Modeling Mobility for Vehicular Ad Hoc Networks

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ABSTRACT

Without realistic modeling of node mobility, simulation evaluation of performance of mobile ad hoc networks may not correlate well with performance in a real deployment. In this paper, we propose a realistic model of node motion based on the motion of vehicles on real street maps. As a consequence, our model has the advantage of generating mobile scenarios that are unique to the geographical area that might be the target for the deployment of a mobile ad hoc network. We compare our model with the Random Waypoint mobility model, the most widely used mobility model. Results show that, in many ways, the Random Waypoint mobility model is a good approximation for simulating the motion of vehicles on a road, but there are situations in which our new model is better suited. Our mobility model can be used with the ns-2 *simulator, thus making it easy for other researchers to use it for realistic simulation analysis.*

Categories and Subject Descriptors

I.6.5 [**Simulation and Modeling**]: Model Development—*modeling methodologies*

General Terms

Design

Keywords

Modelling, mobility, vehicular ad hoc networks, street mobility, ns2, simulation, wireless networks

1. INTRODUCTION

During the last decade, tremendous progress has been made in methods of providing network connectivity to mobile users. Notable among such technologies are infrastructure-based networks and, more recently, mobile ad hoc networks. Examples of infrastructure-based networks include cellular networks and IEEE 802.11 [12] (WiFi) access point networks; however, such networks depend on the existence of an infrastructure (base stations and access points). Mobile ad hoc networks, on the other hand, do not require such infrastructure and hence promise to be more easily deployable and more flexible than infrastructure-based networks.

One emerging, new type of ad hoc network is a *vehicular ad hoc network*, in which vehicles constitute the mobile nodes in the network. As a result of each node being a vehicle, certain traditional concerns with mobile nodes, such as power efficiency, are no longer of primary importance. However, the utilization of a vehicular ad hoc network can be for very different purposes than the purposes for which traditional mobile ad hoc network might be used. In particular, a vehicular ad hoc network should enable applications that improve the safety and comfort of passengers inside vehicles, possibly in that order of importance.

Research in the general area of mobile ad hoc networks has made great progress toward making such networks more practical so that they can be deployed in real applications. Arguably, simulation is the most effective tool available to the research community for the evaluation of protocols and architecture. Even though real world deployment is essential to understanding the effectiveness and performance of ad hoc networks, simulation provides some advantages over actual deployment. In particular, simulations are fast and repeatable and it is possible with simulation to isolate parameters affecting the performance of a design. Isolation of parameters is essential to understanding the effect of each parameter on the design. Also, simulations allow testing a design on a wide variety of scenarios and parameter values, which is difficult or impossible in a real deployment.

Some of the most important properties of a *mobile* user population are the characteristics and pattern of the users' mobility. In simulating mobile systems, it is important to use a realistic mobility model so that the evaluation results from the simulation correctly indicate the real-world performance of the system. However, almost all mobility models that are in use in current simulation tools such as *ns-2* [2] are not realistic. For example, the most commonly used mobility model, the Random Waypoint model [6], does not attempt to model any particular real mobility situations.

In this paper, we propose a realistic mobility model based on vehicular traffic, suitable for evaluating vehicular ad hoc networks. We make use of the publicly available TIGER (Topologically Integrated Geographic Encoding and Referencing) [1] database from the U.S. Census Bureau, giving detailed street maps for the entire United States of America, and model automobile traffic on these maps. As an advantage of using real street map data, our modeling tool can generate mobile scenarios that are unique to the particular geographical area that might be the target for the deployment of a future mobile ad hoc network. We show that, surprisingly, in many cases the Random Waypoint mobility model is a good approximation of our new vehicular mobility model, but there are scenarios for which our model is better suited. Our mobility model generates scenario files that are compatible with *ns-2* and hence can be easily used by the research community.

The rest of the paper is organized as follows. In Section 2, we explore related work. In Section 3, we explain the design of our methodology to obtain a mobility model from the TIGER database. We present the characteristics of our new vehicular mobility model in Section 4. In Section 5, we discuss the limitations of this model, how this model can be enhanced, and how this model can be used for other types of networks. Finally, we conclude in Section 6.

2. RELATED WORK

Several surveys of models for mobility of nodes in a network have been presented in previous works, including those by Camp et al. [7] and Bettstetter [3]. We briefly review some of the common mobility models below.

A basic type of mobility model is the *Random Walk* model, in which a node chooses a direction and a speed from a given speed distribution and moves in that direction for a specified time. When this time ends, the node repeats this motion. A very similar model is the Random Direction model in which the nodes chooses a direction and speed and moves till the node reaches a specified distance from the boundary of the network upon which the nodes chooses another random direction and speed and repeats the process.

