Mobility Models in adhoc networks

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Abstract

Mobility management in ad hoc wireless networks faces many challenges. Mobility constantly causes the network topology to change. In order to keep accurate routes, the routing protocols must dynamically readjust to such changes. Thus, routing update traffic overhead is significantly high. Different mobility patterns have in general different impact on a specific network protocol or application. Consequently the network performance will be strongly influenced by the nature of the mobility pattern. In the past, mobility models were rather casually used to evaluate network performance under different routing protocols. In this seminar, we present a survey of various mobility models in both cellular networks and multi-hop networks. One of the main themes of this seminar is to investigate the impact of the mobility model on the performance of a specific network protocol or application. As expected, the results indicate that different mobility patterns affect the various protocols in different ways. In particular, the ranking of routing algorithms is influenced by the choice of mobility pattern.

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1 Introduction

Ad hoc wireless networks are networks which do not rely on a pre-existing communication infrastructure. Rather, they maintain a dynamic interconnection topology between mobile users, often var multihoping. Ad hoc networks are expected to play an increasingly important role in futurecivilian and military settings where wireless access to a wired backbone is either ineffective or impossible. Ad hocnetwork applications range from collaborative, distributed mobile computing to disaster recovery (fire, flood, earth-quake), law enforcement (crowd control, search and rescue) and digital battlefield communications. Some key charac-teristics of these systems are team collaboration of large number of mobile units, limited bandwidth, the need forsupporting multimedia real time traffic and low latency access to distributed resources (e.g., distributed database ac-cess for situation awareness in the battlefield).

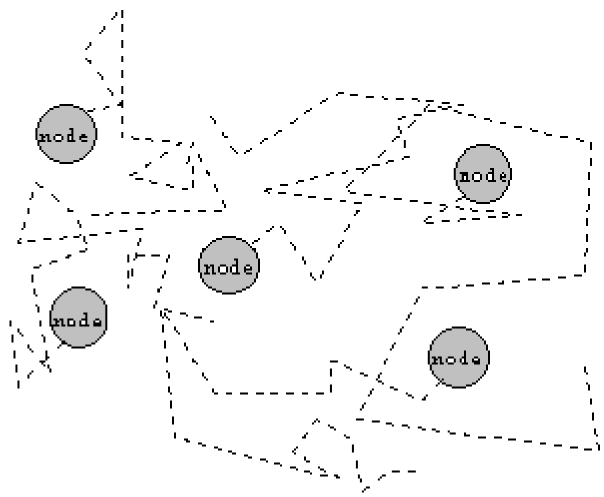
The hosts in an ad hoc network move according to various patterns. Realistic models for the motion patterns are needed in simulation in order to evaluate system and protocol performance. Most of the earlier research on mobility patterns was based on cellular networks. Mobility patterns have been used to derive traffic and mobility prediction models in the study of various problems in cellular systems, such as handoff, location management, paging, registration, calling time, traffic load. Recently, mobility modelshave been explored also in ad hoc networks. While in cellular networks, mobility models are mainly focused on individual movements since communications are point to point rather than among groups; in ad hoc networks, communications are often among teams which tend to coordinate their movements (e.g., a firemen rescue team in a disaster recov-ery situation). However, as the members of an ad hoc network move, the performance tends to degrade. One reason of such degradation is the traffic control overhead required for maintaining accurate routing tables in the presence of mobility. Different mobility patterns will affect the performance of different network protocols in different ways. Therefore, it is very important to study the impact of mobility patterns on different network protocols in order to achieve the best performance in each scenario.

2 ExistingMobility Models for Cellular and adhoc Networks

In a wireless network, mobile hosts (MHs) can move in many different ways. Mobility models are commonly used to analyze newly designed systems or protocols in both cellular and ad hoc wireless networks. In cellular wireless networks, studies for mobility models not only aim at describing individual motion behaviors such as changes in direction and speed, but also consider the collective motion ofall the mobiles relative to a geographical area (cell) over time. Models for ad hoc network mobility generally reflect the behavior of an individual mobile, or a group of mobiles. But there is no notion of collective movement of all mobiles with reference to a particular "cell". We shall discuss the various Mobility Models in the Mobile network in general with special emphasis on adhoc networksd as and when applicable.

