

Classification and Evaluation of Mobility Metrics for Mobility Model Movement Patterns in Mobile Ad-Hoc Networks

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ABSTRACT

A mobile ad hoc network is collection of self configuring and adaption of wireless link between communicating devices (mobile devices) to form an arbitrary topology and multihop wireless connectivity without the use of existing infrastructure. It requires efficient dynamic routing protocol to determine the routes subsequent to a set of rules that enables two or more devices to communicate with each others. This paper basically classifies and evaluates the mobility metrics into two categories- direct mobility metrics and derived mobility metrics. These two mobility metrics has been used to measure different mobility models, this paper considers some of mobility models i.e Random Waypoint Model, Reference Point Group Mobility Model, Random Direction Mobility Model, Random Walk Mobility Model, Probabilistic Random Walk, Gauss Markov, Column Mobility Model, Nomadic Community Mobility Model and Manhattan Grid Model.

KEYWORDS

Mobility metrics, Mobility Models, Connectivity Graph

1. Introduction

Mobile ad hoc network (MANET) is a collection of mobile nodes forming a temporary network, without the aid of pre-establishment network infrastructure, although commercial wireless technologies are generally based on towers and high-power base stations [1, 2]. They are fixed in location and relationship to their client devices. Many researchers have shown their interest in the field of MANET and all sorts of protocols aiming at different issues. The performance of these protocols need to be carefully evaluated before they are ready for the commercial market, so for this network simulation plays vital role as well as a key method to comprehend the overall performance of the MANET. The performance of these protocols could be evaluated with the imperative mobility model that precisely represents mobile nodes (MNs) to provide realistic performance measurement. In mobility modelling research, there are two direction of research which could be performed. First direction is towards designing of new models which predicts new era of real world scenario. Second direction is to analyze mobility models on account of mobility metrics and influences of mobility models on routing protocols. There are many mobility models have been proposed in the literature (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17). Brief descriptions of some mobility models are:

Random Waypoint Model: it includes pause times between changes in direction and speed .A mobile node stay in one location for certain period of pause time [8].

Random Walk Mobility Model: an MN moves from its current location to a new location by randomly choosing a direction and speed in which to travel [10].

Probabilistic Random Walk Model: A model that utilizes a set of probabilities to determine the next position of an MN [11].

Random Direction Mobility Model: A model that forces MNs to travel to the edge of the simulation area before changing direction and speed, to overcome density waves produced by RWP[12].

Reference Point Group Mobility Model: A group mobility model where group movements are based upon the path travelled by a logical center [13].

Gauss Markov: A model that uses one tuning parameter to vary the degree of randomness in the mobility pattern. Initially each MN is assigned a current speed and direction [14].

Column Mobility Model: A group mobility model where the set of MNs form a line and are uniformly moving forward in a particular direction [15].

Nomadic Community Mobility Model: A group mobility model where a set of MNs move together from one location to another [15, 16].

Manhattan Grid Model: In this model nodes move only on predefined paths. The arguments -u and -v set the number of blocks between the paths [17].

This paper basically classifies and evaluates the mobility metrics into two categories- direct mobility metrics and derived mobility metrics. These two mobility metrics has been used to measure different mobility models which are tabulated in table 1.

2. Classification of Mobility Metrics

The mobility model can be classified based on two kinds of mobility metrics categories, first is direct mobility metrics and second is derived mobility metrics [6]. The direct mobility metrics like host speed or relative speed, are measurement of clear physical behavioural meaning while the derived mobility metrics, like graph connectivity, are measurement of physical observation through mathematical modelling. A good effort of mobility models classification has been carried out based on mobility metrics taking account of above two categories and tabulated in table 1 by several studies of the literature [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17].

