Designs and Evaluations of a Novel Mobility Model in Mobile Ad Hoc Networks

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ABSTRACT

The performances of most wireless protocols and algorithms proposed in Mobile Ad Hoc Networks (MANET) are often evaluated and compared by using simulations. We can change various simulation parameters to verify different networking scenarios. The impacts of various simulation parameters, such as transmission ranges, data rates, are noticeable. However, the effects of the mobility model do not attract many attentions until recently. The Random Waypoint (RWP) mobility model, due to its simplicity, is one of the most often deployed mobility models in simulations. However, it implicitly introduces many unexpected defects, such as average speed decaying and border effect. In this paper, we propose a novel mobility model, General Ripple Mobility Model (GRMM), to reduce the above mentioned problems in RWP. Furthermore, GRMM can provide another great feature, Diverse Average Speed (DAS), to generate different average speed mobility patterns easily within the same speed range. By providing DAS, simulations can be run with more general cases. We also provide the solution of warm-up time elimination for GRMM. Simulation results have shown that GRMM can generate steady results in the beginning and simultaneously achieve uniform node distribution and diverse average speed.

1: INTRODUCTIONS

Creating a sound simulation environment is an important procedure for researches in Mobile Ad Hoc Networks (MANET). It is difficult and time-consuming to construct a real MANET environment for evaluating proposed protocols. Given different simulation parameters, we can evaluate and compare the performance of different proposed protocols.

There are many simulation parameters that play crucial roles for simulation results. Among them, the mobility model plays an important role in MANET simulation [1]. Different mobility models generate different node movements and mobility patterns, which can form diverse topology. Random Waypoint (RWP) [2] is the most often deployed mobility model in many researches. RWP is well-known for its simplicity and easy implementation. Over the past few years, the implicit properties of RWP are inspected in several reports. In summary, there are two major problems of RWP: decaying average speed and border effects. In RWP, there will be an uncertain warm-up time to reach the steady undesired low average speed. If without the acknowledgement of the defects, the simulation results will be biased and will not show the correct information.

Some mobility models are proposed for certain specified situations. Since the targeted scenario is clear, we can design the mobility models fitting to the requirement. However, if the proposed protocols are not designed for any special environment, a general mobility model for evaluation is thus necessary. Besides uniform node distribution, achieving different average speed under the same speed range is one of the properties which are neglected in most mobility models. The concept of Diverse Average Speed (DAS) for the same speed range is not available in most proposed mobility models. Instead, they assign different speed range to obtain different average speed.

In this paper, we propose a mobility model, General Ripple Mobility Model (GRMM), which is the extended version of our previous work [14]. It maintains the simple structure as RWP, provides solutions for the problems incurred in RWP, and generates the property of Diverse Average Speed. In the following section, we review the related works of mobility models. The GRMM is described in details in the third section. Finally, we present the simulation results and conclusions.

2: RELATED WORKS

RWP is widely used for many MANET simulations. The workflow of RWP is briefly described here: Given V_{min}, V_{max}, X_{min}, X_{max}, Y_{min}, and Y_{max}, the node randomly picks up a moving speed V within $[V_{min}, V_{max}]$ and a destination coordinate (X,Y) within the moving area, $X_{min} \leq X \leq X_{max}$ and $Y_{min} \leq Y \leq Y_{max}$. The node then moves with the selected speed V constantly until it reaches the selected destination coordinate (X,Y). After arriving the destination (X, Y), the node selects another speed and a new destination coordinate again then the procedures repeat.

Although RWP is deployed in many research papers, the implicit characteristics of RWP are disclosed in recent years. One of them is the spatial distribution [3-8]. Because the destinations are picked randomly in the

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moving area, we may expect that the node spatial distribution is also uniformly distributed at any time we observe. However, the node spatial distribution is found to exhibit the border effect instead of uniform distribution [6]. Nodes have higher probabilities to be located near the center area other than the boundary area. Another implicit property is the average speed decaying to zero [9-12]. Since the speed and the destination are picked independently in RWP, a low speed node may choose a long path and spend lots of time with the low speed. Given the same distance, the travel time will be very different with low and high speed nodes.

Some papers provide the solutions for the decaying average speed problems. In [10], the authors simply assign the minimum speed larger than 0 to overcome the decaying problem easily. [11] shows more details and [12] achieves steady state in the initial condition. [13] targets to modify RWP to eliminate the speed decaying.