The most commonly used mobility model in the mobile ad hoc wireless research community is the *Random Waypoint* model [6]. In this model, each node individually chooses a random destination within the simulated network boundary and also chooses a random speed, between a minimum and maximum speed, with which the node moves towards that destination. Once the node reaches the destination, the node pauses at the destination for a *pause time* period. After the pause time, the node repeats the process, choosing another random destination and random speed. The characteristics and properties of this mobility model have recently been studied in detail [4, 5]. Bettstetter [3] modified this model so that instead of suddenly changing to a new random speed after a node has reached a destination, the node accelerates to reach the target speed, and before reaching the destination, the node decelerates to come to a halt.

Mobility models that restrict nodes to move only until the boundary of a network have the characteristic that, over time, nodes tend to congregate toward the center of the network area and thus present a skewed node distribution. In order to remove that limitation, Haas proposed the Boundless Simulation Area mobility model [9], in which, when a node reaches the boundary of the network area, the node wraps around to the other side of the area.

All the above mobility models do not represent any type of *real* node motion. There have been some attempts to design mobility models that reflect more realistic mobility. For example, Hong et al. [10] proposed the *Reference Point Group* mobility model, in which users belong to groups and the motion of users belonging to the same group are not independent but are governed by the motion of reference point for the group. Jardos et al. [13] introduced obstacles into the scenario so that both node mobility as well as wireless transmission was restricted. Jetcheva et al. [14] used actual movement traces of the fleet of city buses, running on their normal routes, in the Seattle, Washington metropolitan area.

The prior mobility model that is closest to our work is the *City Section* mobility model proposed by Davies [8]. However, the main difference is that Davies proposes a model in which the streets in the city section are created by the user and hence is only as realistic as the user's imagination of the actual street network. In contrast, we use actual street maps, thus making the model much more realistic. Also, the our method is easier to use since the actual street network for the U.S. is publicly available. Moreover, to the best of our knowledge, ours is the first work analyzing the characteristics of a realistic street mobility model.

3. DESIGN

We first explain the format of the street map data that is available from the U.S. Census Bureau and then discuss the actual design of how to generate mobility scenario using this data.

3.1 U.S. Census Bureau Street Map Data

The United States Census Bureau makes available detailed street maps for the entire United States, based on the Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) database. These maps, in the form of TIGER/Line files, contain selected geographic and cartographic information, and are freely available to the public. These files are typically used to provide the digital map base for Geographic Information Systems or mapping software.

TIGER/Line file are organized according to United States counties. There can be up to 17 data files for each county, each file representing a different data type; some counties do not require all of the 17 data types. Within these files, we use one type of data, the *Complete Chain Basic Data Record*, and specifically those which correspond to different kinds of roads. Among various information about a road, the following essential information is present for each road:

1. Road identifier: A unique identifier for the road.

2. Road type: This can be one of several types, such as *highways* and *unseparated city streets*. However, the type of road does not identify whether the road is a one-way road or not. We currently assume all roads to be bidirectional.

3. Start longitude: The longitude of the starting intersection for this segment of the road. If a road does not start at an intersection but starts at a dead end, the longitude of the dead end is given.

4. Start latitude: The latitude of the starting intersection for this segment of the road. If a road does not start at an intersection but starts at a dead end, then the latitude of the dead end is given.

5. End longitude: The longitude of the ending intersection for the road segment.

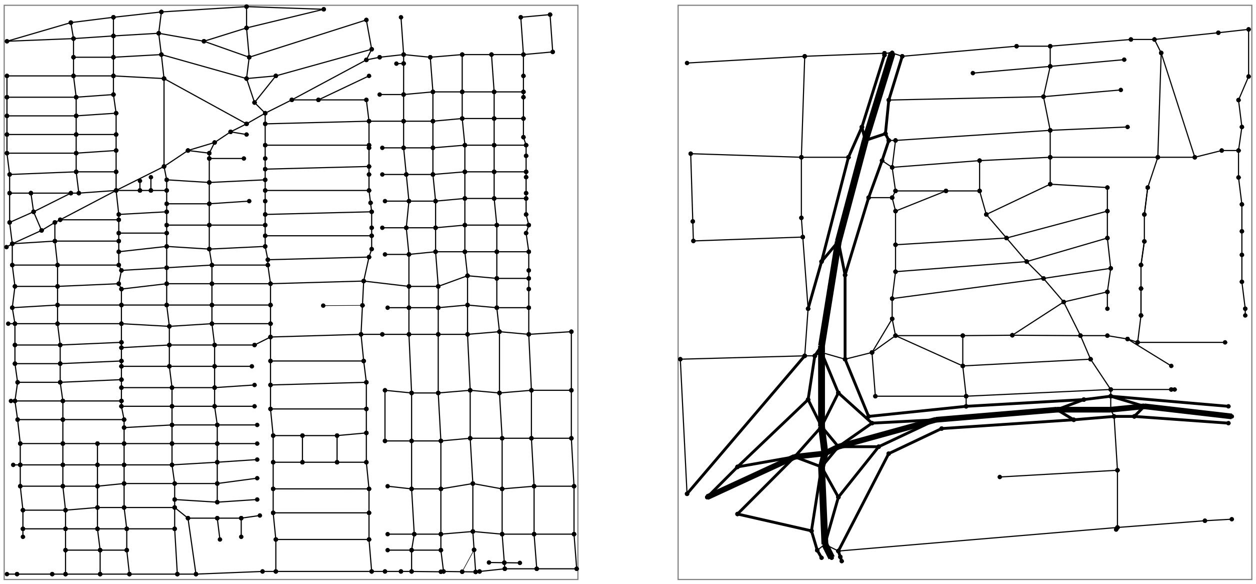
6. End latitude: The latitude of the ending intersection for the road segment.

