A CANONICAL MEASURE OF MOBILITY FOR MOBILE AD HOC NETWORKS

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ABSTRACT

For assessing different routing protocols for MANETs, it is important to have some index or quantitative measure of mobility that is relevant *to the performance of the network. In this paper, we proposed a mobility measure that is "canonical" in that it is flexible and consistent. It is flexible because one can customize the definition for relevant mobility using a* remoteness function*. It is consistent because the mobility measure has the same linear relationship to the link change rate for a wide range of mobility scenarios.*

I. Introduction

The performance of a mobile ad hoc network (MANET) in terms of throughput, latency, and scalability is related to the efficiency of the routing protocol in adapting to changes in the network topology due to mobility of the nodes [1], [2]. The movement of a node out of, or into, the communication range of other nodes changes not only its neighbor relationships with those other nodes, but also all routes based on the relationships. Signaling overhead traffic for maintenance of routes for a MANET is proportional to the rate of such changes, which in turn is a function of the mobility of the nodes. Therefore, for assessing different routing protocols for MANETs, it is important to use models for mobility and to have some index or quantitative measure of mobility [3] that is relevant to the performance of the network. In this paper, we introduce a measure for mobility that focuses on the effect of mobility on link changes and thereby is useful for comparative studies of MANET routing protocols in various scenarios.

Several mobility models have been proposed for simulation of the movement of nodes in a MANET [4], [5], [6], [7], [8]. However, the use of many different mobility models without a unified quantitative "measure" of the mobility has made it very difficult to compare the results of independent performance studies of routing protocols. Being able to measure the amount of relevant mobility is as important as the realism of the mobility model itself. However, there is no unified approach for quantifying the degree of mobility or its effect on routing traffic. In [4], [5] the average speed of the nodes is used to represent their mobility, while the maximum speed is used in [3]. The problem with using average or maximum speed as a measure of mobility is that the relative motion between the nodes is not reflected in such a measure; also, using the same average or maximum speed in different mobility models or in networks with different physical dimensions often leads to different rates of route changes. In [1] and [2], the performance of different routing protocols are compared using simulation with the random waypoint model, where the "pause time" is used to represent the degree of node mobility. However, the pause time is a parameter unique to the random waypoint model, and it is not the only parameter that affects the mobility in this model. In [7], the link change rate itself is used as a measure of mobility; in our view, this approach is not satisfactory because the measure does not represent mobility in physical terms—what is needed is a measure of mobility that can accurately predict the rate of link changes. Furthermore, it is tricky to calculate an accurate link change rate when the network is not in steady state since we only observe discrete events of link changes from which the link change rate can be calculated. By time averaging link changes over a certain period of time, we obtain the link change rate. However, the time interval must be chosen depending on how dynamically the link change rate varies in time as well as the link change rate itself if the network is not in steady state or time varying.

The authors of [9] make a significant improvement to this situation by recognizing that not all node movement is relevant to MANET routing protocol assessment—for example, if all the nodes are moving at the same speed and in the same direction, the motion does not affect network topology. However, we have found that the relationship of their mobility factor to the number of link changes is not the same for different mobility models. In [10], the influence of the patterns of node mobility to the routing protocol is also recognized and several protocol independent metrics are proposed to differentiate between different mobility patterns. However, the maximum speed of nodes is used as a measure of mobility in [10].

In this paper, we propose a mobility measure that is "canonical" in that it is flexible and consistent. It is flexible because one can customize the definition for relevant mobility using a *remoteness function* for a given application. It is consistent because the mobility measure has the same linear relationship to the link change rate for a wide range of mobility scenarios, where a scenario consists of the choice of mobility model, the physical dimensions of the network, the number of nodes, etc. This consistency is the strength of the proposed mobility measure because the link change rate can be reliably represented by the mobility measure regardless of the mobility scenario of the network.

This paper is organized as follows. In Section II, we introduce the concept of the *remoteness* of nodes, then the proposed mobility measure using the concept of remoteness. In Section III, simulation results for various wireless network scenarios are shown and the proposed mobility measure is evaluated. Section IV is the conclusion of this paper.