3: GENERAL RIPPLE MOBILITY MODEL

General Ripple Mobility Model (GRMM) is the superset of the previous proposed Ripple Mobility Model [14]. GRMM can be also regarded as a mobility model based on Random Waypoint (RWP). One of the problems in RWP is the border effect, which is caused by the way how the destination is chosen in RWP. Another well-known mobility model, Random Direction [15,16], does not exhibit such effects. The destination in Random Direction is treated fairly among all directions while the one in RWP is not. In GRMM, the destination is not picked up in the moving area but within a disk whose radius is r. The selected destination may be out of the moving area and if it is, the node will bounce off when it reaches the boundary.

Table 1. GRMM Parameters

R_{min}	Minimum Radius of a Node
R_{max}	Maximum Radius of a Node
V_{min}	Minimum Speed of a Node
V_{max}	Maximum Speed of a Node
λ	Scenario Controller

In Table 1, we define the following parameters in GRMM: V_{min}, V_{max}, R_{min}, and R_{max}. In the following, we describe how a node selects a new moving speed ***v*** and a new destination ***r***.

1. The node randomly chooses a speed ***v*** from [V_{min}, V_{max}]

2. The value of ***r*** is generated by (and set equal to the value of) $R(v, \lambda, V_{min}, V_{max})$, where $R_{min} \leq R(v, \lambda, V_{min}, V_{max}) \leq R_{max}$.

3. The node randomly picks up a destination within the disk of radius ***r*** with its own position as the disk center.

4. The node moves toward the destination, and if it reaches the wall or boundary, it will bounce off and maintain the same speed. Bouncing action is set according to the rule that incidence angle is equal to the reflection angle.

It is noted that $R(v, \lambda, V_{min}, V_{max})$ is the main idea of Diverse Average Speed (DAS). With its value between [R_{min}, R_{max}], $R(v, \lambda, V_{min}, V_{max})$ is designed as a monotonic increasing function of the picked speed, **v**. The content of the function is shown below:

$$R(v,\lambda,V_{\min},V_{\max}) = R_{\min} + (R_{\max} - R_{\min}) * \frac{g(\lambda,v) - g(\lambda,V_{\min})}{g(\lambda,V_{\max}) - g(\lambda,V_{\min})} \qquad (1)$$

where $g(\lambda,v)$ is a function of v and λ. We take Figure 1 for an example. There are 4 mobile nodes, N_1, N_2, N_3, and N_4, in the moving area. Each node chooses its speed of V_1, V_2, V_3, and V_4, respectively. By replacing v with V_1 to V_4 in (1), we obtain the corresponding R_1 to R_4. Following the procedures, nodes choose destinations within a circle of radius R_1 to R_4.

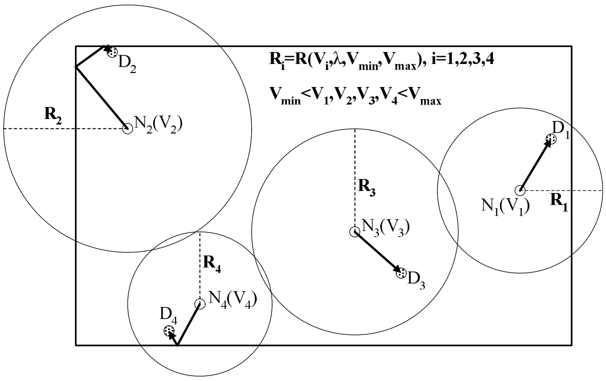

Figure 1. General Ripple Mobility Model

In our previous work [14], we present an instance of the formula (1). [14] sets a threshold $V_{Lower\ Speed}$. To create the mobility model of [14], we can assign $g(\lambda,v) = 0$ if $v \leqq V_{Lower\ Speed}$ and $g(\lambda,v) = 1$ if $v > V_{Lower\ Speed}$. [14] simply separates the distance range into two groups. When $v \leqq V_{Lower\ Speed}$, $R(v, \lambda, V_{min}, V_{max}) = R_{min}$ otherwise $R(v, \lambda, V_{min}, V_{max}) = R_{max}$. In this paper, we redesign $R(v, \lambda, V_{min}, V_{max})$ to extend our works including warm-up time elimination and more diverse average speed.