For example, Figure 1 shows two sections of a major U.S. city, which we used in our evaluation of our vehicular mobility model based on these maps.

The TIGER/Line database also contains supplementary files that describe the latitude and longitude of intermediate points in on a road so that the curvature of the road can be approximated by a piecewise linear curve. However, we currently model each road segment as a straight line between its starting and the ending intersection.

3.2 Simulation Model Map Generation

For each road segment in a map, we extract the the starting and ending coordinates of the road and convert the coordinates to x-y coordinates using a standard *Mercator projection*. We represent



(a) Region *A*: Street scenario corresponding to a square area of size 2400 m×2400 m

(b) Region *B*: Street scenario corresponding to a square area of size 1900 m×1900 m

Figure 1: Sample regions used for simulation study.

internally the set of roads in a graph data structure in which the road intersections are represented by nodes in the graph.

A street from a start intersection S to an end intersection E is represented in the graph by the *weighted* undirected edge $\overline{SE}$. The lower the weight of an edge, the easier it is for a vehicle to drive on that road. For this work, the edge weights are calculated as the expected time to cross the road segment represented by this edge. We model the expected time as a function of the speed limit allowed on the road segment, the distance between the starting and the ending intersections of the road segment, and the number of cars on the road at that time. The TIGER/Line database does not provide speed limit information and so we assume it based on the type of road. We do not currently model the edges as directed edges since the TIGER data does not identify one-way roads.

3.3 Mobility Modeling

To introduce mobile nodes into the network, each node starts at a random point on some road in the network and moves towards a another random point on a random destination street. We use the standard Dijkstra's single source shortest path algorithm to calculate the route from source to destination. The motion of the node is then constrained along this shortest route to the destination. Since, in addition to the speed limit on the road represented by an edge, the weight of an edge in this shortest path computation also changes with the number of vehicles on that road, the weight of an edge changes dynamically, and thus the actual route taken between a source and destination can change depending upon the load on the roads. Once a vehicle reaches its destination, it chooses another random destination, and repeats this process. We assume the speed limit for each road based on the type of road as indicated in the TIGER/Line files, and we randomly pick a speed for each movement of a vehicle on a road uniformly distributed about this speed limit; based on our own experience driving actual roads, we currently use a speed range 5 miles/hour above and below the speed limit.

4. EVALUATION

We evaluated our new vehicular mobility model by analyzing its characteristics and comparing it the Random Waypoint model, currently the most widely used mobility model. To determine the effect of these differences on real ad hoc network protocols, we also compared the performance of the Dynamic Source Routing protocol (DSR) [15], a popular mobile ad hoc network routing protocol, on both mobility models.

As shown in Figure 1(a) and Figure 1(b), we consider two sample regions, *A* and *B* from a well known city in the US. Both the regions are connected such that no street in the region is partitioned from the rest of the region. We choose these areas since these are representative of a large number of city sections all across the US. Region *A* was chosen because it has a very dense street network, thus allowing vehicles to be placed with lesser restrictions. Incidentally Region *A* also consists primarily of one type of road and thus our modeling tool considers all of the roads to have the same speed limit. In particular streets in Region *A* have a speed limit of 35 miles/hour. The other region, Region *B*, has a much sparser street network and hence more restrictive to vehicle mobility. This city section, however, has a section of a freeway, which is missing in the first section. It also has a greater variety of street types and the speed limit varies from 75 miles/hour (for highways) to 35 miles/hour (for normal streets). We analyze these areas and compare them to mobility scenarios over the same sized area and generated using the Random Waypoint model. Also, we choose continuous mobility since that is the most demanding operating condition.