II. Mobility Measure

A. The concept of remoteness

Let $\mathbf{n}_i(t)$, $i = 0, 1, \cdots, N-1$, represent the location vector of node i at time t. Define $d_{ij}(t) = \mid \mathbf{n}_j(t) - \mathbf{n}_i(t) \mid$ as the distance from node i to node j at time t. Then, the *remoteness* of node i from node j at time t is defined as

$$\mathcal{R}_{ij}(t) = F(d_{ij}(t)), \tag{1}$$

where $F(\cdot)$ is a function of the distance. The simplest choice for $F(\cdot)$ is the identity function, that is, the remoteness is just the distance between the nodes. However, in applications such as MANET, a more sophisticated definition of remoteness is more useful. For example, with a wireless node with communication range R, a node located at a distance of three times R can be considered as remote as a node located at a distance of ten times R. Similarly, if a node is well within the communication range R, the node would not seem very remote even if the distance were doubled. On the other hand, if a node is in the vicinity of the communication range R, the subjective remoteness of the node will dramatically vary as the node moves in or moves away. In the light of these observations, we require that $F(\cdot)$ satisfy:

a) $F(0) = 0$, $\lim_{x\to\infty} F(x) = 1$;
b) $\frac{dF(x)}{dx} \geq 0$ for all $x \geq 0$;
c) $\frac{dF(x)}{dx} \mid_{x=0} = 0$;
d) $\lim_{x\to\infty} \frac{dF(x)}{dx} = 0$;
e) $\frac{dF(x)}{dx} \mid_{x=R} \geq \frac{dF(x)}{dx}$ for all $x \geq 0$.

Requirement (a) normalizes $F(\cdot)$ to have unity maximum value. Requirement (b) guarantees that the remoteness is a monotonically increasing function of distance, and as a result $0 \leq F(\cdot) \leq 1$ from (a). Requirements (c) and (d) give the boundary condition of $F(\cdot)$, which guarantee that the remoteness of a node at extreme locations does not change with the movement of the node. Finally, requirement (e) makes the remoteness most sensitive to the movement of a node at communication range.

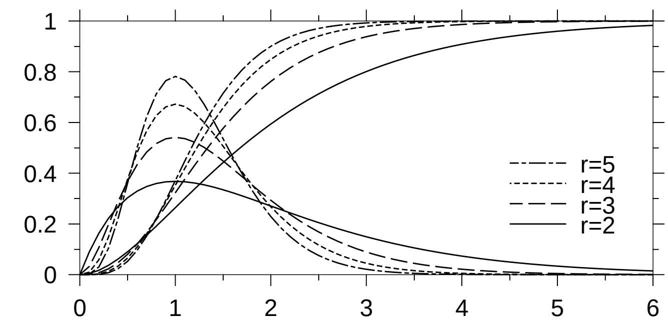


Fig. 1. Plots of Gamma cdf and pdf functions for $r = 2, 3, 4, 5$, where $\lambda = (r-1)/R$ and $R = 1$. ($F(x)$ and $f(x)$ in (2) and (3).)

One of the functions that satisfy all of the requirements is

$$F(x) = \frac{1}{\Gamma(r)} \int_0^x (\lambda\tau)^{r-1} \lambda e^{-\lambda\tau} d\tau, \quad x \geq 0,\ r \geq 2, \tag{2}$$

with $\lambda = (r-1)/R$. Note that the derivative of $F(x)$ is the probability density function of a gamma random variable with parameter r:

$$f(x) = F'(x) = \frac{1}{\Gamma(r)} (\lambda x)^{r-1} \lambda e^{-\lambda x}. \tag{3}$$

Fig. 1 shows plots of $F(x)$ and its derivative $f(x)$ for various values of r, where the communication range R is normalized to unity. As shown in the figure, larger r means more dramatic change of remoteness at the communication range. As a result, we can give more emphasis on the movement of the nodes at and near the communication range by choosing larger r.

Note that (2) is only one of many possible choices of $F(x)$. Any function that satisfies the above requirements can be used to define the remoteness, which constitutes the flexibility of the proposed mobility measure.

