# A Novel Semi-Markov Smooth Mobility Model for Mobile Ad Hoc Networks.

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***Abstract*— Existing random mobility models have their limitations such as speed decay and sharp turn which have been demonstrated by the previous studies. More importantly, mobility models need to mimic the movements that abide by the physical law for accurate analysis and simulations of mobile networks. Therefore, in this paper, we propose a novel mobility model, *Semi-Markov Smooth* (SMS) model. Each SMS movement includes three consecutive phases: *Speed Up* phase, *Middle Smooth* phase, and *Slow Down* phase. Thus, the entire motion in the SMS model is smooth and consistent with the moving behaviors in real environment. Through steady state analysis, we demonstrate that SMS model has no average speed decay problem and always maintains a uniform spatial node distribution. The analytical results are validated by extensive simulation experiments. In addition, we compare the simulation results on link lifetime and percentage of node degree with Random Waypoint model, Gauss-Markov model and the proposed SMS model.**

## I. Introduction

The study and performance evaluation on a mobile ad hoc network (MANET) is very sensitive to node mobility. However, the lack of mobility trace files from real-life applications becomes a main hurdle for characterizing realistic mobility patterns. Hence, on the purpose of accurately modeling node mobility, it is necessary to use synthetic mobility models to describe the moving behaviors of mobile nodes, especially for performance evaluation and research study on a large scale network before its commercial deployment. Therefore, mobility modeling plays an important role in many research areas such as routing protocol design, path duration analysis and network mobility management.

However, several comparative studies of mobility models ( [1] and [2]) have shown that all existing mobility models have their limitations in different MANET operation scenarios, such as non-smooth moving behaviors in random mobility models and non-stopping problem in Gauss-Markov model [3]. Hence, how to effectively mimic moving behaviors of ad hoc nodes in a real environment is a challenging issue. Our goal is to design a mobility model which integrates a variety of nice properties of existing mobility models and is flexible to mimic the realistic network scenarios. To achieve our objective, the following requirements must be fulfilled in this new model.

- A mobility model should be a temporal mobility model, in which a node's current moving behavior is dependent on its moving history [1], to avoid the abrupt moving behaviors, such as sudden speed change and sharp turn.
- A mobility model should generate stable nodal movements [4] and maintain a uniform nodal distribution convenient for both theoretical parameter analysis [5], [6], [7] and simulation study [2] in a mobile wireless system.
- A sound mobility model need to mimic the movements that follow the physical law of real-life moving objects for correct analysis and simulations of mobile networks.
- A mobility model should be able to describe microscopic moving behaviors, such as speed acceleration/deceleration and direction change, and can be flexibly controlled for different network scenarios.

Based on these requirements, we propose a new temporal mobility model: *Semi-Markov Smooth* (*SMS*) model, in which microscopic moving behaviors based on the physical law of real-life mobile users are described. Each SMS movement is quantized into $\mathcal{K}$ equidistant time steps, where $\mathcal{K} \in \mathbb{Z}$. The time interval between two consecutive steps within one movement is denoted as $\Delta t$, in the order of seconds. Later in this paper, we will show that the proposed SMS model has a variety of nice properties of existing mobility models, and is flexible to mimic a wide range of network scenarios.

The remainder of the paper is organized as follows: Section II briefly discusses the related work of mobility models. Section III describes the mobility pattern of the proposed SMS model. Section IV proves that SMS model has no average speed decay problem. Section V shows that SMS model maintains uniform node distribution. Section VI validates the theoretical analysis of SMS model by simulation results and further compares the simulation results on link lifetime and percentage of node degree with the RWP, GM, and SMS models. Finally, our conclusions are described in Section VII.

## II. Related Work

Random mobility models includes *Random Waypoint* (*RWP*) model [8], *random direction* (*RD*) model [9], and their variants [1]. Because nodal movements in random mobility models are total randomness, the unrealistic moving behaviors are invoked and could cause invalidate or wrong conclusions on the network evaluations [10]. Moreover, random mobility models are insufficient to mimic the minute moving behaviors of mobile users, such as speed acceleration and direction change within each movement. While temporal mobility models, such as *Smooth Random* (*SR*) model [10] and *Gauss-Markov* (*GM*) model [3], can provide smooth movements by avoiding the abrupt behaviors. In the SR model, a node moves at a constant speed along a specific direction until either a speed or direction change event occurs based on indpendent Poisson process. Hence, the movement duration of SR nodes cannot be controlled. In the GM model, the velocity of a mobile node at any time slot is a function of its previous velocity with a Gaussian random variable. While, GM nodes cannot stop and can hardly travel along a straight line [2].