Table 1 Classification of Mobility Metrics & its characteristics

Sl.No	Mobility Metrics Categories	Metrics class	Characteristics	Mobility Model
1.	Direct Mobility	Random based	Without any dependencies and restriction invoked in model	RWP, RWM, RDM, Cluster
		Temporal dependence	A node actual movement influenced with its past movement	GM, S R
		Spatial dependence	The movement of a node influenced by node around it happen in group mobility	RPGM, SGM, CMM, NCMM, Pursue
2.	Derived mobility	Geographical restrictions	Node movement restricted in certain geographical area	Graph Based, Geographic division based, Map-based, Voronoi-based
		a. Hybrid structure	All mobility metrics classes are integrated to attain the structure	CVTM, Freeway, MGM,
		b. User – Oriented-with three components	provide an modeling approach for complex mobility scenario- spatial environment, observation based, temporal and spatial dependencies	Tactical scenario Model like- Catastrophe-scenario, platoon, Disaster-area model

2.1 Direct Mobility Metrics

This mobility metrics is basically a protocol independent metrics, its attempt are to extract the characteristics of mobility behaviour in between the mobile nodes. It is known as direct mobility because of it measures the host movement directly like average host speed. There are some other metrics are defined in this categories like average relative speed, temporal dependence and spatial dependence. An attempt has been carried out to characterize the temporal dependence of the movements of an individual nodes and the spatial dependence between various nodes [6, 18]

2.1.1 Relative speed

It is defined based on relative speed [6, 18] of all pairs of nodes in networks over time t i.e. the speed of first node i , relative to the second node j .

$$RS(i, j, t) = |\vec{V}_i(t) - \vec{V}_j(t)| \quad (1)$$

Average Relative Speed

Average relative speed $RS(i, j)$ of hosts i, j at time t will be-

$$\overline{RS} = \frac{\sum_{i=1}^N \sum_{j=1}^N \sum_{t=1}^T RS(i, j, t)}{P} \quad (2)$$

where P is the number of tuples (i, j, t) such that $RS(i, j, t) \neq 0$.

2.1.2 Degree of Temporal Dependence

The temporal dependencies imply how an individual node changes its velocity with respect to time or a node actual movement influenced with its past movement [6]. For each node, it is defined as a product of relative direction and relative speed (relative to its past itself) i.e.

$$D_{temporal}(i, t, t') = RD(\vec{v}_i(t), \vec{v}_i(t')) * SR(\vec{v}_i(t), \vec{v}_i(t')) \quad (3)$$

The value of $D_{temporal}(i, t, t')$ will increase if the node moves in the same direction and almost at the similar speed and decreases if the relative direction or the speed ratio decreases over a certain time interval. $D_{spatial}(i, j, t)$ will be zero if

$$|t - t'| > c \Rightarrow D_{temporal}(i, t, t') = 0 \quad (4)$$

where $c > 0$ is a constant

Average Degree of Temporal Dependence

The average degree of temporal dependence $D_{temporal}(i, t, t')$ is the value of averaged over nodes and time instants [6] i.e.

$$D_{temporal} = \frac{\sum_{i=1}^N \sum_{t=1}^T \sum_{t'=1}^T D_{temporal}(i, j, t')}{P} \quad (5)$$

where P is the number of tuples (i, t, t') such that $D_{temporal}(i, t, t') \neq 0$. It has two conditions that is obvious, first, if the present velocity of a node is fully independent of its velocity at previous time period, then the mobility pattern is expected to have a smaller value for $D_{temporal}$. Second, if the current velocity is strongly dependent on the velocity at some previous time step, then the mobility pattern is expected to have a higher value for $D_{temporal}$.

2.1.3 Degree of Spatial Dependence

The degree of spatial dependence is a measure of a node's correlation with others nodes in the networks [6]. This could be measured with equ. (6).

$$D_{spatial}(i, j, t) = RD(\vec{v}_i(t), \vec{v}_j(t)) * SR(\vec{v}_i(t), \vec{v}_j(t)) \quad (6)$$

The value of $D_{spatial}(i, j, t)$ will increase when nodes i and j moves in same direction with almost similar speed and decreases when nodes i and j moves in relative direction or dissimilar speed over certain time interval. The spatially dependent on a far away node will be zero and satisfy the conditions of equ. (7).

$$D_{i,j}(t) > c * R \Rightarrow D_{spatial}(i, j, t) = 0 \quad (7)$$

where $c > 0$ is a constant.

Average Degree of Spatial Dependence

The average degree of spatial dependence is an average of degree of spatial dependence of all nodes pairs in the network [6] i.e.

$$D_{spatial} = \frac{\sum_{t=1}^T \sum_{i=1}^N \sum_{j=i+1}^N D_{spatial}(i, j, t)}{P} \quad (8)$$

where P is the number of tuples (i, j, t) such that $D_{spatial}(i, j, t) \neq 0$.