B. The proposed mobility measure

As the nodes move, the remoteness changes in time. Thus, we define the *mobility measure* or simply *mobility* of a wireless network in terms of the time derivatives of the remoteness as follows:

$$M(t) = \frac{1}{N} \sum_{i=0}^{N-1} M_i(t), \tag{4}$$

where N is the number of nodes and

$$M_i(t) = \frac{1}{N-1} \sum_{j=0}^{N-1} \left| \frac{d}{dt} F(d_{ij}(t)) \right|. \tag{5}$$

$M_i(t)$ is a measure of the relative movement of other nodes as seen by node i. Thus, the mobility $M(t)$ represents the *average amount* of the movement of the nodes in the network at time t. For a network in steady state, we can use the time average of the mobility defined as follows:

$$M = \frac{1}{T}\int_0^T M(t)dt.$$

If we choose $F(\cdot)$ defined in (2), then

$$M^G(t) = \frac{1}{N}\sum_{i=0}^{N-1} M_i^G(t), \quad (6)$$

where the superscript "G" means "gamma", and

$$M_i^G(t) = \frac{1}{N-1}\sum_{j=0}^{N-1} \mid d'_{ij}(t)\cdot f(d_{ij}(t)) \mid . \quad (7)$$

On the other hand, if we choose the *identity* function for $F(\cdot)$, the mobility can be written as

$$M^I(t) = \frac{1}{N}\sum_{i=0}^{N-1} M_i^I(t), \quad (8)$$

where the superscript "I" means "identity", and

$$M_i^I(t) = \frac{1}{N-1}\sum_{j=0}^{N-1} \mid d'_{ij}(t) \mid, \quad (9)$$

$$d'_{ij}(t) = \text{the time derivative of } d_{ij}(t).$$

Note that (7) is a function of the time derivative of the distance weighted by a function of the distance. As shown in Fig. 1, since $f(x)$ has small values for $x \ll R$ or $x \gg R$, and has its maximum at $x = R$, the movements of the nodes around the vicinity of the communication range R is emphasized. Thus, $M^G(t)$ is suitable for applications such as MANET, where the communication range is an important factor of the network. On the other hand, the identity function dose not satisfy the requirements given in Section II-A and (9) is a function of the time derivative of the distance between nodes. Thus, $M^I(t)$ simply represents the relative movement of the nodes in the entire network and is inappropriate for multi-hop wireless applications including MANETs.

III. SIMULATIONS

A. Mobility Models

We use a variety of network scenarios based on widely used mobility models to evaluate the proposed mobility measure. The mobility models used are the random waypoint (RWP) mobility model, the random Gauss-Markov (RGM) model [4], [5], and the reference point group mobility (RPGM) model [8].

In the RWP model, a node selects a random destination uniformly distributed over a predefined region and moves to the destination at a random speed uniformly distributed between the minimum and maximum speed. Reaching the destination, after pausing for a certain period of time, the node selects a new random destination and speed.

In the RGM model, each node is assigned a speed v and direction θ, and v and θ are updated every Δt as follows:

$$v(t+\Delta t) = \min[\max(v(t)+\Delta v, V_{\min}), V_{\max}],$$
$$\theta(t+\Delta t) = \theta(t) + \Delta\theta,$$

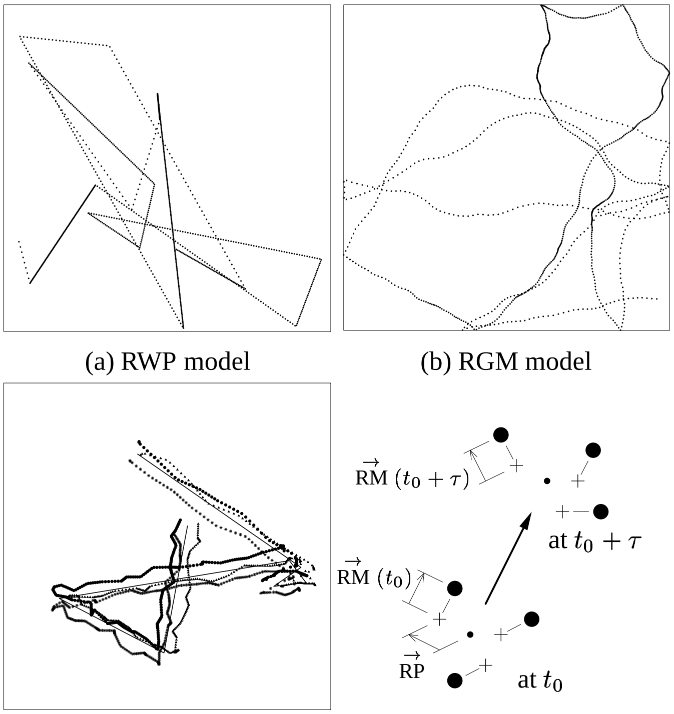
where $V_{\min}$ and $V_{\max}$ are the minimum and maximum speed of the node, and Δv and $\Delta\theta$ are random variables with uniform distribution over the intervals $[-\Delta v_{\max}, \Delta v_{\max}]$ and $[-\Delta\theta_{\max}, \Delta\theta_{\max}]$, respectively. When a node reaches a boundary, the node reflects off the boundary by choosing a new random direction. However, the updates of the v and θ can be implemented in various ways. For another example of the implementation of the RGM model, see [5].