## III. Semi-Markov Smooth Model

Based on the physical law of a smooth motion, a movement in the SMS model contains three consecutive moving phase: *Speed Up* phase, *Middle Smooth* phase, and *Slow Down* phase, respectively. After each movement, a mobile node may stay for a random pause time.

### A. Speed Up Phase ($\alpha$–Phase)

For every movement, an object needs to accelerate its speed before reaching a stable speed. During time interval $[t_0, t_\alpha] = [t_0, t_0 + \alpha\Delta t]$, an SMS node travels with $\alpha$ time steps. At initial time $t_0$, the node randomly selects a *target speed* $v_\alpha \in [v_{\min}, v_{\max}]$, a *target direction* $\phi_\alpha \in [0, 2\pi]$, and the total number of *time steps* $\alpha \in [\alpha_{min}, \alpha_{\max}]$. These three random variables are independently uniformly distributed. In reality, an object typically accelerates the speed along a straight line. Thus, the direction $\phi_\alpha$ does not change during this phase. To avoid sudden speed change, the node will evenly accelerate its speed along direction $\phi_\alpha$ from starting speed $v(t_0) = 0$, to the target speed $v_\alpha$, which is the ending speed of $\alpha$–phase, i.e., $v(t_\alpha) = v_\alpha$. An example of speed change in $\alpha$–phase is shown in Fig. 1, where the node speed increases evenly step by step and reaches the stable speed $v_\alpha$ of the movement by the end of this speed up ($\alpha$–phase).

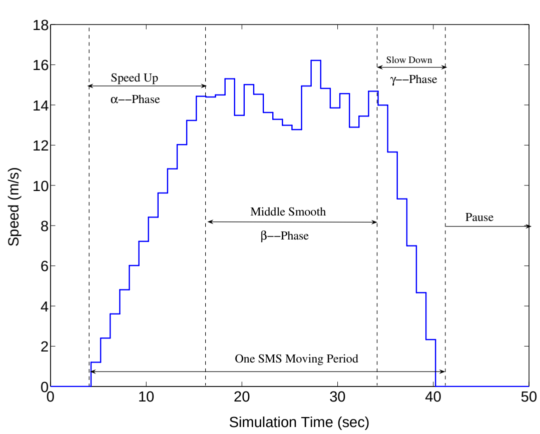



Fig. 1. An example of speed vs. time in one SMS movement.

### B. Middle Smooth Phase ($\beta$–Phase)

In reality, after the speed acceleration, a moving object should have a smooth motion according to its stable velocity. Correspondingly, once the node transits into $\beta$–phase at time $t_\alpha$, it randomly selects $\beta$ time steps to determine the middle smooth ($\beta$–phase) duration interval: $(t_\alpha, t_\beta] = (t_\alpha, t_\alpha + \beta\Delta t]$. Where $\beta$ is uniformly distributed over $[\beta_{min}, \beta_{\max}]$. Within $\beta$–phase, the mobility pattern at each time step is similar to what is defined in Gauss Markov (GM) model [3]. In detail, the initial value of speed $v_0$ and direction $\phi_0$ in $\beta$–phase are $v_\alpha$ and $\phi_\alpha$, respectively. Then, the following speed and direction of an SMS node at each time step fluctuate with respect to $v_\alpha$ and $\phi_\alpha$. Hence, we respectively substitute $v_\alpha$ for $\overline{V}$ and $\phi_\alpha$ for $\overline{\phi}$, where $\overline{V}$ and $\overline{\phi}$ denote the asymptotic mean value of speed and direction, represented in equation (4) in [3]. We assume that the memory level parameter $\zeta \in [0, 1]$, used for adjusting the temporal correlation of node velocity, is constant for both speed and direction at each time step. Hence, by adjusting the parameter $\zeta$, we can easily control the degree of temporal correlation of velocity between two consecutive steps. The standard deviation $\sigma_v$ and $\sigma_\phi$ are set as 1. This implies that the speed or direction difference between two consecutive time steps are less than 1 $m/s$ or 1 rad within $\beta$–phase. Specifically, the speed and direction at the $j^{th}$ time step for an SMS node in $\beta$–phase are:

