A Mobility Framework for Ad Hoc Wireless 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. Here, we propose a universal mobility framework, Mobility Vector Model, which can be used for recreating the various mobility patterns produced in different applications. Case studies on optimal transmission range as a function of mobility and on network performance under various mobility models are presented in the paper. Simulation results show that excessively large transmission range will not improve network performance significantly because of the increased collisions. There is an optimal range between 1.5 – 2 times the mean node distance for free space channel. Also, simulation results show that different mobility models will have different impact on the network performance for a variety of routing protocols (AODV, DSR, FSR). When choosing routing protocols for ad hoc network applications, performance studies under multiple mobility models are recommended. The Mobility Vector model can provide a realistic and flexible framework for reproducing various models. ...

1 Introduction

Multi-hop wireless networks are an ideal technology to establish an instant communication infrastructure for civilian and military applications. Target applications range from collaborative, distributed mobile computing to disaster recovery (such as fire, flood, earthquake), law enforcement (crowd control, search and rescue) and tactical communications. 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

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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.

Many mobility models have been proposed for ad hoc wireless networks. Each one of them was designed to produce a particular motion behavior. A popular scheme is the Random Walk model [3]. In this model, a mobile host moves from its current position to the next with memoryless, randomly selected speed and direction. Many mobility models were derived from this one. Among them, is the Random Waypoint mobility model [6]. The model breaks the entire movement of a mobile host into a sequence of pause and motion periods. A mobile host stays in a location for a certain time then it moves to a new random-chosen destination at a speed uniformly distributed between [0, MaxSpeed].

The above mobility models apply to individual motion behaviors. However, in a real environment, a group of mobile hosts tend to move with a common objective (e.g., military deployment). Therefore, the group motion behavior is also important in some applications. To this end, the Reference Point Group Mobility (RPGM) model was proposed [4]. In this model, there is a logical "center" for each group. The center's motion summarizes the entire group's behavior. Each node is assigned a reference point (i.e., relative position with respect to the center) which follows the center movement. The random displacement in the neighborhood of the reference point represents the individual random motion component for each node.

One of the major applications of ad hoc wireless networks is the digital battlefield. In the tactical environment, mobile nodes could be individual soldiers, artilleries, SAM launchers, trucks, helicopters, support vehicles, UAVs in the sky and even satellites at higher elevations. Each different entity has different communication capabilities. So, it is reasonable to assume that the whole network is a heterogeneous environment. In this environment, different types of mobile nodes will have different types of motion behavior. Therefore, a flexible mobility framework is needed to model this hybrid motion patterns. The Mobility Vector model [5] is suitable for this need. Even in a homogeneous environment, the Mobility Vector model can be used to advantage, for example to avoid some unrealistic random movements such as sudden stops, turn backs, sharp turns, etc. The Mobility Vector model will be described in the next section. The ability of representing versatile models suggests that the model can be used as a mobility framework for various simulation.

The paper is organized as follows. In Section 2, the Mobility Vector framework is described. Section 3 discusses average speed and transmission range issues related to mobility models. Section 4 presents the performance results using various mobility models. Section 5 concludes the paper.

2 Mobility Vector Model

In this section, we introduce a new mobility framework, which can simulate 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.

2.1 Mobility Vector Model

The mobility of a node is expressed by a vector (x_v, y_v), which represents 2-dimensional velocity components of the node. The 3-dimensional extension is straight forward. 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 $\overrightarrow{M} = (x_m, y_m)$ or (r_m, θ_m) is the sum of 2 sub vectors: the Base Vector, $\overrightarrow{B} = (bx_v, by_v)$ or (r_b, θ_b) and the Deviation Vector, $\overrightarrow{V} = (vx_v, vy_v)$ or (r_v, θ_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.

2.2 Mobility Vector Model as a Framework

Gravity Model In some wireless communication systems, receivers may tend to move towards the signal source, looking for a better signal. For example, in a cellular system, if a user experiences a low quality of communication and can move around, he may try to move towards a Base Station. The Gravity Model reproduces the above mobility patterns. Every mobile node in this model is assigned a charge. Some of them have positive charges, others have negative charges, and the rest of them are not charged. The latter are free from gravity. For example, in the above cellular system, the Base Station has a negative charge and some of the mobile nodes have positive charges. Nodes with the same polarity repel each other; and nodes with opposite polarity attract each other. The force between any two nodes can be modeled by base vector using the Mobility Vector model. It is a function of distance and charges.