In the RPGM model, each group of nodes has a logical center, which defines the group's motion behavior such as location, speed, direction, etc. Thus, the trajectory of a group is determined by the trajectory of its logical center, which is given by a sequence of check points. As time goes by, the logical center of a group keeps moving from one check point to the next. In addition to the logical center, the RPGM model defines a reference point and a random motion vector for each node. A reference point is a point about which a node moves in random fashion, and is pre-defined for each node with respect to the logical center. The random motion of a node is determined by a random motion vector, which represents the random deviation of a node from the reference point. The random motion vector is updated periodically and is given by the length and the direction which have uniform distributions over the intervals $[0, \mathrm{RM}_{\max}]$ and $[0, 2\pi)$, respectively. Let $\mathbf{n}(t_0)$ be the location vector of a node of the RPGM model at $t = t_0$; then

$$\mathbf{n}(t_0) = \mathbf{c}(t_0) + \overrightarrow{\mathrm{RP}} + \overrightarrow{\mathrm{RM}}(t_0), \quad (10)$$

where $\mathbf{c}(t_0)$ is the location vector of the logical center of the group at $t = t_0$, $\overrightarrow{\mathrm{RP}}$ is a vector from the logical center to the reference point, and $\overrightarrow{\mathrm{RM}}(t_0)$ is the random motion vector at $t = t_0$. Let τ be the update interval of the random motion vector; then at $t = t_0 + \tau$,

$$\mathbf{n}(t_0+\tau) = \mathbf{c}(t_0+\tau) + \overrightarrow{\mathrm{RP}} + \overrightarrow{\mathrm{RM}}(t_0+\tau). \quad (11)$$



(a) RWP model (b) RGM model

(c) RPGM model (3 nodes) (d)

Fig. 2. Typical traveling patterns of a mobile node(s) moving in (a) RWP model, (b) RGM model, and (c) RPGM model. (d) Description of RPGM model.

For $t_0 \le t \le t_0 + \tau$, $\mathbf{n}(t)$ is given by

$$\mathbf{n}(t) = \frac{(t_0 + \tau - t) \cdot \mathbf{n}(t_0) + (t - t_0) \cdot \mathbf{n}(t_0 + \tau)}{\tau}. \quad (12)$$

Fig. 2(c) depicts the movement of the RPGM model for a group with three nodes.

Fig. 2(a), (b), and (c) illustrate the typical traveling patterns of a mobile node(s) in the RWP, RGM, and RPGM models, respectively. The larger spacing between the dots means higher speed of the node. The RWP model has a higher spatial node distribution at the center of the network than near the boundaries [11], while the RGM model has a relatively uniform spatial node distribution over the entire network. Fig. 2(c) illustrates a group of three nodes in the RPGM model with the logical center moving according to the RWP model. Also shown in the trajectory of the logical center of the group.

B. Network Scenarios

In this paper, three different types of network scenarios are used to evaluate the proposed mobility measure. In all simulations, a normalized communication range $R = 1$ is used. For both RWP and RGM models, the minimum speed $V_{\min} = 0.1$ and the maximum speed $V_{\max} = 1$ are used. For the RGM model, the speed v and the direction θ are updated every $\Delta t = 0.2$ seconds, where $\Delta v_{\max} = 0.1$ and $\Delta\theta_{\max} = 0.1\pi$.

Random Waypoint				Random Gauss-Markov		
	network dimension	N	pause time		network dimension	N
S1	6×6	**30**	0	S8	6×6	**30**
S2	6×6	**40**	0	S9	6×6	**40**
S3	6×6	**50**	0	S10	6×6	**50**
S4	$\mathbf{5 \times 5}$	40	0	S11	$\mathbf{5 \times 5}$	40
S5	$\mathbf{4 \times 4}$	40	0	S12	$\mathbf{4 \times 4}$	40
S6	6×6	40	**2.0**			
S7	6×6	40	**4.0**			

Fig. 3. Type 1: a group of randomly moving nodes in a square region.