We used our mobility to model to generate scenarios corresponding to Regions *A* and *B*. We generated scenarios with increasing number of mobile nodes (vehicles) in the network and with different wireless transmission ranges. In order to compare with the Random Waypoint model, we generated scenarios of the same dimensions and same number of nodes. For example, in or-

Table 1: Parameters used for simulation analysis

Wireless transmission range (m)	Simulated area (m^2)	Number of nodes	Density of nodes ($\frac{\text{nodes}}{m^2}$)	Nodes within transmission range
250	1500×300	50	1.1×10^{-4}	21.82
250	1000×1000	100	1.0×10^{-4}	19.64
500	1200×1200	50	3.5×10^{-5}	27.28
500	2400×2400	150	2.6×10^{-5}	20.46

der to compare with the scenarios generated with our model for Region *A* with 100 nodes, we generated scenarios with the Random Waypoint model for 100 nodes moving around in a square area of 2100 m×2100 m. Nodes move with an average speed of about 35 miles/hour (15 m/s), uniformly distributed between 10 and 20 m/s.. Each scenario models mobility for 900 s. Each point in our graphs represents the average of 10 runs for that combination of parameters and scenarios. Also, we evaluate the scenarios at regular intervals of 10 seconds. We evaluate the scenarios along the following metrics:

- *Normalized unreachable pairs*: Two nodes in a network are said to constitute an *unreachable pair* if there exist no multi-hop wireless path between the two. This metric is the ratio of the total number of such unreachable pairs to the total number of possible pairs. This metric is also a measure of the *connectivity* present in the network. The higher the value of this metric, the lower the connectivity in the network.

- *Average path length*: The *path length* between two nodes is defined as the minimum number of wireless hops required to reach from one node to the other. This metric is this path length averaged over all connected pairs.

- *Neighbor change*: The change in the neighbors of a node for a particular interval of time. This includes nodes which were neighbors in the previous interval but have moved away so that they are no longer neighbors in the the current interval and the metric also includes nodes which were previously not neighbors but have moved in to become neighbors in the present interval.

Figure 2 shows the characteristics the the scenarios which correspond to Region *A* and with transmission range of 250 m. The figure shows that even with a 200 nodes the connectivity of a the network is poor. The scenarios generated by our mobility model has worse connectivity, especially with 100,150, or 200 nodes. Even with 200 nodes in the network the connectivity is poor with around 10% of node pairs unable to communicate throughout the entire length of the simulation. This implies that the transmission range of 250 m is too small for an area of this size. We could of course make up for the insufficient transmission range with more nodes in the network but having too many nodes in the network is unrealistic. So for further analysis of the scenarios for Region *A* we chose the wireless transmission range to be 500 m instead of 250 m. As shown in Table 1, this is in keeping with the *transmission range — simulation area — total nodes* combinations that are among the ones normally used [6, 11]. The first two rows in Table 1 show previously used parameters whereas the last two rows show parameters used in this paper.

Figure 3 shows the characteristics of the scenarios with a transmission range of 500 m. Expectedly, with just 50 nodes in the network, the connectivity fluctuates a lot. Besides the connectivity with a particular number of nodes in the network is lower for the scenarios generated by our model as compared to the connectivity for the scenarios generated with the Random Waypoint model. Figure 3(a) justifies our choice of 150 nodes to increase the connectivity of the network to an acceptable level. Also, as shown in Figure 3(b) and Figure 3(e) the average path length is more or less the same between scenarios generated using our model and scenarios generated using the Random Waypoint model. However, due to the fact that our mobility model is more restrictive than the Random Waypoint model, the average path length is consistently longer in scenarios generated using our mobility model. Figure 3(c) and Figure 3(f) shows that the number of neighbor changes in an interval is slightly lesser in scenarios generated using our mobility model as compared to scenarios generated using the Random Waypoint model. This is expected since vehicle move in a predictable manner. For example, two cars, one following the other can be expected to stay at a similar relative distance for some time. Such is not the case in Random Waypoint motion since nodes in the Random Waypoint mobility model move independently of nearby nodes.