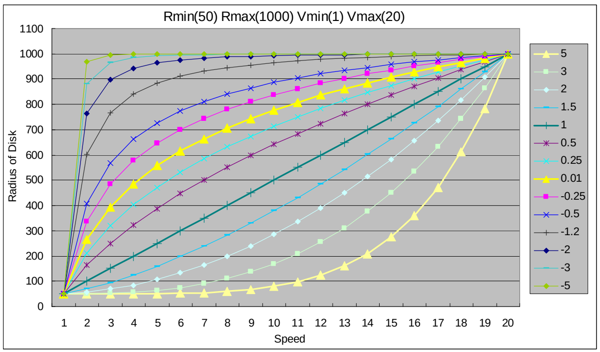

Figure 2. v^λ with different λ

From researches and our previous work, we have observed that the low speed nodes dominate the average speed. Thus if both r and v values in the **(r,v)** pair are small, the average speed may be high. We can also generate mobility patterns with different average speed by assigning the function g(λ,v) with various λ. For example, we may choose g(λ,v) as the power function, g(λ,v)=v^{λ} for effectively limiting the moving distance of lower speed nodes. Figure 2 shows the function *R(v, λ, V_{min}, V_{max})* with different λ, V_{min}=1, V_{max}=20, R_{min}=50, R_{max}=1000 and g(λ,v)=v^{λ}.

Although there are some specific solutions to solve the problem of decaying-to-zero average speed, we choose to keep the simplicity and rapid implementation similar to RWP. To overcome the average speed decaying to zero in RWP, we adopt the proposal of [10] which assigns V_{min} larger than 0.

Mobility models which choose initial speed uniformly are likely to observe long warm-up simulation time to reach steady state of average speed. In steady state, the instantaneous average speed presents the result corresponding to the time ratio of all speeds. We follow the derivation of [11] to formulate the average speed. We derive the expectation of average speed (E[V]) from the expectations of average distance (E[R]) and average travel time (E[S]). We can derive the average speed of GRMM with g(λ,v)=v^{λ} using equation (2).

$$E[V]=\frac{E[R]}{E[S]},\ E[R]=E[E[R\mid V]],\ E[S]=E[E[S\mid V]] \qquad (2)$$

There is another method to simulate with the steady state at the initial simulation. We sample the network in a fixed interval. The average speed can be decided by the ratio of the travel time which the nodes move with. If the travel time of speed *v* is longer, we can expect that the nodes will move with speed *v* when we sample the network. This is also the explanation for decaying average speed in RWP or other mobility models. A slow-moving node with speed close to zero generally travels with longer time duration of same speed than the mobile node with higher moving speed. So we use the travel time expectation of nodes to eliminate the warm-up time.

The travel time in GRMM is decided when the speed and distance parameters are selected. However, since the distance is related to the speed, we may use the conditional expectation to calculate the average travel time, as shown in equation (3). It is notes that $\int_{V_{\min}}^{V_{\max}}\frac{r(v)}{v}dv$ in (3) is calculated in (4).

$$E[S\mid V=v]=E[\frac{R}{V}\mid V=v]=\frac{1}{v}E[R\mid V=v]=\frac{1}{v}\cdot\frac{2}{3}r(v)=\frac{2\cdot r(v)}{3v}$$

$$\begin{aligned}
&E[S]=E[E[S\mid V]]\\
&=\int_{V_{\min}}^{V_{\max}}\frac{2\cdot r(v)}{3v}\cdot(\frac{1}{V_{\max}-V_{\min}})dv \qquad (3)\\
&=\frac{2}{3(V_{\max}-V_{\min})}\cdot\int_{V_{\min}}^{V_{\max}}\frac{r(v)}{v}dv
\end{aligned}$$

where $r(v)=R(r,v,V_{\min},V_{\max})$

$$\begin{aligned}
&\int_{V_{\min}}^{V_{\max}}\frac{r(v)}{v}dv\\
&=\int_{V_{\min}}^{V_{\max}}\frac{R_{\min}+(R_{\max}-R_{\min})\cdot(\frac{v^{\lambda}-V_{\min}^{\lambda}}{V_{\max}^{\lambda}-V_{\min}^{\lambda}})}{v}dv\\
&=[R_{\min}-(\frac{R_{\max}-R_{\min}}{V_{\max}^{\lambda}-V_{\min}^{\lambda}})\cdot V_{\min}^{\lambda}]\cdot\ln\frac{V_{\max}}{V_{\min}} \qquad (4)\\
&+\frac{R_{\max}-R_{\min}}{\lambda}
\end{aligned}$$

After we calculate $\int_{V_{\min}}^{V_{\max}}\frac{r(v)}{v}dv$ and derive formula in (4), we are able to formulate the cumulative distribution function of nodal travel time in (5). We can then generate the initial speed according to the steady state distribution.