Location Dependent Model This model represents a collective mobility pattern in a specific area. For example, if a node is on a freeway, its mobility vector has a common component which represent the direction and the allowed speed of the freeway. If we have a digitized map and traffic pattern based on the map, we can use the base vector to implement the collective mobility. When a node moves around the area, it acquires the location dependent base vector specified at the current position.

Targeting Model Targeting is a common pattern of mobility, where nodes move towards a target. Given the target coordinate, it is simple to calculate a proper base vector. When a node approaches a target, it reduces its velocity using negative acceleration factor and then pause when the mobility vector is adjusted to zero. This is an improved implementation of Random Waypoint model which avoids sudden stops.

Group Motion Model In ad hoc networks, communications are often among teams which tend to coordinate their movements (e.g., a firemen rescue team in a disaster recovery situation). To support this kind of communications and movements, the Mobility Vector model can provide efficient and realistic group mobility models. Different group patterns can be represented using base vectors while deviation vectors show the individual behaviors of members in a group. Thus the model can provide flexible group motion patterns for heterogeneous networks, such as those including UAVs (Unattended Airborne Vehicles). UAV backbone nodes and ground nodes typically will exhibit different motion behavior.

3 Calibration of Mobility Parameters

3.1 Average Speed and Distance Traveled

As we mentioned in Section 1, many models adopt random motion. 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.

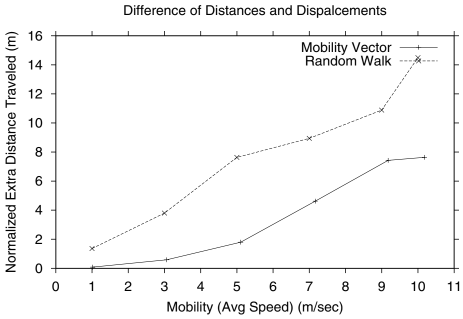

Fig. 1. Displacement Measure

Figure 1 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. The positive influence of this phenomenon to routing protocol will be seen further in Section 4.

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, as we will study in this section.

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 as defined in Section 3.1).

We monitor the change of link status (up, down) caused by the motion of nodes. The rate of the change is used as an indicator of topology change. We