2.2 Derived mobility metrics

The derived mobility metrics captures the property of graph theoretic models as well as some mathematical models. It is well known that the mobility of nodes dependent over the network topology dynamics, therefore it is oblivious that the performance of routing protocol will also affected by this. To study the effect of mobility it requires analyzing the connectivity graph between the mobile nodes [6].

Connectivity Graph Metrics

The connectivity graph is the graph $G=(V,E)$ where $|V|=N$, a link $(i, j) \in E$ iff $D_{i,j}(t) \leq R$. Let $X(i, j, t)$ be an indicator random variable which has a value 1 iff there is a link between nodes i and j at time t [6]. $X(i, j) = \max_{t=1}^T X(i, j, t)$ be an indicator random variable which is 1 if a link existed between nodes i and j at any time during the simulation, 0 otherwise. The graph connectivity metrics includes total link, number of link changes, link duration and path availability.

2.2.1 Number of Link Changes

Number of link changes for a pair of nodes i and j is the number of times the link between them transitions from “down” to “up” [6] and defined as-

$$LC(i, j) = \sum_{t=1}^T C(i, j, t) \quad (9)$$

Where $C(i, j, t)$ is indicator random variable such that $C(i, j, t) = 1$ iff $X(i, j, t-1) = 0$ and $X(i, j, t) = 1$ i.e. if the link between nodes i and j is down at time $t-1$, but comes up at time t .

Average Number of Link Changes

Average Number of Link Changes is the value of $LC(i, j)$ averaged over node pairs satisfying certain condition [6] i.e

$$\overline{LC} = \frac{\sum_{i=1}^N \sum_{j=i+1}^N LC(i, j)}{P} \quad (10)$$

where P is the number of pairs i, j such that $X(i, j) \neq 0$

2.2.2 Link Duration

It is a duration of the link active between two nodes i and j . It measures the stability of nodes between these two nodes and defined as [6]-

$$LD(i, j) = \begin{cases} \frac{\sum_{t=1}^T X(i, j, t)}{LC(i, j)} & \text{if } LC(i, j) \neq 0 \\ \sum_{t=1}^T X(i, j, t) & \text{otherwise} \end{cases} \quad (11)$$

Average Link Duration

It is the value of $LD(i, j)$ averaged over node pairs meeting certain condition[6]-

$$\overline{LD} = \frac{\sum_{i=1}^N \sum_{j=i+1}^N LD(i, j)}{P} \quad (12)$$

where P is the number of pairs i, j such that $X(i, j) \neq 0$.

2.2.3 Path Availability

It is the fraction of time during which a path is available between two nodes i and j . At this fraction of time pairs of node communicate traffic with available path [6]. So, the path availability is defined as-

$$PA(i, j) = \begin{cases} \frac{\sum_{t=start(i, j)}^T A(i, j, t)}{T - start(i, j)} & \text{if } T - start(i, j) > 0 \\ 0 & \text{otherwise} \end{cases} \quad (13)$$

where $A(i, j, t)$ is an indicator random variable which has a value 1 if a path is available from node i to node j at time t , and has a value 0 otherwise. $Start(i, j)$ is the time at which the communication traffic between nodes i and j starts.

Average Path Availability

It is the value of $PA(i, j)$ averaged over node pairs meeting certain condition [6].

$$\overline{PA} = \frac{\sum_{i=1}^N \sum_{j=i+1}^N PA(i, j)}{P} \quad (14)$$

where P is the number of pairs i, j such that $T - start(i, j) > 0$.

2.2.4 Total links

Total links prediction value probabilistic factor and predicts the future status of wireless link. The status of link is depends on various system and environmental factors that affect transmitter and receiver range [19]. Nodes are mobile in wireless ad hoc networks therefore, some links will be broken and new links will be established in the networks. The evaluation of total links in transmission range 200 meters is carried out for the some mobility model and shown in figure 7.

3. Simulation Based Validation of Mobility Metrics

For the validation of mobility metrics, we used BonnMotion, a Java software which creates and analyses mobility scenarios. It is developed within the Communication Systems group at the

Institute of Computer Science of the University of Bonn, Germany, where it serves as a tool for the investigation of mobile ad hoc network characteristics. The scenarios can also be exported for the network simulators ns-2, GloMoSim/QualNet, COOJA, MiXiM and ONE [20]. In our experiment, a Network simulator ns-2 is used for creating and analysing mobility scenario.