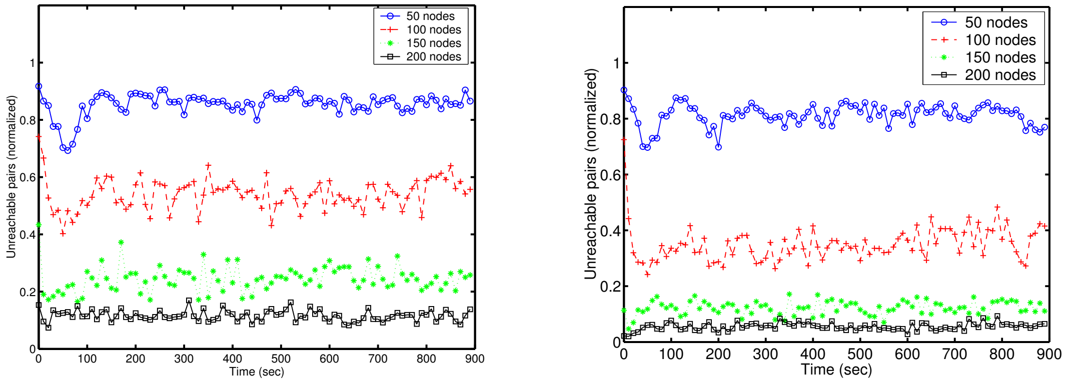
Figure 4 shows our analysis of scenarios corresponding to Region *B* with a wireless transmission range of 250 m shows. Even though the connectivity is much better as compared to the connectivity in Region *A* (Figure 2(a)) yet, even with 200 nodes in the network roughly 5% of node pairs were disconnected. The difference between the connectivity in the scenarios generated by our model and the scenarios generated using the Random Waypoint model is more pronounced since Region *B* has sparser roads and hence is more restrictive than Region *A* as far as node mobility is concerned. As in the case of Region *A* we increased the transmission range to 500 m and then analyzed the scenario. In order to analyze the neighbor change metric we chose 50 nodes since that would give a neighbor count comparable to the other combinations of parameters, as shown in Table 1.

Figure 5 shows the characteristics of the network with a wireless transmission range of 500 m. Since the area covered in Region *B* is less than the area covered in Region *A*, the connectivity achieved in scenarios corresponding to Region *B* is better as compared to scenarios corresponding to Region *A*. The scenarios generated using the Random Waypoint consistently has better reachability than the scenarios generated using our model. The average path length and the neighbor change metrics show trends similar to scenarios corresponding to Region *A*.

4.1 DSR Performance

DSR is a source routing protocol i.e. each packet sent using DSR contains a source route. The DSR protocol consists of two mechanisms: Route Discovery and Route Maintenance. To perform a Route Discovery for a destination node *D*, a source node *S* broadcasts a ROUTE REQUEST that gets flooded through the network in a controlled manner. This request is answered by a ROUTE REPLY from either *D* or some other node that knows a route to *D*. To reduce frequency and propagation of ROUTE REQUESTs each node aggressively caches source routes that the node learns or overhears. Route Maintenance detects when some link over which a data packet is being transmitted breaks. When such a route breakage is detected, a ROUTE ERROR is sent to *S*. Upon receiving a ROUTE ERROR, *S* can use any other route to *D* that it has in its route cache, or *S* can initiate a new Route Discovery for *D*.

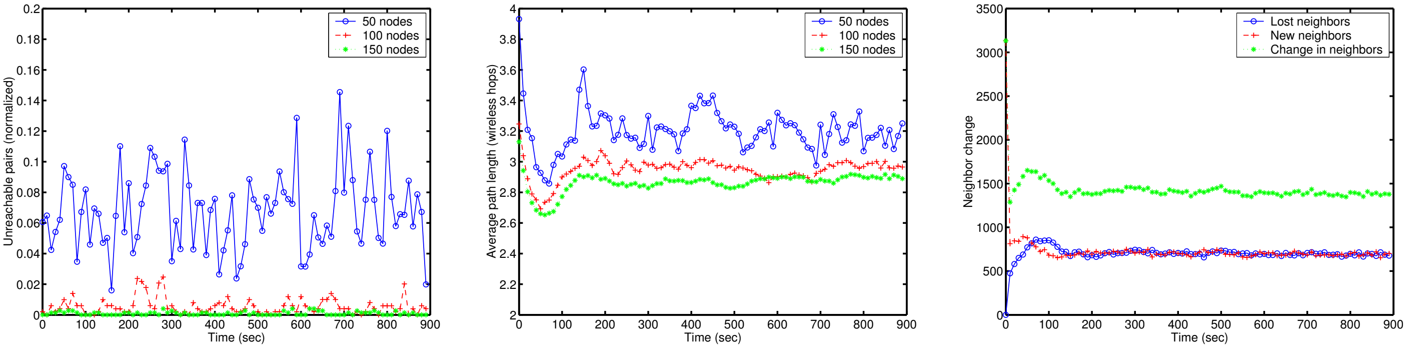
We evaluated the performance of the Dynamic Source Routing (DSR) protocol on the scenarios corresponding to Region *A*. We use the *ns-2* network simulator, with mobility extensions from the Monarch project [17]; version 2.1b8a of *ns-2* was used, with



(a) Number of unreachable pairs (normalized) in the scenario corresponding to Region *A* with 250 m transmission range

(b) Number of unreachable pairs (normalized) in the Random Waypoint scenario with 250 m transmission range