2.1 Brownian Motion Model [Einstein 1926]

It is the basic totally random motion pattern. It is not a very realistic model in the sense that only a few activities can present such erratic behaviour.

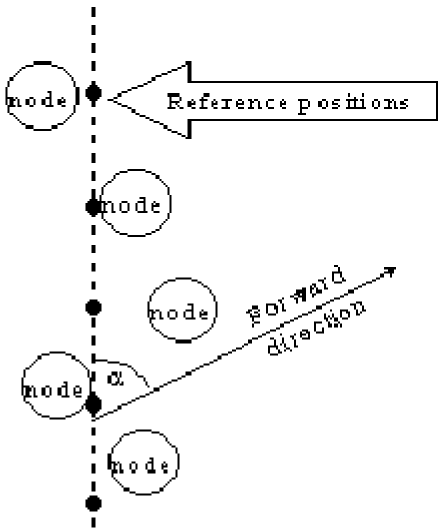


$new\_pos = old\_pos + random\_pos$

Although it can be useful as a first model and for special conditions testing.In this model each node moves a certain amount of space after a random period. The movement of nodes is totally isolated.

2.2 Column Model [Sanchez]

The column model tries to represent the moving pattern of a row of robots moving in a certain direction. This behavior can be found on a searching activity (e.g: anti-personal mines deactivation robots).



$new\_pos = (old\_reference\_pos + advance\_vector) + random\_vector$

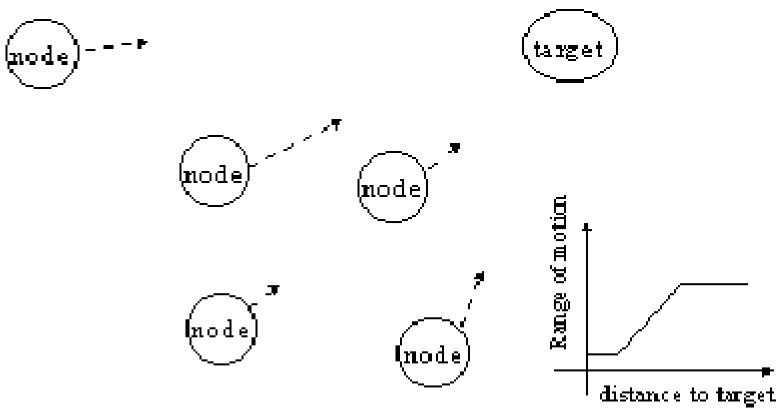
$new\_reference\_pos = old\_reference\_pos + advance\_vector$

But the model is not limited to a forward direction normal to the row axis, but any angle could be possible to, for example, forming a "one behind the other" motion, also present in some robotics activities (e.g: transportation convoy).

Of the different approaches to implement the model, the simpler one is to have a reference initial grid (forming a column of nodes) and then allow a node to move around its reference position.

2.3 Pursue Model

Nodes chase after a single target that may or may not be moving. Here we have a collection of robots (nodes) trying to catch a single robot that acts as a target. This kind of behavior is found in multiple robotics activities (e.g: people or equipment tracking).



$$new\_pos = old\_pos + acceleration(target\_old\_pos) + random\_vector$$

Here the idea is to allow only a limited maximum step in each new movement (that is what does the acceleration function) and also maintaining a little random movement (which is certainly limited to allow the effective tracking of the target).

The model is based on the fact that physics does not let a pursuer robot to follow any position change of the target but its acceleration is limited and so, the tracking is usually done with some error, that may also be due to other factors. This model also suposses certain randomness of the movements even when the target is stopped and tracked.

2.4 Random Walk Model [Zonoozi and Dassanayake]

The most common model in cellular mobility modelling is the random walk model. The model describes individual movement relative to cells. In this model, a mobile host moves from its current position to the next position randomly. The speed and direction are picked uniformly from the numerical ranges [V_{min},V_{max}] and [0, 2π]respectively. In a typical Markovian model for one dimensional random walk, a MH in cell i is assumed to moveto cells $i + 1, i - 1$ or to stay in cell i with given transition probalities.