$$\because \frac{r(v)}{v}\geq 0\forall v>0$$

$$\therefore 0\leq\frac{\frac{2}{3(V_{\max}-V_{\min})}\cdot\int_{V_{\min}}^{v}\frac{r(v')}{v'}dv'}{\frac{2}{3(V_{\max}-V_{\min})}\cdot\int_{V_{\min}}^{V_{\max}}\frac{r(v'')}{v''}dv''}\leq 1$$

$$\Rightarrow 0\leq\frac{\int_{V_{\min}}^{v}\frac{r(v')}{v'}dv'}{\int_{V_{\min}}^{V_{\max}}\frac{r(v'')}{v''}dv''}\leq 1$$

$$\Rightarrow 0\leq\frac{f(v)-g(v)+h(v)}{f(V_{\max})-g(V_{\max})+h(V_{\max})}\leq 1 \qquad (5)$$

$$f(v)=2\cdot R_{\min}\cdot(\ln\frac{V_{\max}}{V_{\min}})(\ln\frac{v}{V_{\min}})$$

$$g(v)=2\cdot\ln V_{\min}\cdot(R_{\max}-R_{\min})\cdot\ln\frac{v}{V_{\min}}$$

$$h(v)=[(\ln v)^{2}-(\ln V_{\min})^{2}]\cdot(R_{\max}-R_{\min})$$

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$$h(v)=[(\ln v)^{2}-(\ln V_{\min})^{2}]\cdot(R_{\max}-R_{\min})$$

But even if we generate the initial speed with a well-defined function, we are still not able to eliminate warm-up time. The nodes are not located at termination point but in moving state along the path when we observe their speeds. Besides the initial speed distribution, we propose the Random Midpoint method to eliminate warm-up time. The operation of Random Midpoint is: when the destination is picked in the initial state, we randomly choose a point between the starting and ending point as the remaining distance. Using Figure 1 as an example, N_1 chooses the destination D_1 and in initial state, we randomly select a point between N_1 and D_1 as the destination at initial state.

4: SIMULATION RESULTS

We implement GRMM and RWP on OMNeT++ [17]. The simulation scenario is described as follows: There are **N** mobile nodes moving freely in **X*Y** rectangle area (m^2). A node randomly chooses speed within [$\mathbf{V_{min}}$,$\mathbf{V_{max}}$], where [$\mathbf{R_{min}}$,$\mathbf{R_{max}}$] represents the minimum and maximum distance of the destinations. The network is sampled and observed every second.

The evaluation metrics include the following:

Initial Speed Patch: We will show the instantaneous speed with simulation time for two scenarios: initial speed generated uniformly and initial speed patch. We will observe the warm-up time of the simulation.

Average Speed: During the simulation, we sample the instantaneous speeds of N nodes at each second, accumulate them and then take average of the sum to obtain the Average Speed.

Average Number of Active Links: We denote ***D*** as the effective transmission range of nodes. Therefore, if the distance between Node A and Node B is smaller than or equal to D, there exists a link between Node A and Node B. At each sampling time, we check how many links exist then take average of them. If the node distribution is dense, the number of links will be larger. If the network of different average speed maintains a constant value, it indicates that the spatial distribution of network nodes is not affected by the speed.

Average Connection Time: Similar to Average Number of Links, we collect the duration time of links once they exist. If the average duration of links is smaller, we can assume that the network topology changes more frequently.

Spatial Distribution: We partition the rectangle area **X*Y** into the sections of 100m*100m. During sampling, we calculate and accumulate how many nodes are located within each section. The numbers of network nodes within each section are identical in a completely uniform spatial distribution.

Spatial Entropy: Entropy is a measure of the randomness. The number of network nodes within each section is obtained from Spatial Distribution. We divide the number of nodes within each section by the sum of them, we thus can obtain the probability of a node located in each section. We compare the entropy of different scenarios with completely uniform spatial distribution, in which the probabilities of sections are the same.

Table 2. Simulation Parameters

X Coordinate	1000 meters
Y Coordinate	1000 meters
Number of Nodes (N)	50
Simulation Time	120 minutes
V_{min}	1 m/s
V_{max}	20 m/s
R_{min}	50 meters
R_{max}	1000 meters
Effective Range (D)	300 meters

Table 2 describes the parameters in our simulations. There are 50 mobile nodes randomly positioned within 1000mx1000m square area. The simulation time is 120 minutes. The velocity range of mobile nodes is [1,20] and the moving distance range of mobile nodes is [50,1000]. The nodes can communicate with each other if their distance is smaller than or equal to effective range (D) of 300m.