3.1 Scenario description

In this paper, mobility scenario generator produced different mobility patterns for our considered mobility model i.e Random waypoint model, Reference Point Group Model, Random Direction Model, Random Walk, Probabilistic Random Walk, Gauss Markvo, Column mobility model, and Nomadic Community Mobility Model. In all these mobility patterns, 40 mobile nodes move in the area of 1000 x 1000 m for a period of 900 seconds. The simulation is carried out with varying speed of 10, 20,30,40,50, 60 m/s and fixed transmission range of 200 meters. For Reference point group mobility model, there are two different mobility scenarios. First is a single group of 40 nodes and second is 4 groups of 10 nodes each moving independently with overlapping fashion. Both speed deviation ratio and angle deviation ratio is considered 0.1.

3.2 Validation of Direct Mobility Metrics

Average Relative Speed

In this paper, from the simulation its has been observed that the average relative speed of Column Mobility Model is lowest as compared to others mobility models, as its nature of group movement pattern, we considered 4 groups in the simulated scenario, however, its average relative speed is less as compared to RPGM (1-groups 40 nodes) and RPGM (4-groups 10 each). The Nomadic Community Mobility Model is also based on group mobility pattern. Each group of mobile nodes has an invisible reference node that they track around the simulation. The average relative speed is good as compared to others i.e Column and RPGM model but not consistent as V_{max} increases.

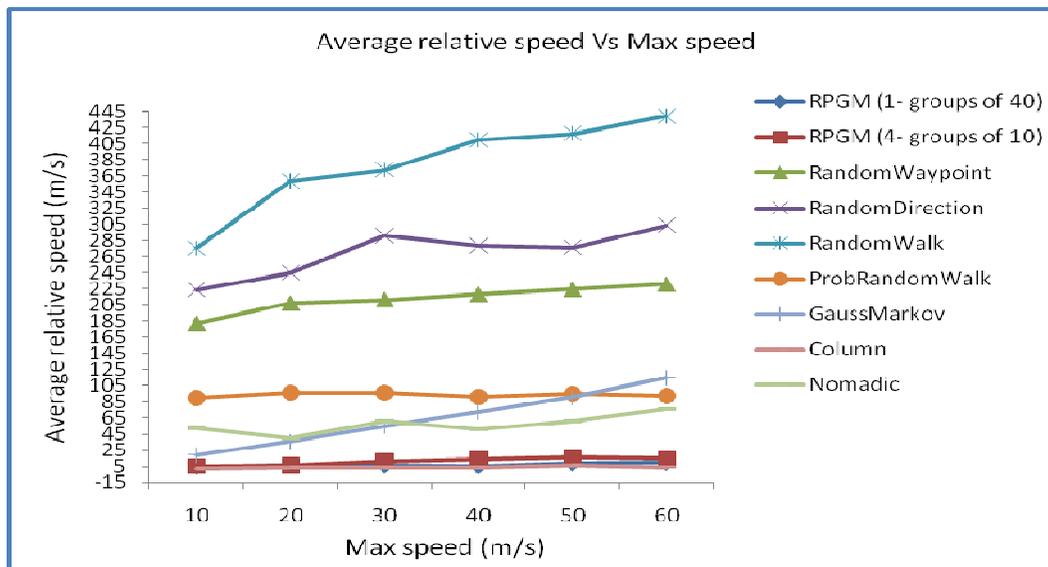


Figure 1 Average relative speed Vs Max speed (m/s)

As its simplicity, the average relative speed of all pairs of nodes in Random Walk mobility is highest than any other considered simulated model as the V_{max} increases. The average relative speed of all pair of nodes in Random Direction is also increases as the V_{max} increases and get highest than rest of other models except Random Walk as shown in figure 1. In Random Waypoint model the average relative speed increases almost linearly as the V_{max} increases and achieves highest value rather than others model except Random Walk and Random Direction respectively. In Probabilistic Random walk model, the average relative speed is approximately consistent as shown in figure 1. The average relative speed of all pair's nodes in Gauss Markov Model is linearly increases as the V_{max} increases and finally gets highest value except Random Walk, Random Direction and Random Waypoint model.