The first type of network scenario involves a group of nodes randomly moving in a square region. By various combinations of the mobility model, dimension of the region, number of nodes N, pause time (in the case of the RWP model), a variety of network scenarios is generated as shown in Fig. 3. For example, scenario S6 has 40 nodes moving in the RWP model with pause time 2.0 seconds in 6×6 square region.

The second type of network scenario involves two independently moving groups of nodes as shown in Fig. 4(a). We assumed that each group has 20 randomly moving nodes. The link characteristic between two nodes in different groups depends on the degree of the overlap of the two groups as well as the movement of the nodes. Three different cases of overlap are considered:

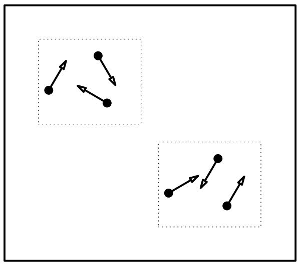
1) The two groups occupy two different areas that do not overlap.
2) The two groups partially overlap.
3) The area one group occupies completely covers the smaller area that the other group occupies.

The coordinates of the lower left corner (llc) and the upper right corner (urc) of the area each group occupies are as follows.

	group 1		group 2	
	llc	urc	llc	urc
case 1)	$(0,0)$	$(6,6)$	$(8,8)$	$(14,14)$
case 2)	$(0,0)$	$(6,6)$	$(3,3)$	$(9,9)$
case 3)	$(0,0)$	$(10,10)$	$(2.5,2.5)$	$(7.5,7.5)$

The combination of these three cases with the two mobility models gives 6 different scenarios shown in Fig. 4(b). For example, scenario S17 has two groups of nodes moving in partially overlapping areas in the RGM model. When the RWP model is used, a pause time of zero is used for all scenarios with two groups.

The third type of network scenario uses the RPGM model moving in 6×6 square region. For the trajectory of the logical center of each group, the RWP model is used with



(a) Two groups of nodes.

	overlap	mobility model
S13	case 1)	RWP
S14	case 2)	RWP
S15	case 3)	RWP
S16	case 1)	RGM
S17	case 2)	RGM
S18	case 3)	RGM

(b) Network scenarios.

Fig. 4. Type 2: two independently moving groups of nodes.

	Description
G1	5 groups, 7 nodes/group, $\text{RM}_{\max} = 0.25$, $\overrightarrow{RP} = 0$, $n = 0$, $\lvert\overrightarrow{RP}\rvert = 0.25$, $\angle\overrightarrow{RP} = n \cdot 60^o$, $n = 1, \cdots, 6$.
G2	7 groups, 5 nodes/group, $\text{RM}_{\max} = 0.5$, $\overrightarrow{RP} = 0$ $\forall$ nodes.
G3	3 groups from G1 and 4 groups from G2
G4	3 groups from G1 and 20 RWP nodes
G5	3 groups from G1 and 20 RGM nodes

Fig. 5. Type 3: group mobility models.

$V_{\min} = 0.1$, $V_{\max} = 1$, and pause time of uniform distribution $U[0, 5]$. The update interval $\tau = 1$ is used for the random motion vector. Fig. 5 summarizes the type 3 network scenarios. In scenario G1, there are 5 groups each consisting of 7 nodes (total of 35 nodes). One of the reference points of the nodes is located at the logical center of each group, and the other 6 reference points are located at the corners of a regular hexagon centered at the logical center with the length of its side 0.25. The length of the random motion vector has a uniform distribution $U[0, 0.25]$, that is $\text{RM}_{\max} = 0.25$. Scenario G2 has 7 groups each consisting of 5 nodes (total of 35 nodes). All reference points of the 5 nodes are located at the logical center of each group. Scenario G2 allows more intra-group motion compared to scenario G1 by having $\text{RM}_{\max} = 0.5$. Scenario G3 consists of 3 groups from scenario G1 and 4 groups from G2. Scenarios G4 and G5 are composed of 3 RPGM model groups from scenario G1 put together with 20 individual nodes of RWP and RGM models, respectively. Scenarios G3, G4, and G5 all have total of 41 nodes.