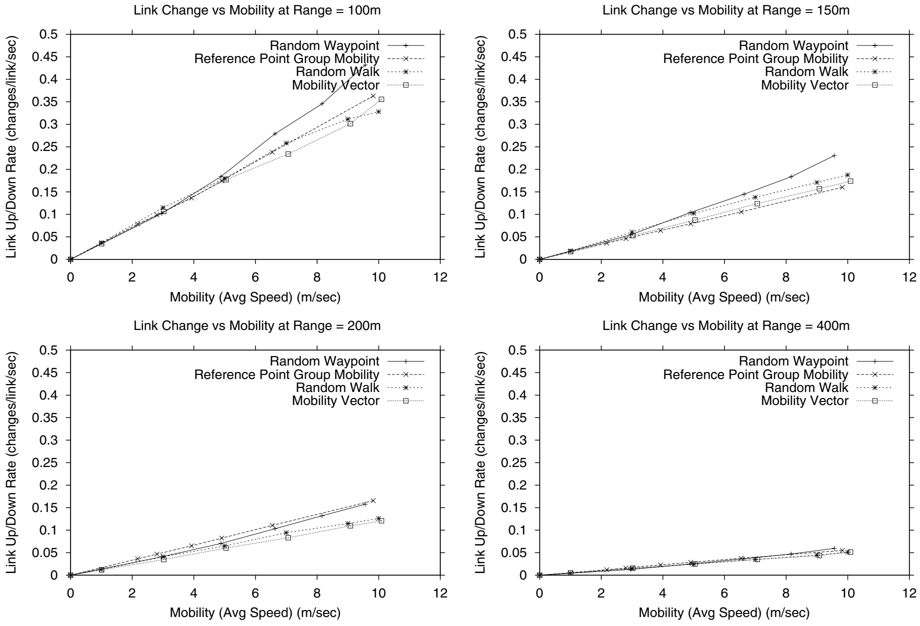

Fig. 2. Link Change vs Mobility at Various Transmission Ranges

evaluate the effect of mobility to the link change rate under various transmission ranges from 100m to 400m. The simulation area is 1km × 1km with 100 nodes uniformly distributed at initialization. The mean distance between nodes is 100m. Free space channel model is used to calculate the transmission range. We initialize our topology with same density and same scatter pattern for every model for each set of parameters. We run three experiments using the same initial density but different scatter pattern. The final results are the average over of all the executions. For RPGM, a rectangular group motion trajectory is used.

The experiment results given in Figure 2 show 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.

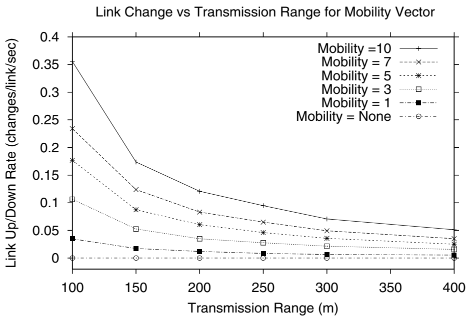

Fig. 3. Link Change Using Mobility Vector

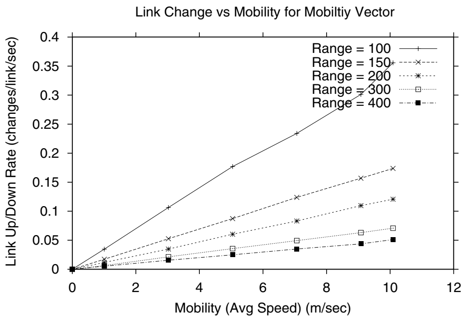

Fig. 4. Link Change Using Mobility Vector

Figure 4 gives another view of the relation between link change rate and mobility. The increase of mobility increases the changing rate.

4 Impact on Network Performance

In a multi-hop network, even relatively small node movements can cause noticeable changes in network topology and thus affect the performance of upper layer protocols, such as throughput and delay. An example of ranking of routing protocols for various scenarios is given in [4]. Exploiting the observations in previous sections regarding the relationship between transmission range and link dynamics, we study in this section the impact of mobility on routing performance.

We will not conduct a complete comparison across "all" routing protocols. Good surveys in this subject can be found in [9,10,11,12]. Here we study a restricted set of routing protocols to which we apply various mobility models with varying transmission ranges.

4.1 Experimental Configuration

The routing protocols used are Dynamic Source Routing (DSR) [6], Ad hoc On Demand Distance Vector Routing (AODV) [7], and the Fisheye State Routing (FSR) [8]. They are all provided within the GloMoSim library [1]. The GloMoSim library is a scalable simulation environment for wireless network systems using the parallel discrete-event simulation language PARSEC [2]. The packet delivery ratio – the ratio between the number of packets received and those originated by the sources, is used as a performance metric.

We use previous mobility models, they are: Mobility Vector, Random Waypoint, Reference Point Group Mobility (RPGM) and Random Walk. The parameters of the four models are set so as to achieve the same average speed. For Mobility Vector model, the acceleration factor is set to zero and for Random Waypoint, the pause time is fixed to 10 seconds. The Min/Max speeds for both model are set to be ±1 around various average speed for experiments. For RPGM model [4], all the nodes are in the same group. The group's trajectory is a rectangular cycle. The center of the group moves 250m on each edge. The simulation area is 1km × 1km with 100 nodes uniformly distributed at initialization. The RPGM has 1.25km × 1.25km simulation area to keep nodes spreading in 1km × 1km field and moving in a rectangular cycle. The transmission range will change in our simulation. In the simulation, 50 Constant Bit Rate (CBR) source-destination pairs randomly spreading over the network are used. The size of the data payload is 512 bytes. The distributed coordination function (DCF) of IEEE 802.11 is used as the MAC layer in our experiments. The radio model has the capture function turned on. Free space propagation model is used. The channel capacity is 2 Mbits/sec.