Average Degree of Temporal Dependence

This metrics could not differentiate accurately various mobility patterns but still some effort has been made in this paper. Figure 2 shows that none of mobility model signify average temporal dependence with respect to increasing V_{max} all has gone in negative value except Probabilistic Random Walk model. In Probabilistic Random Walk model this metrics value increases upto V_{max} 30 m/s but gets sudden fall as speed increases more than 30 m/s.

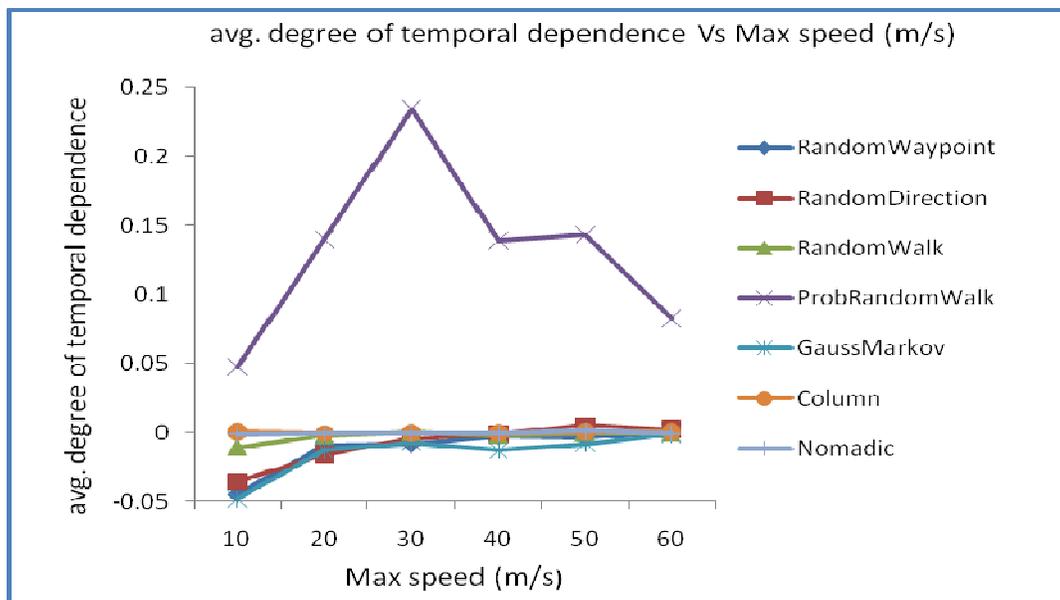


Figure 2 Average degree of temporal dependence Vs Max speed (m/s)

The above results cause uncertainty for validation of different mobility pattern .The usefulness of this metrics is still in research.

Average Degree of Spatial Dependence

The average degree of spatial dependence is maximum in RPGM (1-group of 40 nodes) , RPGM (4- groups of 10 nodes) and Nomadic model respectively but as the V_{max} increases then it decreases from its maximum spatial dependencies while in the case of Nomadic Community Mobility Model average degree of spatial dependence increases a little as V_{max} increases as shown in figure 2.