$$\begin{aligned} v_j &= \zeta v_{j-1} + (1-\zeta)v_\alpha + \sqrt{1-\zeta^2}\widetilde{V}_{j-1} \\ &= \zeta^j v_0 + (1-\zeta^j)v_\alpha + \sqrt{1-\zeta^2}\sum_{m=0}^{j-1}\zeta^{j-m-1}\widetilde{V}_m \\ &= v_\alpha + \sqrt{1-\zeta^2}\sum_{m=0}^{j-1}\zeta^{j-m-1}\widetilde{V}_m, \end{aligned} \quad (1)$$

and

$$\begin{aligned} \phi_j &= \zeta\phi_{j-1} + (1-\zeta)\phi_\alpha + \sqrt{1-\zeta^2}\widetilde{\phi}_{j-1} \\ &= \phi_\alpha + \sqrt{1-\zeta^2}\sum_{m=0}^{j-1}\zeta^{j-m-1}\widetilde{\phi}_m, \end{aligned} \quad (2)$$

where $\widetilde{V}_j$ and $\widetilde{\phi}_j$ are two Gaussian random variables with zero mean and unit variance. As shown in Fig. 1, the node speed gently fluctuates around the target speed $v_\alpha$ within $\beta$–phase.

### C. Slow Down Phase ($\gamma$–Phase)

In real-life, every moving object needs to reduce its speed to zero before a full stop. In order to avoid the sudden stop event happening in the SMS model, we consider that the SMS node experiences a slow down phase to end one movement. In detail, once the node transits into slow down ($\gamma$–phase), at time $t_\beta$, it randomly selects $\gamma$ time steps and a direction $\phi_\gamma \in [0, 2\pi]$. Where $\gamma$ is uniformly distributed over $[\gamma_{min}, \gamma_{\max}]$. In $\gamma$–phase, the node evenly decelerates its speed from $v_\beta$, the ending speed of $\beta$–phase, to $v_\gamma = 0$ during $\gamma$ time steps. Fig. 1 shows the exact case of speed change in $\gamma$–phase. Also in reality, a moving object typically decelerates the speed along a straight line before a full stop. Thus, the direction $\phi_\gamma$ does not change during the $\gamma$–phase. Furthermore, in order to avoid the sharp turn event happening during the phase transition, $\phi_\gamma$ and $\phi_\beta$ are correlated. Specifically, $\phi_\gamma$ is obtained from (2), by substituting $\beta$ for $j-1$. At the phase ending time $t_\gamma = t_\beta + \gamma\Delta t$, the node fully stops and finishes the current movement which lasts over time interval $[t_0, t_\gamma]$.

### D. Semi-Markov Process of SMS Model

We consider *pause* as another phase, then the stochastic process of SMS model is described as an iterative four-state transition process. Let $I$ denote the set of phases in an SMS movement, then $I(t)$ denotes the phase of SMS process at time $t$, where $I = \{I_\alpha, I_\beta, I_\gamma, I_p\}$. Accordingly, $\{\mathcal{Z}(t); t \geq 0\}$ denotes the process which makes transitions among phases in the stochastic modeling of SMS movements. Since the transition time between consecutive moving phases (states), i.e., phase duration time, has discrete uniform distribution, instead of an exponential distribution, $\{\mathcal{Z}(t)\}$ is a *semi-Markov process* [11]. *This is the very reason that our mobility model is called Semi-Markov Smooth model* because it has an Semi-Markov process and it complies with the physical law with smooth movement. Let $\pi = (\pi_\alpha, \pi_\beta, \pi_\gamma, \pi_p)$ denote the time stationary distribution of SMS process. Then, the time stationary distribution for each phase of SMS model is:

$$\pi_m = \lim_{t\to\infty} Prob\{I(t) = I_m \in I\} = \frac{E\{T_m\}}{E\{T\} + E\{T_p\}}, \quad (3)$$

where $E\{T_m\}$ is the expected duration time of $m$–phase in an SMS movement. $E\{T\}$ and $E\{T_p\}$ are the expected SMS movement period and pause period, respectively. Specifically, $E\{T\} = E\{\alpha\Delta t\} + E\{\beta\Delta t\} + E\{\gamma\Delta t\}$. Since $\Delta t$ is a constant unit time, for the sake of simplicity, $\Delta t$ is normalized to 1 second in the rest of the paper.

