is derived from the distribution of the location of the nodes. For both initial distributions the obtained results show no difference in the estimation of the mean link duration. In fact, this distribution just affects the network connectivity during a short period of time. Figure 7 depicts the evolution of the mean number of active links as the simulation time increases.

The displacements tend to concentrate the nodes on the central zone of the simulation area. As a consequence, the uniform distribution causes a higher dispersion of the nodes within the simulation area. So, in that case the initial number of the active links is considerably lower than that obtained if a stationary distribution is employed for the initial node location. However, the figure illustrates that the instabilities in the measurements disappear for values of T_{sim} generated with a ratio r higher than 1. This implies than this transient effect is negligible in comparison with the simulation time that is needed to achieve a stable estimation of the mean link duration.

duration to characterise the effects of node mobility on the network performance. The paper has investigated the importance of the simulation time to achieve a stable estimation of the statistics of the link duration. We concluded that this parameter should not be set up with independence of the node mobility as it is commonly performed in the literature. We propose that the simulation time (T_{sim}) must be defined in proportion to the mean expected value (T_{mov}) of the times between two consecutive movements of a node.

Basing on a wide set of simulations, the minimum recommendable values for the ratio $r=T_{sim}/T_{mov}$ were found to be 5 or 50 depending if the utilised statistic to describe the mobility is the estimated median or the mean of the link durations. This minimum just considers the stability of the link duration. In any case, the traffic pattern (not considered here) could impose a longer “warm-up” period. Our analysis also showed that, using these minimum simulation times, the employed distribution for the initial node location is irrelevant. Similarly, if a reasonable value for the minimum velocity (v_{min}) is established, the problem of the convergence of the node speed can also be ignored. In this sense we propose a value for v_{min} of about 1 m/s, which is representative of those scenarios in which the mobility is determined by humans walking.

Our simulations were focused on the behaviour of Random Waypoint model. However, we think that these results could be extended to other models using arbitrary distributions for the election of the node speeds and the destination points.

Acknowledgements

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