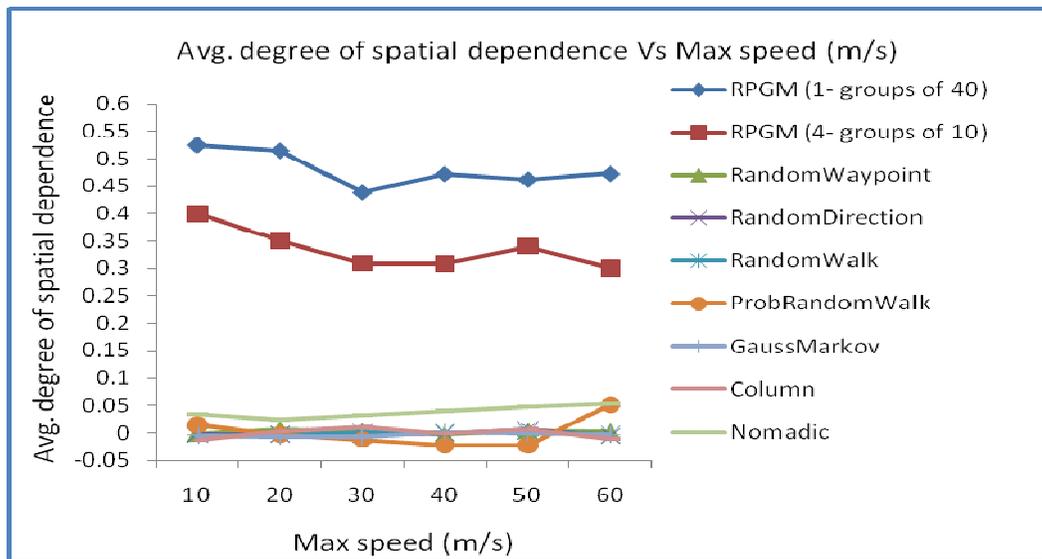


Figure 3 Average degree of spatial dependence Vs Max speed (m/s)

In the case of Random Waypoint and Probabilistic Random Walk it get a very small as the V_{max} increase but not consistent, therefore, the simulation validates the rest of mobility models taken in the simulation gone in negative average degree of spatial dependence. In other words, these models are free from spatial dependence and could not be conceded the part of this metrics.

3.3 Validation of Derived Mobility Metrics

Average Number of Link Changes: Although the average number link change metric is unable to differentiate the several mobility patterns but in this paper, we made an effort for this task. It has been observed in the simulation the average number of link change probability is very high in case of Original Gauss Markov model as compared to Gauss Markov. The literature [21] study shows the performance of Gauss Markov is better as compared to Original Gauss Markov.

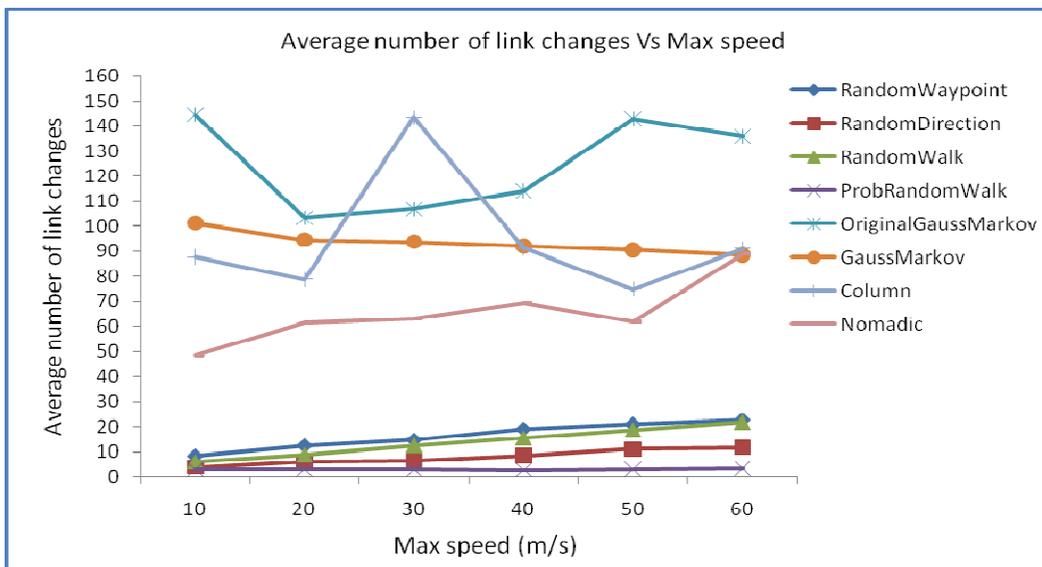


Figure 4 Average number of link changes Vs Max speed (m/s)

The average number of link change of Probabilistic Random walk is very less and consistent with V_{max} among all simulated mobility pattern. In the case of Random Direction, Random Walk and Random Waypoint, it increases linearly as V_{max} increases but these models's link change probability is very less as compared to rest shown in figure 4.

Average Link Duration

The average link duration as shown in figure 5 has higher and consistent value for RPGM single group than others and in case of Column Mobility Model this value decreases as V_{max} increases not linearly because of in simulation setup the group change probability and group size standard deviation is zero. This metric value of RPGM (4-group of 10) decreases as V_{max} increases as comparison to single group because of a single group of 40 nodes breaks into small 4 groups, controlled with its centre head and do not change its membership.