4.2 Results

Figure 5 gives the simulation results for AODV in high mobility (10m/sec) and low mobility (2m/sec) respectively. Figure 6 gives the results for DSR, and Figure 7 for FSR.

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. These results are constant with those in Section 3.2, i.e.,

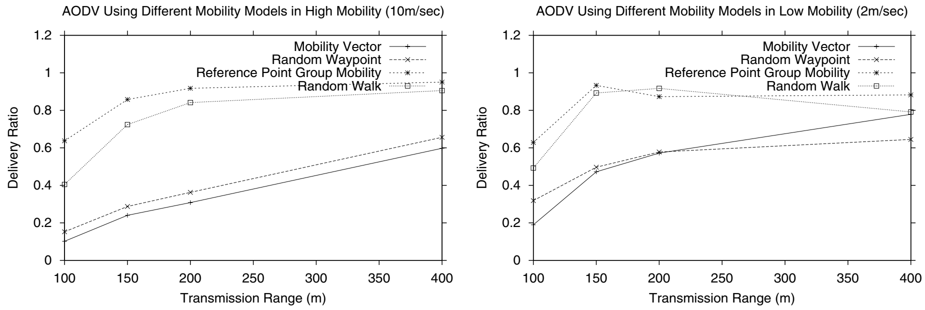

Fig. 5. Packet Delivery Ratio for AODV

link up/down statistics. 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.

The increase in transmission range has different effects on different routing schemes as well. In particular, FSR (Figure 7) has large degradation of delivery ratio from 200m to 400m. This is because at large transmission range, there will be too many nodes within the fisheye scope. Then, the increased routing table size and corresponding periodic update traffic overhead degrades the packet delivery capability.

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. For

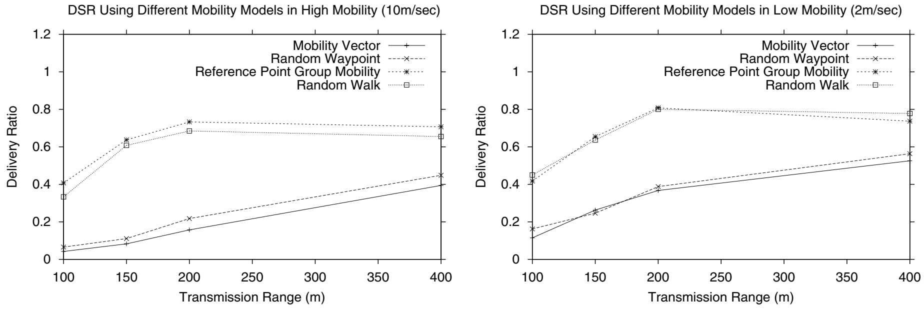

Fig. 6. Packet Delivery Ratio for DSR

Random Walk, recall from subsection 3.1 that nodes also tend to swing forward which leads to mobility underestimation and thus higher packet delivery ratio is observed.

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.

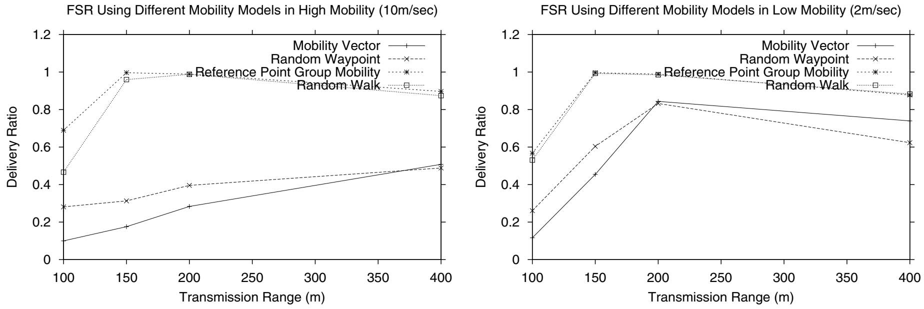

Fig. 7. Packet Delivery Ratio for FSR

5 Conclusion

In this paper we have proposed a mobility framework - Mobility Vector model. The model uses sub vectors for keeping current mobility information and providing partial changing in motion. Mobility Vector model provides realistic and flexibility for reproducing various models within a single framework in various simulations. 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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