The random walk model has been used to investigate abroad set of different system parameters. For example, Rubin uses the random movement assumption to get the mean cell sojourn time E(S) first, then to derive many other system measures. Zonoozi conducts a systematic tracking of the random movement of a MH. At each instant, he partitions the whole area into several regions according to previous, current and next motion directions of a mobile host. He mathematically gives the conditions for movements from the current region into the next region. His tracking of mobility leads to the calculation of channel holding time and handover number. Decker characterizes an individual MH with the mean duration of stay in the current position and the probability of choosing a moving path. A predesigned state-transit matrix can give the mobile host a motion pattern such as moving on a highway, on streets or just like arandom pedestrian.

Haas presents a Random Gauss-Markov model forcellular networks. His model includes the random-walk model (totally random) and the constant velocity model(zero randomness) as its two extreme cases.

This model was extended to various other models such as

- Random Way Point Model
- Random Gauss Markov Model
- Markovian Model

2.4.1 Random Waypoint mobility model

Johnson's Random Waypoint mobility model is also an extension of random walk. This model breaks the entire movement of a MH into repeating pause and motion periods. A mobile host first stays at a location for a certain time then it moves to a new random-chosen destinationat a speed uniformly distributed between [0, MaxSpeed].

2.4.2 Random Gauss Markoov Model

Similar to Chiang's Markovian model, other models consider the relationship between a mobile host's previous motion behavior and the current movement inspeed and/or direction. In particular, presents an incremental model in which speed and direction of currentmovement randomly diverge from the previous speed and direction after each time increment. Namely, speed v and direction θ are expressed as below

$$v(t + \Delta t) = min[max(v(t) + \Delta v, 0), V_{MAX}]$$

$$\theta(t + \Delta t) = \theta(t) + \Delta(t)$$

where Δv and $\Delta\theta$ are uniformly picked from a reasonable data range of $[-A_{max}\Delta t, A_{max}\Delta t]$ and $[-\alpha\Delta t, \theta\Delta]$.
A_{max} is the unit acceleration/ deceleration and α is the maximal unit angular change.

2.5 Mobility Vector Model

This model simulates natural and realistic mobility for various applications, especially in heterogeneous network applications. Most of the existing mobility models allow random movements, such as sudden stops, turn backs, sharp turns, and etc., which are physically impossible in the real world. By "remembering" mobility state of a node and allowing only partial changes in the current mobility state, we can reproduce natural motions. With this scheme, it is possible for us to imitate almost any existing mobility model. As we will see, the advantages of this model are: simplification of position updates, ease of implementation and opportunity for mobility prediction.

The mobility of a node is expressed by a vector (x_v, y_v) which represents 2-dimensional velocity components of the node.The scalar value (norm) of a mobility vector is the speed, computed as the distance between the current position of a node and the next position after a unit time. The mobility vector $\overrightarrow{M} = (x_{m,}y_m) \quad or \quad (r_{m,}\theta_m)$ is the sum of 2 sub vectors: the Base Vector $\overrightarrow{B} = (bx_v, by_v) \quad or \quad (r_m, \theta_m)$ and the Deviation Vector, $\overrightarrow{V} = (vx_v, vy_v) or (r_v, \theta_v)$. A Base Vector defines the major direction and speed of a node. A Deviation Vector stores the mobility deviation from the base vector. The model shows that $\overrightarrow{M} = \overrightarrow{B} + \alpha \times \overrightarrow{V}$,

, where α is an acceleration factor. By properly adjusting the acceleration factor and make the speed varing in the range [Min, Max], it is possible to generate a smoother trajectory and eliminate the chance of unrealistic node motions. This is an important feature of the new mobility vector model. For radian coordination, the Min/Max steering angle and the steering factor also can ensure more natural direction change.

The other models which were defined keeping Mobility Vector Model as the framework are as follows

1. Gravity Model

   - Receivers tend to move towards signal source.
   - Every MH node is assigned a charge (+ve -ve or none) Base stn is -ve
   - Mobility Vector is function of distance and charges

2. Location Dependant Model

   - Collective mobility pattern in specific area
   - MV has common component which represent the direction and speed