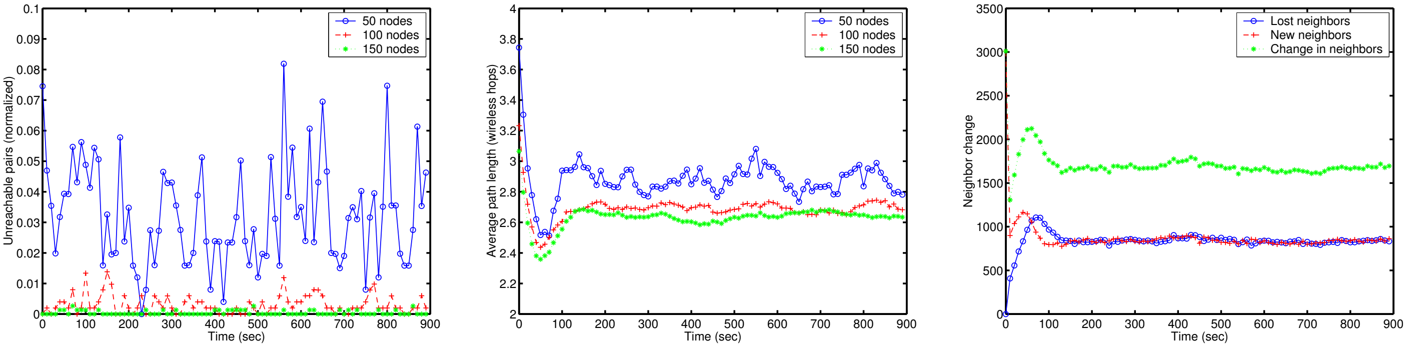
Figure 2: Connectivity in scenarios corresponding to Region *A* (Figure 1(a)) with 250 m transmission range



(a) Number of unreachable pairs (normalized) in the street scenario with 500 m transmission range

(b) Average path length per source destination pair in the street scenario with 500 m transmission range

(c) Change in neighbors every 10 s in the street scenario with 150 nodes and 500 m transmission range

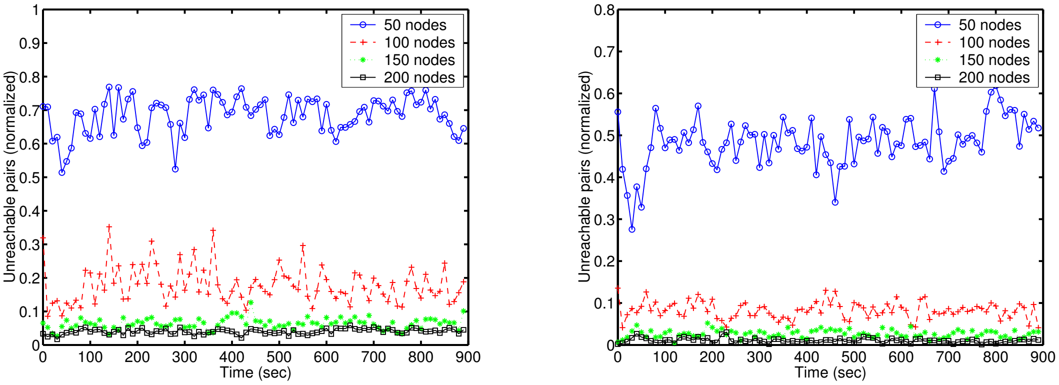


(d) Number of unreachable pairs (normalized) in the Random Waypoint scenario with 500 m transmission range

(e) Average path length per source destination pair in the Random Waypoint scenario with 500 m transmission range

(f) Change in neighbors every 10 s in the Random Waypoint scenario with 150 nodes and 500 m transmission range

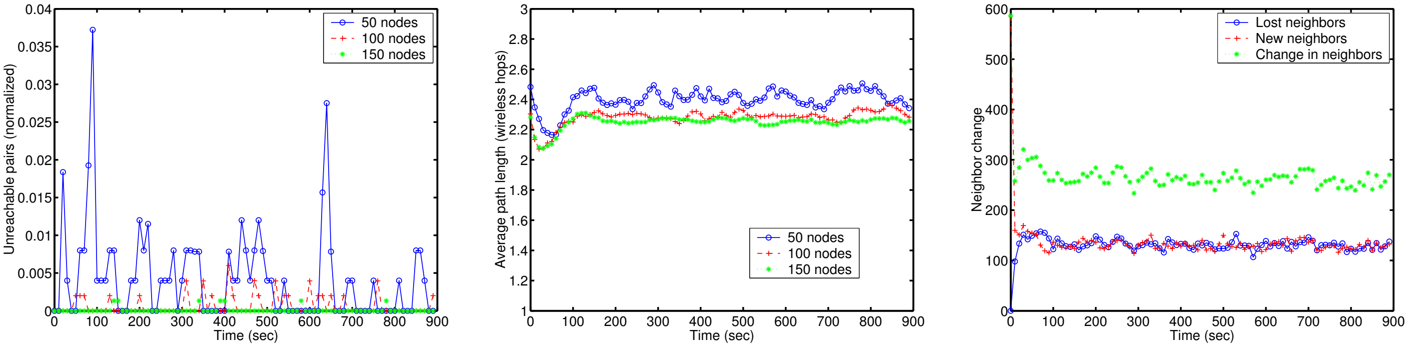
Figure 3: Characteristics for scenarios corresponding to Region *A* (Figure 1(a)) with 500 m transmission range