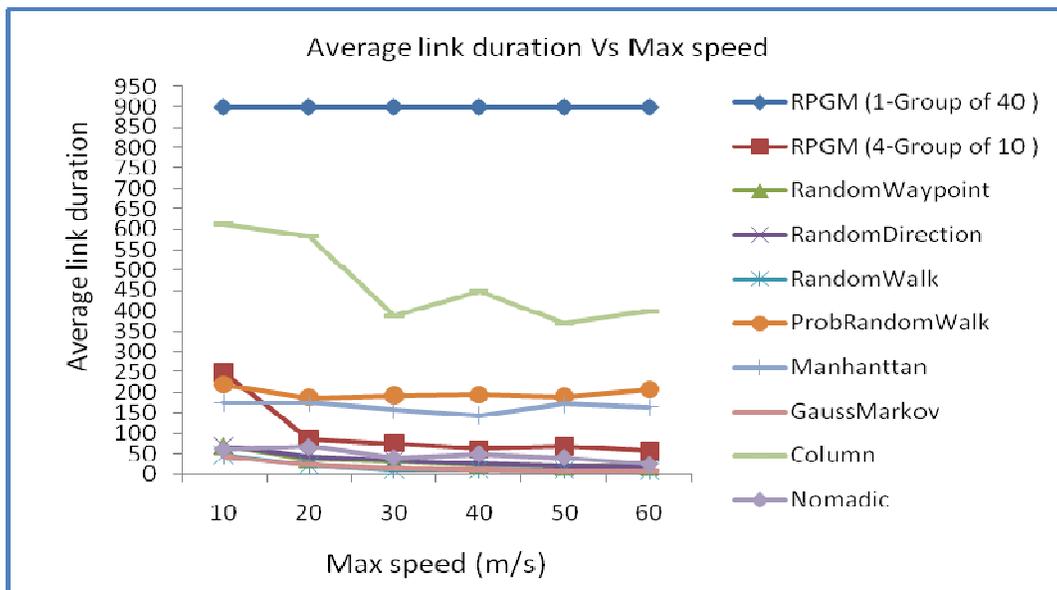


Figure 5 Average link duration Vs Max speed (m/s)

The average link duration of Probabilistic Random Walk model in the beginning and ending of simulation is high but in mid time or when the speed is above 10 m/s & 60 m/s, it is almost consistent. This metric value for Manhattan mobility model decreases as the speed increases and the rest of model has very small value as compared to above described model shown in figure 5.

Average Path Availability

It is the fraction of time during which a path is available between two nodes i and j . As in figure 6, the average path availability of Random Waypoint Model has highest value and decreases as the V_{max} increases and the Gauss Markov Model average path availability is at second highest position, it decreases as max speed increases.

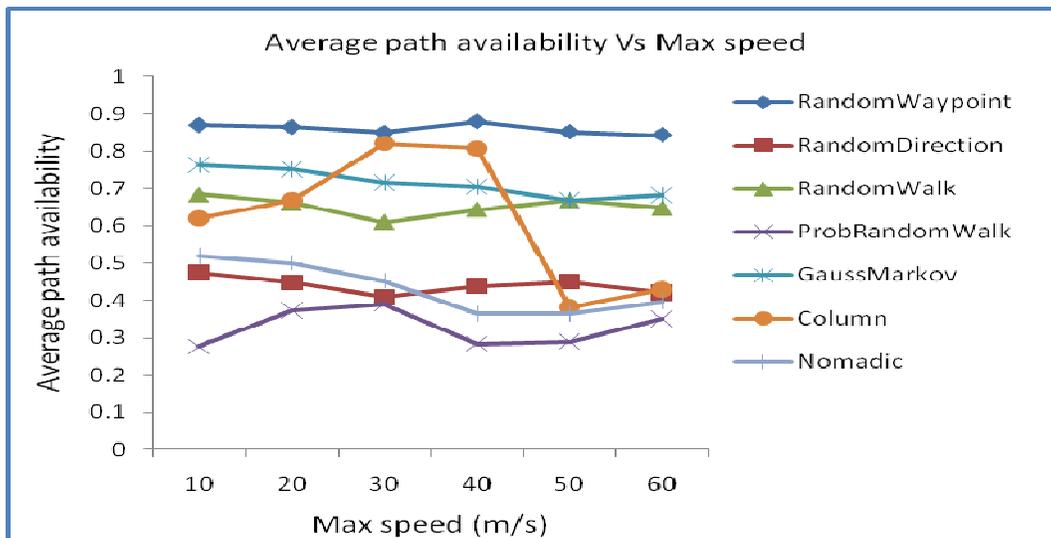


Figure 6 Average link duration Vs Max speed (m/s)

The rest model path availability value is shown in figure 6.