3. Targetting Model

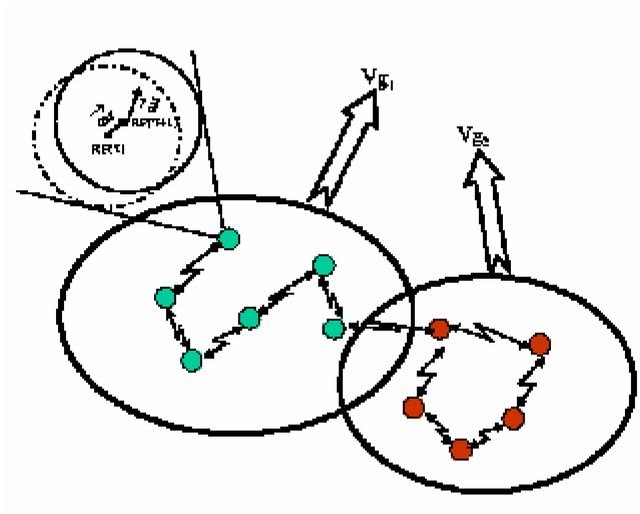
   - Nodes move toward a common target
   - Given a target co ordinate it is easy to calculate a base vector

4. Group Motion Model

   - Teams which tend to co ordinate their movements
   - Different Group Patterns can be represented using a Base Vector and different Deviation Vector

2.6 Reference Point Group mobility Vector

In Reference Point Group Mobility (RPGM) model, each group has a logical "center". The center's motion defines the entire group's motion behavior, including location, speed, direction, acceleration, etc.. Thus, the group trajectory is determined by providing a path for the center. Usually, nodes are uniformly distributed within the geographicscope of a group. To node, each is assigned a reference point which follows the group movement. A node is randomly placed in the neighborhood of its reference point at each step. The reference point scheme allows independentrandom motion behavior for each node, in addition to the group motion. gives an example of a two-group model. Each group has a group motion vector.



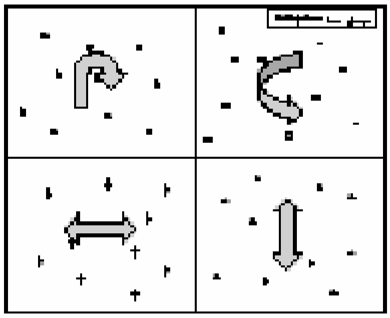
Above figure gives an example of a two-group model. Each group has a group motion vector $\overrightarrow{V_{g_i}}$. the figurealso gives an illustration of how a node moves from time tick τ to $\tau + 1$. First, the reference point of a node moves from RP (τ) to RP (τ+ 1) with the group motion vector $\overrightarrow{GM}$ (Here, $\overrightarrow{GM} = \overrightarrow{V_{g_i}}$). Then the new node position is generated by adding a random motion vector $\overrightarrow{RM}$ to the new reference point RP($\tau + 1$). Vector $\overrightarrow{RM}$ has its length uniformly distributed within a certain radius centered at the reference point and its direction uniformly distributed between 0 to 2π. This random vector $\overrightarrow{RM}$ is independent from the node's previous location.

The RPGM model defines the motion of groups explicitly by giving a motion path for each group. A path which agroup will follow is given by defining a sequence of check points along the path corresponding to given time intervals. As time goes by, a group moves from one check point to the next on a continuing basis. Each time the group center reaches a new check point, it computes the new motion vector $\overrightarrow{V_{g_i}}$ from current and next check point locations and from the time interval.

2.6.1 Various Applications of RPGM

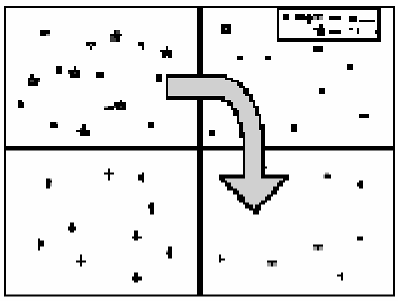
By proper selection of check point path and initial grouplocation and parameters in the RPGM model, it is easy to model various mobility applications. In this section, we il-lustrate the use of RPGM in a few representative cases.