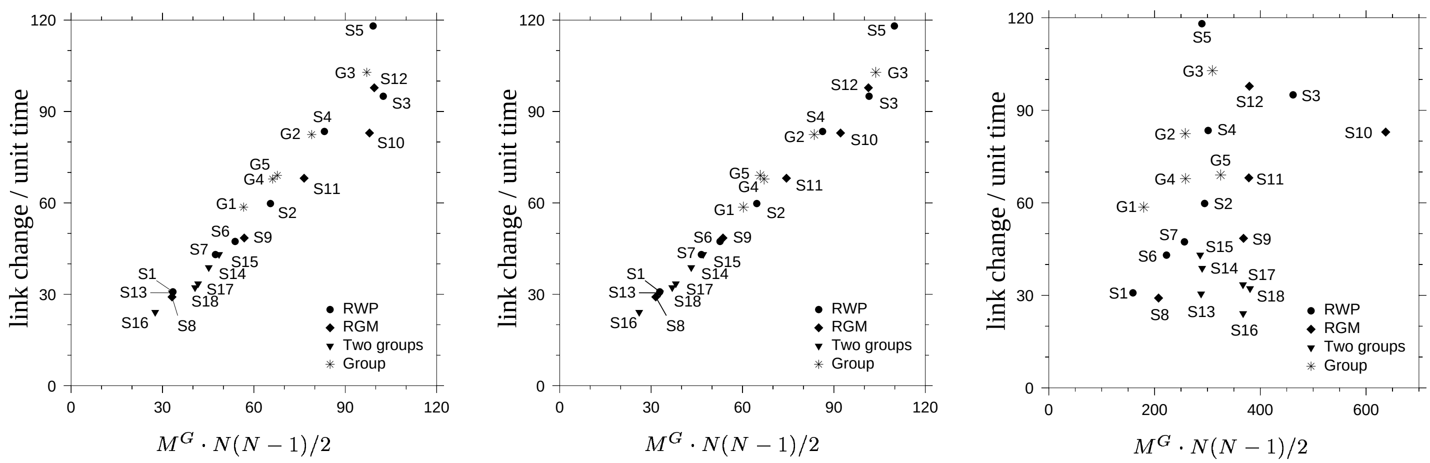
C. Simulation results

For each network scenario, the average number of link changes per second is compared with the mobility measures. 100 seconds of simulation were run for each scenario in type 1 and type 2, and 500 seconds of simulation time was used for each group mobility scenario in type 3. The mobility measures $M^I(t)$ and $M^G(t)$ were taken every 0.01 seconds, and averaged in time to obtain M^I and M^G. Fig. 6(a), (b), and (c) illustrate the results for M^G with parameter $r = 3$, M^G with parameter $r = 5$, and M^I, respectively. Note that M^I and M^G are mobility measures normalized by the number of nodes N. Thus, the mobility measure multiplied by $N(N-1)/2$ reflects the actual link change rate, where $N(N-1)/2$ is the total number of node pairs in the network.

Fig. 6(a) shows the simulation results for the mobility measure M^G with parameter $r = 3$. For RWP scenarios, $M^G \cdot N(N-1)/2$ and the link change rate show a good linear relationship for the changes in the number of nodes N (S1–S2–S3), the physical dimension of the network (S2–S4–S5), and the pause time (S2–S6–S7). A good linear relationship is also observed when nodes are moving according to the RGM model for the changes in N (S8–S9–S10) and the physical dimension of the network (S9–S11-S12). When there are two independently moving groups of nodes (scenarios of type 2), the link change rate is small when the degree of overlap is small. For the scenarios with two independently moving groups of nodes, M^G successfully predicts the link change rate regardless of the mobility model of the network, producing higher values for higher degree of overlap. Note that when the RWP model is used, the scenario with completely overlapping groups of nodes (S15) has more link changes than the scenario with partially overlapping groups of nodes (S14). However, when the RGM model is used, the scenario with partially overlapping groups of nodes (S17) has a slightly higher link change rate than the scenario with completely overlapping groups (S18). This is due to the difference of the spatial distribution of the nodes between RWP and RGM models. For network scenarios with RPGM models, $M^G \cdot N(N-1)/2$ also exhibits a good linear relationship with the link change rate. As shown in the figure, the link change rate and $M^G \cdot N(N-1)/2$ are linearly related for a wide range of scenarios.