## IV. Average Steady-State Speed in SMS model

To generate stable nodal movements, a *sound* mobility model should select the speed independently from travel times [4], which is exactly what occurs in SMS model. Here, we evaluate the stochastic property of steady-state speed in SMS model and verify that SMS model *can* eliminate speed decay problem and achieve stable nodal movements. In order to find out whether there exists the speed decay phenomenon in SMS model, it is necessary to obtain both initial average speed $E\{v_{ini}\}$ and average steady-state speed $E\{v_{ss}\}$.

According to the initial stage, each node starts from an SMS phase with a certain state probability based on the time stationary distribution of the SMS process. The average speed in each moving phase of an SMS movement is obtained as: $E_{I_\alpha}\{v\} = E_{I_\gamma}\{v\} = \frac{1}{2}E_{I_\beta}\{v\} = \frac{1}{2}E\{v_\alpha\}$. Hence, from (3), the average initial speed of the SMS model is derived as:

$$\begin{aligned} E\{v_{ini}\} &= E_{I_\alpha}\{V\}\pi_\alpha + E_{I_\beta}\{V\}\pi_\beta + E_{I_\gamma}\{V\}\pi_\gamma + 0\cdot\pi_p \\ &= \frac{\frac{1}{2}E\{v_\alpha\}(E\{\alpha\} + 2E\{\beta\} + E\{\gamma\})}{E\{T\} + E\{T_p\}}. \end{aligned} \quad (4)$$

The CDF of steady-state speed $Pr\{V_{ss} \leq v\}$ can be derived from the limiting fraction of time when step speeds of a node are less than $v$, as the simulation time $t$ approaches to infinity. Let $\mathcal{M}(t)$ and $\mathcal{M}_p(t)$ denote the total number of time steps that a node travels and pauses during $[0,t]$, respectively. Thus, $Pr\{V_{ss} \leq v\}$ is derived as:

$$Pr\{V_{ss} \leq v\} = \lim_{t\to\infty} \frac{\sum_{n=1}^{\mathcal{M}(t)} \mathbf{1}_{\{v_n \leq v\}} + \sum_{n=1}^{\mathcal{M}_p(t)} \mathbf{1}_{\{v_n \leq v\}}}{\mathcal{M}(t) + \mathcal{M}_p(t)}, \quad (5)$$

where $\mathbf{1}_{\{\cdot\}}$ is the indicator function. Thus, if the event that $\{v_n \leq v\}$ is true, then $\mathbf{1}_{\{v_n \leq v\}} = 1$, otherwise $\mathbf{1}_{\{v_n \leq v\}} = 0$. By differentiating the CDF of steady-state speed $V_{ss}$ from (5) with respect to $v$, we find that the pdf of $V_{ss}$ consists of four distinct components with respect to each SMS phase:

$$f_{V_{ss}}(v) = f_{V_{ss}}^{I_\alpha}(v) + f_{V_{ss}}^{I_\beta}(v) + f_{V_{ss}}^{I_\gamma}(v) + f_{V_{ss}}^{I_p}(v), \quad (6)$$