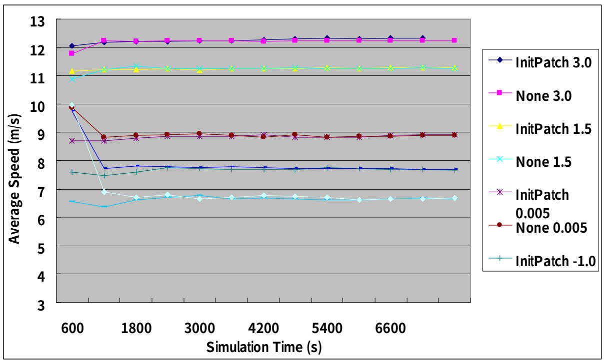

Figure 3. Warm-up Time Elimination

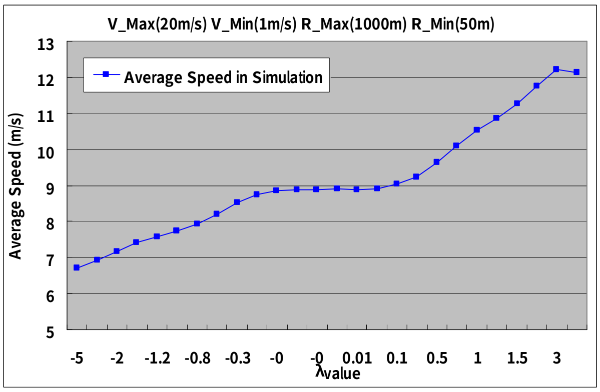

Figure 4. Diverse Average Speed in GRMM

Figure 3 shows the result of warm-up time elimination by cumulative distribution function of travel time in (5). Without implementing our proposed warm-up time solution, there will be about 1000s of warm-up time to obtain steady average speed. If GRMM is patched with initial speed distribution and random midpoint, the warm-up time is effectively diminished. In Figure 4, we show the Diverse Average Speed (DAS) achieved by assigning different λ value in GRMM. The average speeds obtained by selecting different λ spread from 6.38m/s to 12.21m/s. GRMM provides different average speed scenarios within the same speed limitation, [1,20].

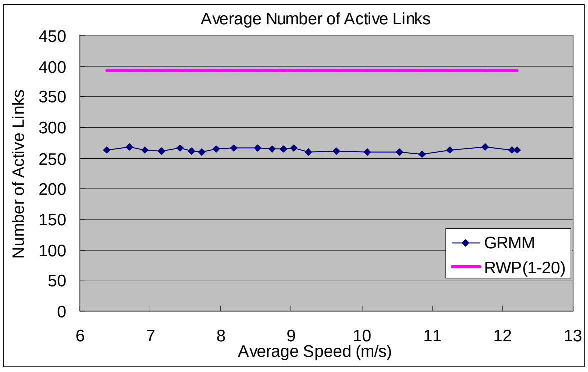

Figure 5. Number of Links in GRMM

Average number of active links is shown in Figure 5. GRMM maintains a stable number of active links. This indicates the node spatial distribution is stable no matter which average speed it achieves. The average number of active links in RWP is also exhibited. Because of border effect, the number of active links in RWP is larger compared to GRMM.

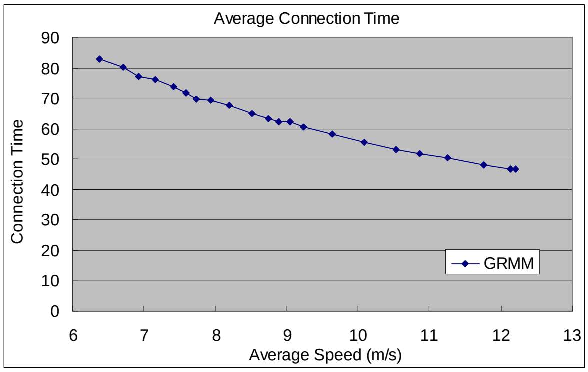

Figure 6. Average Duration of Link in GRMM

Average connection time, shown in Figure 6, can indicate the stability of the links in MANET environment. GRMM generates scenarios with different average speeds and they also present different changing topology. Nodes with lower average speed can maintain longer duration of links with neighboring nodes. When the nodes move with higher average speeds, the network shows instability. Performance of routing protocols can be affected.