Total links

The total links in transmission range 200 meters is carried out for the some mobility model and shown in figure 7. The total links in Gauss Markov is largest as compared to other mobility patterns when the V_{max} increases and the total link in Random Walk Model gets its second position of metric value rest of all mobility models. It has approx same values in Manhattan Mobility Model and Column Model as V_{max} increases.

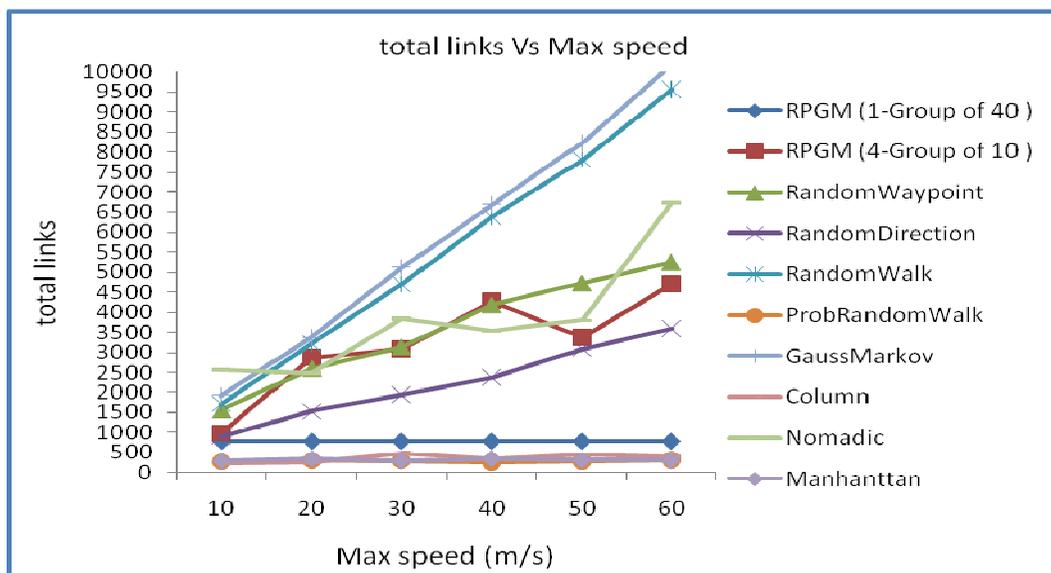


Figure 7 total links Vs Max speed (m/s)

It has approx same values in Manhattan mobility model and column model as V_{max} increases. Total links for RPGM (1-Group of 40) is constant while RPGM (4-Groups of 10) increases as V_{max} increases.

4. Conclusion and Future Work

This paper classifies the mobility model by evaluation of mobility metrics i.e direct metrics and derived metrics in figure 1-3, and validates them by consideration of mobility patterns in a systematic fashion. The effect of mobility patterns has been carried out for connectivity graph between the mobile nodes from figure 4-7. Since mobility pattern influences the connectivity graph as shown in simulated results, therefore, the performance of various routing protocol will also be affected. Some of the mobility models are classified based on evaluation of these metrics, tabulated in table 1.

Future work is intended to classifying the building blocks and investigating its effect on the performance of various Ad-hoc routing protocols, are mainly based on intuitive analysis.

Acronyms

MNs	Mobile Nodes
RWP	Random Waypoint
RWM	Random Walk Mobility
RDM	Random Direction Mobility
SR	Smooth Random
RPGM	Reference Point Group Mobility
GM	Gauss Morkov
CMM	Column Mobility Model
NCMM	Nomadic Community Mobility Model
SGMM	Structured- group- mobility model
CVTM	Complex Vehicular Traffic Models
MGM	Manhattan Grid Model
RS	Relative Speed
SR	Relative Speed
RD	Relative Direction
LC	Link Change
LD	Link Duration
PA	Path Availability

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