Due to space constraints, we only provide the theoretical expressions here and omit the details of derivation represented in [12]. Assume that the range of duration time for each SMS moving phase is equal and set as $[b,c]$. Then the four components of $f_{v_{ss}}(v)$ are obtained as:

$$f_{V_{ss}}(v) = \begin{cases} \frac{\frac{1}{c-b+1}\sum_{m=b}^{c}\sum_{j=1}^{m}\frac{m}{j}f_{V_\alpha}(\frac{vm}{j})}{E\{T\}+E\{T_p\}} & v \text{ of } I_\alpha \\ \frac{\frac{1}{c-b+1}\sum_{m=b}^{c}\sum_{j=1}^{m}f_{V_{I_\beta,j}}(v)}{E\{T\}+E\{T_p\}} & v \text{ of } I_\beta \\ \frac{\frac{1}{c-b+1}\sum_{m=b}^{c}\sum_{j=1}^{m}\frac{m}{m-j}f_{V_\beta}(\frac{vm}{m-j})}{E\{T\}+E\{T_p\}} & v \text{ of } I_\gamma \\ \frac{E\{T_p\}\delta(v)}{E\{T\}+E\{T_p\}} & v \text{ of } I_p, \end{cases} \quad (7)$$

Correspondingly, the expectation of steady-state speed $E\{v_{ss}\}$ is also composed of four components:

$$E_u\{v_{ss}\} = \begin{cases} \frac{\frac{1}{2}E\{v_\alpha\}(1+E\{\alpha\})}{E\{T\}+E\{T_p\}} & u \in I_\alpha \\ \frac{E\{v_\alpha\}E\{\beta\}}{E\{T\}+E\{T_p\}} & u \in I_\beta \\ \frac{\frac{1}{2}E\{v_\alpha\}(E\{\gamma\}-1)}{E\{T\}+E\{T_p\}} & u \in I_\gamma \\ 0 & u \in I_p. \end{cases} \quad (8)$$

Given (8), the average steady-state speed $E\{v_{ss}\}$ of the SMS model is obtained by:

$$\begin{aligned} E\{v_{ss}\} &= E_{I_\alpha}\{v_{ss}\} + E_{I_\beta}\{v_{ss}\} + E_{I_\gamma}\{v_{ss}\} + E_{I_p}\{v_{ss}\} \\ &= \frac{\frac{1}{2}E\{v_\alpha\}(E\{\alpha\} + 2E\{\beta\} + E\{\gamma\})}{E\{T\} + E\{T_p\}}. \end{aligned} \quad (9)$$

By comparing (4) with (9), we can see that the average initial speed is exactly same as average steady-state speed in SMS model, i.e., $E\{v_{ini}\} = E\{v_{ss}\}$. Therefore, we proved that SMS model does not have speed decay problem.

## V. Uniform Node Distribution in SMS Model

Since an SMS node selects direction, speed and phase time independently, SMS model can be considered as an enhanced random direction (RD) model with memorial and microscopic property on step speed and direction. RD model was proven to maintain uniform node distribution in [7]. Here, we want to prove that SMS model also yields uniform node distribution.

We evenly distribute all mobile nodes in the simulation region at the initial time. For a simple representation, we normalize the size of the simulation region to $[0,1)^2$. $(X_j, Y_j)$, $v_j$, and $\phi_j$ denote the ending position, speed and direction in a node's $j^{th}$ step of its first movement, respectively. When an SMS node reaches a boundary of the simulation region, it wraps around and reappears instantaneously at the opposite boundary in the same direction to avoid biased simulation results. Under this condition of border wrap, we have the following Lemma:

*Lemma 1:* In SMS model, if the initial position $\mathbf{P}(0)$ and the first target direction $\phi_\alpha$ of a mobile node are chosen independently and uniformly distributed on $[0,1)^2 \times [0,2\pi)$ at time $t = 0$, then the location and direction of the node remain uniformly distributed all the time.

Given that the initial position $(X_0, Y_0)$ and $\phi_\alpha$ of a node have independently uniform distribution, the joint probability of ending position and direction of the node's first step movement is:

$$\begin{aligned} & Pr(X_1 < x_1, Y_1 < y_1, \phi_1 < \theta) \\ &= Pr(X_1 < x_1 | \phi_1 < \theta) \cdot Pr(Y_1 < y_1 | \phi_1 < \theta) \cdot Pr(\phi_1 < \theta) \\ &= \frac{1}{2\pi} \int_{\phi_1=0}^{\theta} \Big( \int_{x_0=0}^{1} \mathbf{1}_{\{x_0 + v_1 \cos(\phi_1) - \lfloor x_0 + v_1 \cos(\phi_1) \rfloor < x_1\}} dx_0 \cdot \\ & \qquad \int_{y_0=0}^{1} \mathbf{1}_{\{y_0 + v_1 \sin(\phi_1) - \lfloor y_0 + v_1 \sin(\phi_1) \rfloor < y_1\}} dy_0 \Big) d\phi_1 \\ &= \frac{x_1 y_1 \theta}{2\pi}. \end{aligned} \tag{10}$$