- In Place Group Mobility Model



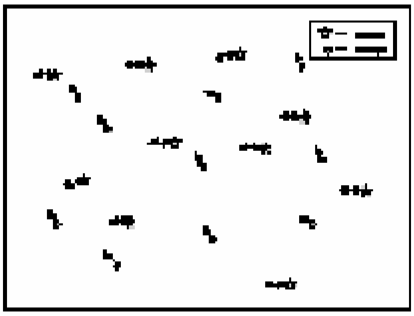
The entire area is divided into several adjacent regions, with a different group in each region. This modelcan be used to model a battlefield situation, where different battalions are carrying out same operations(e.g., land minesearch) in different areas. Each group is in charge of one partition. Another application can be large scale disasterrecovery, where different paramedic, police, firemen teams work in separated neighborhoods

- Overlap Mobility Model



Different groups carry out different tasks over the same area. However, the distinct requirements of each taskmake their mobility pattern quite different. For example, in a disaster recovery area, the rescue team, the medicalassistant team and the psychologist team will be randomly spread out over the area. Yet, each group has a uniquemotion pattern, speed, scope etc.. In Figure 3, there are two groups working in the same area.

- Conventional Model



It models the interaction between exhibitors and attendees. In a convention, several groups give demos of their research projects /products in separate but connecting rooms. A group of attendees roams from room to room. They may stop in one room for a while and then move on to anotherroom. Or, they may pass through one room quickly. Above Figure shows a group of attendees roaming around four exhibitrooms. This is called the Convention Model.

2.7 Other Mobility Models

Flies on a Cake [Sanchez]: Nodes are modeled as the flies flying around a cake while the cake is moving (depending on the acceleration of this movement you'll get different flies density: a fast move will increment the separation between every node, but as the acceleration decreases the cloud of flies will be concentrated in a smaller volume (higher flies density).

Nomadic Community [Sanchez]: Similar to the flies on cake, but minimum and maximum separation between nodes is bounded, and the whole group of nodes movement is done in stages after which the nodes spend an amount of time moving like the Brownian model but only inside its bounded circle

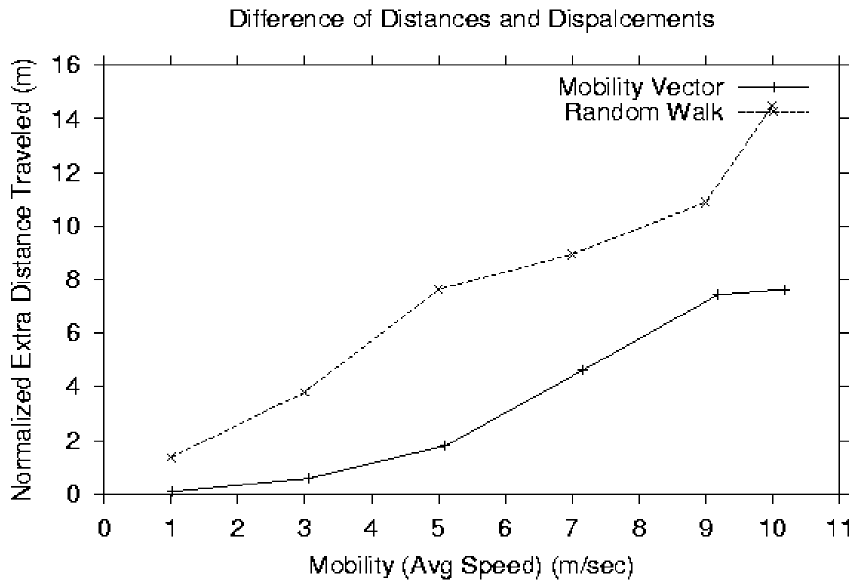
Smooth Random Mobility Model [Bettstetter]: Uses stochastic principles for direction and speed control in which the new values for speed & direction are correlated to previous values. This feature makes movement of nodes more smooth than random movement. Speed control is based on target speeds changing according to Poisson process.

3 Mobility Parameters

3.1 Average Speed and Distance Traveled

With random motion, when an average speed is given, the actual traveled distance may be larger than the geographical displacement over a given time interval. For example, a node may just bounce around its initial location in a certain period where the traveled distance is large but the geographical displacement is near zero. The reduced displacement will lessen the impact of mobility on the applications using random mobility models. Here we analyze different mobility effect under the traveled distance and the geographical displacement.

In simulation, the average speed is defined as the actual traveled distance over simulation time. This measure is conceptually and computationally simple and commonly used. Here we also measure the geographical displacement. We measure the two types of distances over a small time interval. After averaging the two measures over all the intervals in simulation and over all nodes, we normalize actual traveled distance by geographical displacement. The result is the extra distance traveled in order to achieve a certain geographical displacement.