As discussed in Section II, by using larger r, we can give more weight to the movements of the nodes near the communication range R. Fig. 6(b) shows the simulation results for the mobility measure M^G with parameter $r = 5$. As shown in the figure, the relationship between the link change rate and $M^G \cdot N(N-1)/2$ is even more linear than it is observed in Fig. 6(a). While this is a desirable property, one possible drawback of using larger r is that the mobility measure loses its sensitivity to the movements of nodes in distance.

Unlike the mobility measure M^G, a linear relationship between $M^I \cdot N(N-1)/2$ and the link change rate is exhibited only for RWP and RGM scenarios with the change of the number of nodes N (S1–S2–S3, S8–S9–S10). However, the value of $M^I \cdot N(N-1)/2$ shows no significant changes for different physical dimensions of the network (S2–S4–S5, S9–S11–S12), failing to predict the changes of link change



(a) M_G with $r = 3$. (b) M_G with $r = 5$. (c) M_I.

Fig. 6. Link change rate vs. mobility measure.

rate. Furthermore, M^I has almost the same values for different degrees of overlap between the two groups of nodes. This is because M^I does not take advantage of the distance information between the nodes. As in the case of network scenarios of type 1 and 2, M^I does not exhibit a consistent relationship with the link change rate for network scenarios with group mobility. In summary, $M^I \cdot N(N-1)/2$ does not have a consistent linear relationship with the link change rate.

IV. Conclusion

In this paper, we proposed a canonical mobility measure for mobile ad hoc networks which is flexible and consistent for a wide range of scenarios. The consistency of the mobility measure was demonstrated by the simulation results, which showed the ability of the mobility measure to reliably represent the link change rate for various simulation scenarios. The proposed mobility measure provides a unified means of measuring the degree of mobility in MANETs, offering a reference with the help of which independent studies of network performance can be compared.

References

[1] Josh Broch, David A. Maltz, David B. Johnson, Yih-Chun Hu, and Jorjeta Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocols," in *Proc. IEEE/ACM Mobicom'98*, Oct. 1998.

[2] Charles E. Perkins, Elizabeth M. Royer, Samir R. Das, and Mahesh K. Marina, "Performance comparison of two on-demand routing protocols for ad hoc networks," *IEEE Personal Communications*, Feb. 2001.

[3] Jeffery W. Wilson, "The importance of mobility model assumptions on route discovery, data delivery, and route maintenance protocols for ad hoc mobile networks," Virginia Polytechnic Institute and State University, Dec. 2001.

[4] Deepanshu Shukla, "Mobility models in ad hoc networks," M.S. thesis, KReSIT-ITT Bombay, Nov. 2001.

[5] Tracy Camp, Jeff Boleng, and Vanessa Davies, "A survey of mobility for ad hoc network research," *Wireless Communication & Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications*, 2002.

[6] Christian Bettstetter, "Smooth is better than sharp: A random mobility model for simulation of wireless networks," in *Proceedings of 4th ACM International Workshop on Modeling, Analysis, and Simulation of Wireless and Mobile Systems (MSWiM'01)*, Rome, Italy, July 2001.

[7] D. S. Tan, S. Zhou, J. Ho, J. S. Mehta, and H. Tanabe, "Design and evaluation of an individually simulated mobility model in wireless ad hoc networks," in *Proceedings of Communication Networks and Distributed Systems Modeling and Simulation Conference*, San Antonio, TX, 2002.

[8] Xiaoyan Hong, Mario Gerla, Guangyu Pei, and Ching-Chuan Chiang, "A group mobility model for ad hoc wireless networks," in *Proceedings of ACM/IEEE MSWiM'99*, Seattle, WA, Aug. 1999, pp. 53–60.

[9] Tony Larsson and Nicklas Hedman, "Routing protocols in wireless ah-hoc networks – a simulation study," M.S. thesis, Computer Science and Engineering, Luleå University of Technology, Stockholm, 1998.

[10] Ahmed Helmy Fan Bai, Narayanan Sadagopan, "IMPORTANT: A framework to systematically analyze the Impact of Mobility on Performance of RouTing protocols for Adhoc NeTworks," Tech. Rep. 02-765, Computer Science Department, University of Southern California.

[11] Christian Bettstetter and Christian Wagner, "The spatial node distribution of the random waypoint mobility model," in *Proceedings of the 1st German Workshop on Mobile Ah-Hoc Network (WMAN'02)*, Ulm, Germany, March 2002.