The result in (10) shows that $(X_1, Y_1)$ and $\phi_1$ are uniformly distributed on $[0,1)^2 \times [0,2\pi)$. Following the same methodology, by induction on each following step, Lemma 1 is proved. The detailed proof is described in [12].

## VI. Simulation Results and Model Comparisons

In this section, we verify the above theoretical analysis of SMS model in Section IV and V by simulations and compare the results with RWP and GM models.

### A. Simulation Setup

We integrate our SMS model into the *setdest* of ns-2 simulator, which currently provides both an original and a modified version of RWP model. In order to compare simulation results between RWP and SMS model, $1000$ mobile nodes move in an area of $1401m \times 1401m$ during a time period of $1500$ seconds. For a better demonstration, we simulated both the SMS model and the original RWP model with zero pause time. Both GM and SMS model set the time slot $\Delta t$ as $1$ second and the memory parameter $\zeta$ as $0.5$, respectively. In SMS model, we consider the range of each moving phase duration time as $[6, 30]$ seconds.

Note, as the speed and direction in each step of $\beta$-phase are affected by a Gaussian random variable, there exists a non-zero probability that speed or the direction may have a very large value in some step. To avoid this unwanted event, we set a threshold $v_{\max}$ for the speed and a threshold $\pi/2$ for the direction change between two consecutive steps, respectively. If the new calculated value of speed/direction is larger than the threshold, we reselect that value.

### B. Average Speed

Here, we are interested in comparing the average speed between SMS model and RWP model and validate our analytical proof shown in Section IV. To obtain the average node speed, we first calculate the average speed of each node within every $10$ seconds, and then calculate the average speed among all the nodes. The corresponding numerical results of average speed vs. a time period of $1500$ seconds are shown in Fig. 2. Given the simulation condition of zero pause time and $E\{\alpha\} = E\{\beta\} = E\{\gamma\}$, from (9), the theoretical result of $E\{v_{ss}\}$ of SMS model is obtained as: $E\{v_{ss}\} = \frac{2}{3}E\{v_\alpha\} = 6.7$ m/sec. From Fig. 2, we observe that the average speed of the SMS model is stable from the beginning of simulation at the value around $6.7$ m/sec, which perfectly matches the theoretical result. Therefore, the simulation results validate our analytical conclusion that the average speed of SMS model does not decay over time. Whereas, the average speed of RWP model keeps on decreasing as the simulation time progresses, which is its well-known average speed decay problem [13].

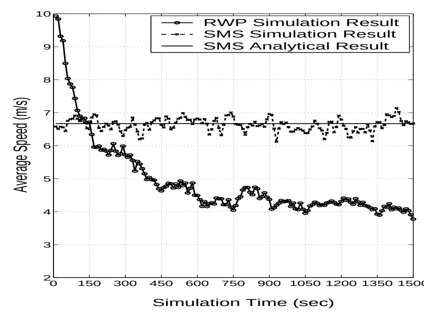


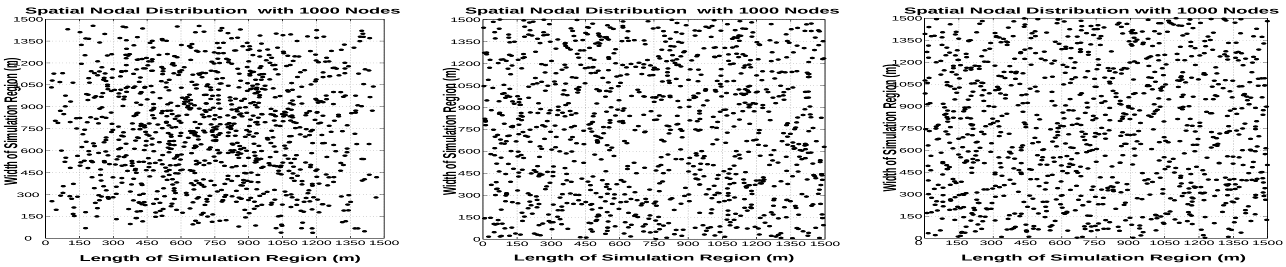

Fig. 2. Average speed vs. simulation time.