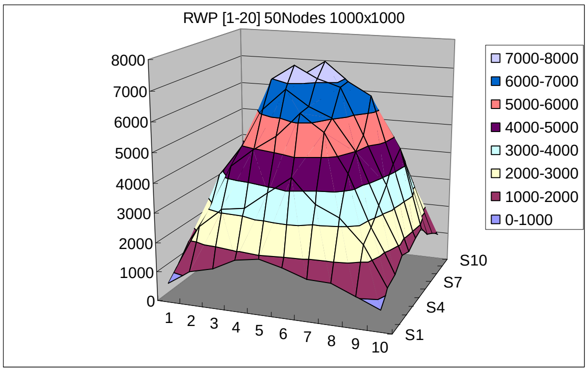

Figure 7. Spatial Distribution of RWP

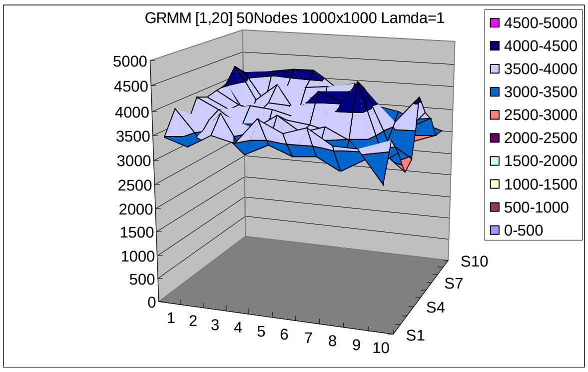

Figure 8. Spatial Distribution of GRMM

Figure 7 and Figure 8 display the histogram of the node spatial distribution of RWP and GRMM, respectively. Figure 7 presents the significant border effect of RWP. The center area in Figure 7 gathers node appearance more than 7000 times and at the same time, there are less than 2000 even 1000 appearance times around the border area. Compared to Figure 7, GRMM in Figure 8 can achieve a more uniform node spatial distribution. The ideal node appearance time of each section is 3600 in our simulations.

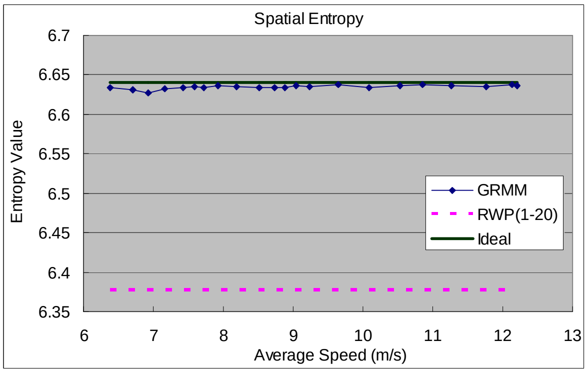

Figure 9. Entropy Value of GRMM, RWP and Ideal

We introduce and explain the idea of the entropy into analysis of node spatial distribution at the beginning of this section. Figure 9 reveals the entropy results of GRMM. The entropy of the most uniform spatial distribution, where the nodal appearance times within each section is identical, is 6.64. The entropy of node spatial distribution generated by GRMM is within the range of 6.62~6.63. The entropy of RWP is shown to be 6.42, which indicates that RWP does not generate a uniform spatial distribution. This result shows that GRMM achieves the uniform node spatial distribution and Diverse Average Speed at the same time.

5: CONCLUSIONS AND FUTURE WORKS

Extended from our previous works [14], we propose the General Ripple Mobility Model (GRMM) in this paper and define a more general R(v, λ, V_{min}, V_{max}) function. GRMM achieves much more uniform node spatial distribution than that by RWP. Furthermore, simulation results reveal that we can achieve both Diverse Average Speed (DAS) and uniform spatial distribution simultaneously. Hence, General Ripple Mobility Model can be used as one of effective mobility models in MANET simulation for performance evaluation. Besides, the initial warm-up time is also eliminated by cumulative distribution function of travel time and random midpoint. From the simulation results, we can find that GRMM not only maintains simplicity and easy implementation but also generates different scenarios which can be used for evaluating various underlying protocols and mechanisms. GRMM is an effective general mobility model and can be deployed with other general mobility models to verify the performance and robustness of protocols and algorithms in Mobile Ad Hoc Networks.

In the future, we will continue on the analytic work on General Ripple Mobility Model and propose revised General Ripple Mobility Model to demonstrate different mobility scenarios or adopt GRMM in the specified MANET environment.

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