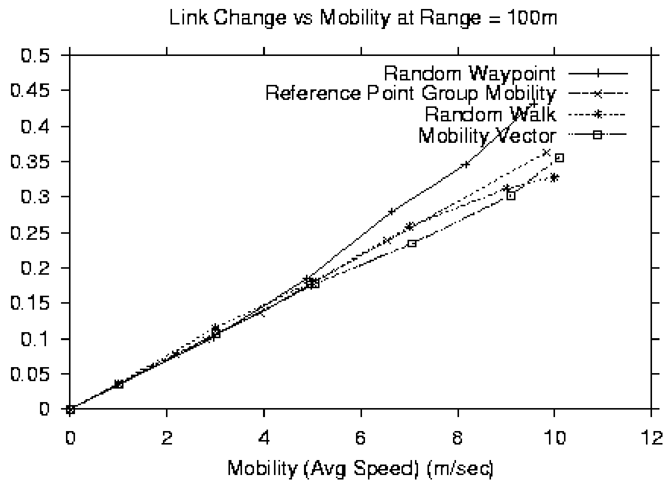


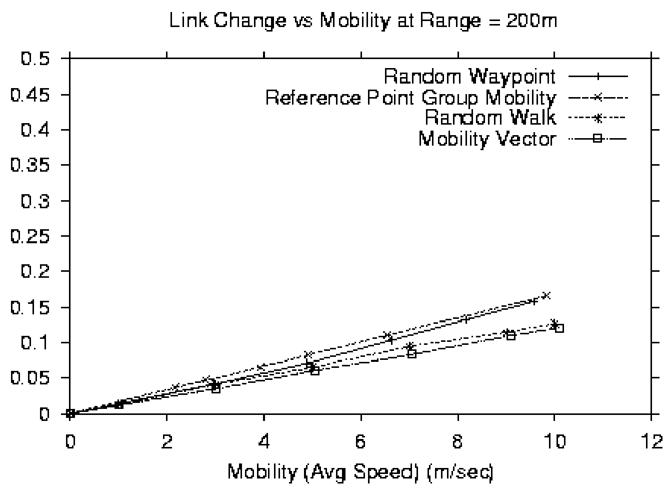
The above Figure reports the extra distance traveled as a function of average speed for two mobility models, i.e., Random Walk and Mobility Vector. The figure shows that Random Walk model produces more extra traveled distance than Mobility Vector model. Which means that given the same instantaneous speed, the Random Walk produces less geographical displacement. This lessens the impact of mobility at instantaneous speed on topology change