### C. Spatial Node Distribution

To verify Lemma 1 proved in Section V, we distribute nodes uniformly in the simulation region at the initial time. Then, we sample the node position at the $500^{th}$ second for SMS model, and the $1000^{th}$ second for both RWP and SMS models. A top view of two-dimensional spatial node position of RWP and SMS models are shown in Fig. 3. The results of RWP model in Fig. 3(a) show that the node density is the maximum at the center of the region, while it is almost zero near the network boundary, which agrees with the previous study [14]. In contrast, in Figs. 3(b) and 3(c), the two node density samples of the SMS model at different time instants are similar and mobile nodes are evenly distributed in the simulation region. Since these two time instants are arbitrarily selected, we verified our proof that the SMS model with border wrap maintains uniform spatial node distribution over time.

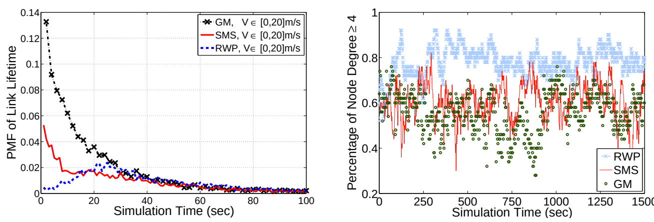
### D. Comparison

Here, we compare the simulation results of link lifetime distribution and average node degree among the RWP, GM and SMS models in Fig. 4. From Fig. 4(a), the probability mass function (PMF) of link lifetime of both SMS model and GM model decreases exponentially with time. In contrast, there is




(a) RWP 2-dimensional at the $1000^{th}$ sec. (b) SMS 2-dimensional at the $500^{th}$ sec. (c) SMS 2-dimensional at the $1000^{th}$ sec.

Fig. 3. Top-View of node distribution of the RWP model at the $1000^{th}$ $sec$ and the SMS model at the $500^{th}$ and the $1000^{th}$ sec, respectively.




(a) PMF of link lifetime. (b) Percentage of node degree.

Fig. 4. Link lifetime distribution and average node degree comparison among RWP, GM and SMS model.

a peak at the $25^{th}$ second of link lifetime distribution in RWP model. Hence, it turns out that mobility models with macroscopic mobility pattern would have different link and path properties from those of mobility models with microscopic pattern, such as the GM and SMS models. Therefore, SMS model is more accurate for the simulation on link lifetime in MANET than other models.

Due to different spatial node distribution, mobility models with same node density ($\sigma$) would yield different average node degree during the simulation. To compare the model effect on the average node degree, 50 nodes are simulated for all the three models. Where the transmission range $R$ for every node is equal and set as $R = 250$m, such that node density of each model is $\sigma = 5/(\pi R^2)$. It implies that on average each node would have 4 neighbors. Fig. 4(b) illustrates the percentage of nodes whose node degree is no less than 4 during the simulation among three models. We find that the result obtained in RWP model is apparently larger than that in GM and SMS model. This is because the majority of nodes move into the center region in RWP model as the simulation time proceeds. That means the network connectivity evaluation based on RWP model could be over optimistic. Therefore, SMS model with uniform node distribution is preferable for network connectivity study in MANET.

## VII. Conclusions

In this paper, we proposed a novel semi-Markov smooth mobility model. This model combines a variety of nice properties of existing ones, including stable node speed in sound mobility model, uniform node distribution in RD model, evenly speed acceleration/deceleration in SR model and temporal correlation of velocity in GM model. Therefore, SMS model is appropriate and flexible to mimic widespread realistic moving behaviors. Moreover, SMS model can be easily implemented in simulation tools such as ns-2. The ns-2 code of our SMS model is available at $http://www4.ncsu.edu/\tilde{}mzhao2/research$. Our future work is to adapt the current SMS model to geographical constraints and support group mobility for different networking scenarios.

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