(a) Number of unreachable pairs (normalized) in the scenario corresponding to Region *B* with 250 m transmission range

(b) Number of unreachable pairs (normalized) in the Random Waypoint scenario with 250 m transmission range

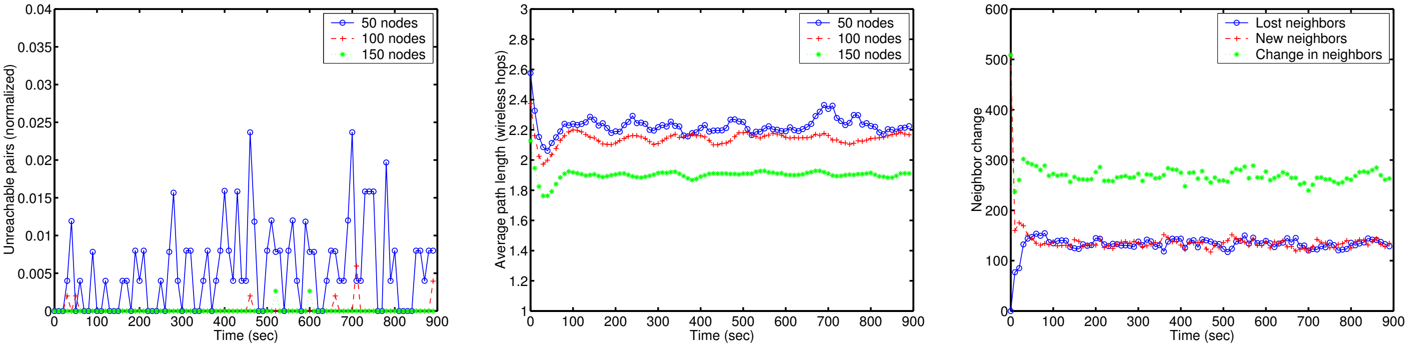
Figure 4: Connectivity in scenarios corresponding to Region *B* (Figure 1(b)) with 250 m transmission range



(a) Number of unreachable pairs (normalized) in the street scenario with 500 m transmission range

(b) Average path length per source destination pair in the street scenario with 500 m transmission range

(c) Change in neighbors every 10 s in the street scenario with 50 nodes and 500 m transmission range



(d) Number of unreachable pairs (normalized) in the Random Waypoint scenario with 500 m transmission range

(e) Average path length per source destination pair in the Random Waypoint scenario with 500 m transmission range

(f) Change in neighbors every 10 s in the Random Waypoint scenario with 50 nodes and 500 m transmission range

Figure 5: Characteristics for scenarios corresponding to Region *B* (Figure 1(b)) with 500 m transmission range

Table 2: DSR performance with 150 nodes and wireless transmission range of 500 m (averages)

Mobility Model	Packet Delivery Ratio	Delivery Latency	Packet Overhead
Our model	0.905	0.0182 s	141862.6
Random Waypoint	0.916	0.0142 s	115795.6

the standard path cache data structure for the Route Cache [6]. This version of *ns-2* simulator models the physical layer and the MAC layer and includes modeling of contention, collisions, capture, backoff, and propagation. The network interface is modeled after the Lucent/Agere WaveLAN/ORiNOCO IEEE 802.11 product, which has a nominal transmission range of 250 m and a data rate of 2 Mbps. However, we modified the simulator to use a transmission range of 500 m. The network interface uses the IEEE 802.11 Distributed Coordination Function (DCF) [12] MAC protocol, which employs physical and virtual carrier sensing for collision avoidance.

We simulated 150 nodes in the network with a wireless transmission range of 500 m since, according to Figure 3, the network stays well connected with this combination of parameters. The communication pattern consisted of 10 constant bit rate (CBR) flows, each sending 4 64 Bytes data packets from the source to the destination. We evaluate the performance of DSR along the following metrics:

- *Packet Delivery Ratio*: The fraction of original data packets sent by the application layer at the source that are successfully delivered to the application layer at the intended destination.
- *Packet delivery latency*: The 95 percentile average latency for data packets successfully delivered from the source to the intended destination. This metric only makes sense for successfully delivered packets.
- *Packet overhead*: The total number of overhead packets, other than the data packets, that are sent by the routing protocol. Each transmission, whether originating or forwarding, is counted once.