3.2 Transmission Range and Link Changes

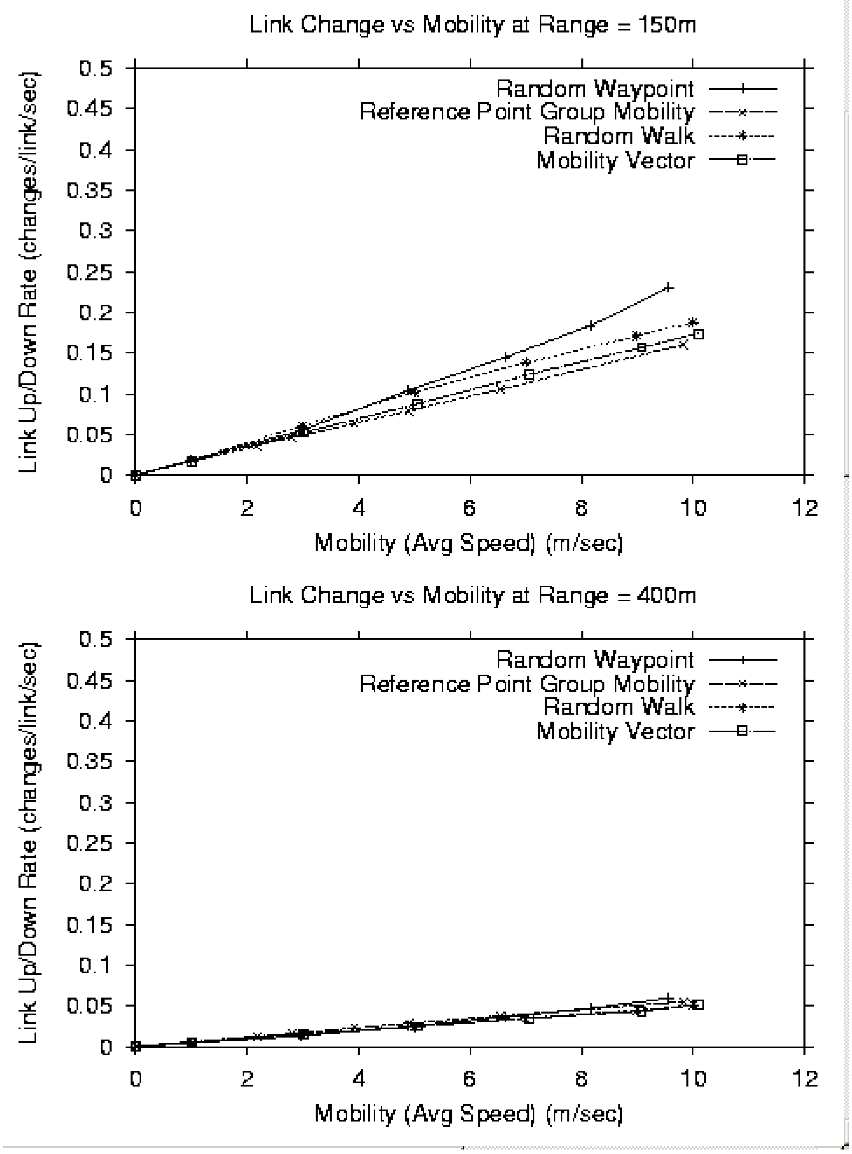
An advantage of the limited simulation space is that it can maintain a certain degree of node distribution density, which is necessary for keeping a node's connection to its neighbors, given the transmission ranges of nodes are limited. However, when nodes are mobile, the distribution of nodes can not keep as uniform as the initial time. To what degree this will affect the network connecting topology and in turn, affect the performance of routing protocols and upper layer protocols will depend on many factors, such as, transmission range and mobility speed.

From intuition, it is understood that in order to get a good performance, the choice of transmission range is related to mobility. As the battery power is a critical constraint for mobile wireless communications, we want to choose the minimum possible range which yet provides adequate connectivity in the face of mobility.





In this section, we use four mobility models to study the link change rate. The models we choose are Random Walk, Random Waypoint, Reference Point Group Mobility (RPGM) model and the Mobility Vector. Every model requires specific parameters to define the motion it will produce. In order to compare them on an equal base, we choose the parameters in such a way that they provide the same average speed (measured through traveled distance).



The above figure shows that in terms of the link change rate, for the same transmission range, the four models do not present great differences. Small differences exist. For example, Random Waypoint has higher rate at high mobility when transmission range is small. When the transmission range is large, every model has very small link change rate. When mobility increases, the link change rate increases for all the mobility models.

As the models behave similarly under different transmission ranges, we only show results from Mobility Vector model to investigate how the link change rate reacts to the change of transmission range at different mobility. Figure 3 illustrates that when transmission range is equal to the mean distance between nodes (i.e., 100m), the change rate is very high - about 35% for mobility = 10; However, when the transmission range increases to 1.5 times of the mean distance, the change rate reduces to a half of the 35%; And when the transmission range increases to 2 times of the mean distance, the change rate decreases to almost one third (about 12%). Further increasing of transmission range decreases the change rate continuously, but does not create dramatic effect. This property holds for all the mobility. Thus, for the sake of minimizing energy consumption, choosing transmission range at a range of 1.5 - 2 time of mean distance is a good solution in free space channel environment.