As shown in Table 2, the performance of DSR in the scenarios generated using our model is very similar to the performance in the scenarios generated using the Random Waypoint model. This suggests that once the network is well connected and the average path length is not very high, DSR is able to deliver a high percentage of packets, irrespective of which kind of mobility model is being used. Also, since the average path length is more or less the same, irrespective of which mobility model was used, the performance does not differ much.

Even though we analyzed the scenarios corresponding to Region *B* with a transmission range of 500 m yet from Figure 4 suggests that even with a transmission range of 250 m, the connectivity is probably enough when there are 150 nodes in the network. Hence, for Region *B* we evaluated the performance of DSR with 150 nodes and a transmission range of 250 m. However, the average percentage of packets successfully delivered was lower than 80%. Thus a transmission range of 250 m is not a practical option. As before, the average path length does not differ much and hence the performance of the routing protocol, though too low to be of any use, is similar, irrespective of the mobility model used.

4.2 Implications of Results

It seems from the results that the Random Waypoint mobility model is a very good approximation of the street mobility model that we have proposed in this paper. Under the scenarios studied in this paper the Random Waypoint mobility model exhibits similar characteristics as our mobility model. However, as the street network becomes more and more sparse, the street mobility model will restrict the motion of vehicles even more, thus making our model behave more differently than the Random Waypoint model. We believe that during the development of a protocol, the Random Waypoint model can be used in the initial phases but when a target site has been chosen for the deployment and testing of the protocol, the street mobility model should be used so that the mobility of nodes in the network can be modeled more accurately.

We believe that our vehicular mobility model will have substantial utility for the testing and development of newer applications, especially applications that are specific to vehicular ad hoc networks. For example, an *accident notification* application could be envisioned in which whenever sensors on a car detect an accident or a flat tire, etc., it uses short range directional antennas to notify cars which are behind it about the accident. This notification can flow multihop to other following cars. Simulation study of such applications will only be meaningful if we can simulate realistic motion of vehicles. *Such applications cannot be modeled using Random Waypoint motion.*

5. DISCUSSION

In this section we discuss some issues with our approach and also suggest ways in which this model can be improved to get even better realistic modeling of node mobility.

We would like to identify residential and business areas in the geographical area for which we generate the mobility scenario. This would help us in getting more realistic movement patterns. For example during morning office hours most traffic is *office going* and is hence directed towards business centers and offices. Similarly, during afternoon office hours most traffic is homebound and is hence directed towards residential areas. This would allow our modeling of congestion to be more realistic. As mentioned earlier, this model can be made even more realistic by introducing obstacles into the model which restrict wireless transmission [13].

Ideally we would like to have more realistic mobility model for individual cars. Right now each vehicle moves independent of other cars. However, in reality, a car needs to pay attention to the distance with the car just in front of it. There are existing models for modeling how cars follow each other [16]. In this model a car pays attention to how far a car is from the car in front of it, how far a car is from the next traffic light, whether a car needs to make a lane change, etc. Besides, a network with a fixed number of cars is highly unrealistic. A model should include arrival rate and departure rate of cars into and out of the geographical area being simulated. In another approach to making the proposed model more realistic one could integrate actual mobility traces from real life measurements such as those available for buses in the Seattle, Washington are King County Metro bus system [14].

Also, our work neglects the waiting time at an intersection and assumes that nodes do not have to wait at an intersection. This is because arriving at an agreeable stochastic model for traffic lights is a problem in its own respect and is outside the scope of this work. Besides, we do not consider that simulating waiting times at intersections would perturb our results noticeably.

Since we only choose those streets which are entirely within the specified bounding box there can exist streets which actually cross the area but are not accounted for in the scenario that we generate. This is because such a street does not both its intersections within the specified bounding box. We do not consider this to be a serious issue and choose to neglect this shortcoming.

Although we have presented our mobility model from the perspective of a mobile ad hoc network, this model can also be used with simulation tools for other kinds of wireless networks such as infrastructure based networks. Realistic modeling of mobility of a mobile user community is important irrespective of what kind of network is used to provide connectivity to the mobile user community.

6. CONCLUSION

We have presented a realistic mobility model for mobile ad hoc networks, especially vehicular ad hoc networks. In particular, our new model uses *real* street map data, modeling vehicles traveling on these streets. We analyzed the properties of this mobility model and studied the performance of a common ad hoc network routing protocol, DSR, on this model. We found that, in many ways, the Random Waypoint mobility model is a good approximation of our model.

We have used publicly available street map data, and our tool generates scenarios in a format that is compatible with the scenario format used in *ns-2*, and hence our tool can easily be used by the research community. We believe that our modeling tool will aid in increasing the realism in simulation study of ad hoc network protocols, particularly vehicular ad hoc networks.

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