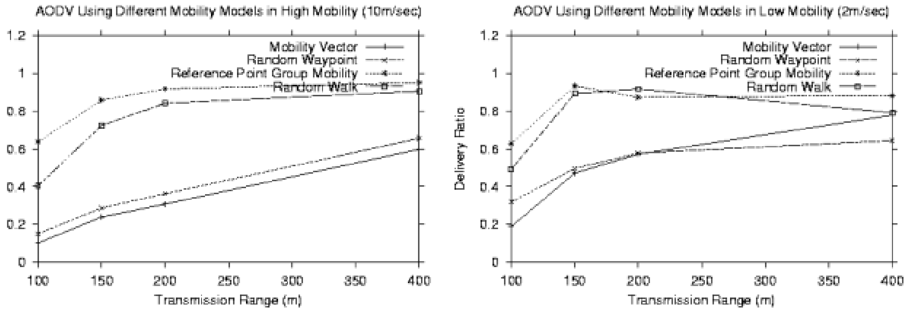
3.3 Network Performance

Here we define several metrics related to mobility. Wefirst monitor the change in link status (up, down) caused by the motion of nodes. When two nodes previously within the transmission range (assuming they have same transmission range) move far away, the connection is lost. This event increments a link down counter. Vice versa, when two nodes move into the transmission range, a connection is gained.This is a link up case. So we evaluate how the mobility affects the link up/down dynamics. Then, we will look at how mobility affects a clustered infrastructure. As the clusterhead serves as a regional broadcast node across clusters and as a local coordinator of transmissions within the cluster, we evaluate the cluster-head change rate. A high clusterhead change rate means an unstable network infrastructure for upper layer. Finally, we observe how routing schemes will perform under various mobility models. We evaluate the performance of routing protocols in two ways:

(a) end-to-endthroughput (kbits over 200-second simulation period) and;

(b) control overhead.

The control overhead is measured as megabits per second per cluster in the cluster infrastructure. With mobility, physically available routes may become in-valid (i.e., may not be found by the routing algorithm), causing packets to be dropped and leading to throughput degradation and increasing control overhead.



Packet Delivery Ratio for AODV

In general, no matter what mobility models are in use, increase of transmission range increases the delivery ratio. Increasing transmission range from one to twice the mean distance (i.e., from 100 to 200m) shows larger improvement with high than low mobility.This effect is particular evident in RPGM and Random Walk model.

A further increase of the transmission range to 4 times the mean distance, however, has different effects on different routing schemes. When transmission range increases, the density of neighboring nodes is increased. Thus more collisions occur. At high mobility, increased density will increase the chance for finding new routes when an old route is broken. The final effects of increased transmission range are mixed with these factors. Mobility Vector and Random Waypoint benefit from the increase in radio range. However, RPGM and Random Walk show little improvement and in some cases, throughput drops. The reason is that RPGM and Random Walk suffer from more collisions because they are more topology stable than the other two models at a given average speed.

In spite of these differences, we can still conclude that transmission range from 1.5 - 2 times the mean distance will produce uniformly the best improvements in delivery ratio. This appears to be the optimal range for a free space channel.

The four mobility models have different impact on routing protocols. Our most realistic model, the Mobility Vector model, produces the worst case routing performance, with the widely used Random Waypoint model coming the second worst. The Waypoint model produces a straight line motion pattern between pauses. Its impact on routing, thus, is more like that of the Mobility Vector, which moves on a smooth trajectory. In the RPGM model, the coordinated motion behavior among group members and the swing around reference points tends to produce a smaller over all topology change, and thus better delivery ratio, though the link change performance is compatible to all others.

4 Conclusion

Simulation results thus show that the choice of the mobility model makes a difference in the study of network performance. The results also suggests that a realistic mobility model is not necessarily producing better routing performance. In a contrary, given a realistic mobility model, studying how well a routing protocol can perform will help in evaluating routing protocols for applications of ad hoc networks. Performance studies among various models are necessary. The study of link dynamics shows different mobility models do not produce remarkably different behavior. However, the simulation results show that a transmission increase from 1.5 - 2 times the mean node distance will drastically reduce link change rate, which, as a consequence, will generate larger packet delivery ratio no matter what routing protocols are used. The effect of further increasing the transmission range is positive for Mobility Vector and Random Waypoint, but is neutral or even negative (in the FSR case) for RPGM and Random Walk.

In summary, the choice of the mobility models makes a difference in the study of network performance. Mobility Vector and Random Waypoint models provide "lower bound" type performance while Random Walk and RPGM produce top performance. These results show that, prior to deploying ad hoc network in a real environment, it is not sufficient to test its performance with a single mobility model since the choice of motion pattern can have major impact on performance.

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