Impact of Mobility Models on Simulated Ad Hoc Network Performance

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***Abstract*—To correctly examine ad hoc network protocol performance, node mobility must be accurately modeled. Many ad hoc networking studies model node mobility using the random waypoint or random walk mobility models because they are easily simulated and might be assumed to represent a worst-case for node mobility. These models, however, do not represent a worst-case in terms of network performance. This paper presents a rigorous simulation of network performance in ad hoc networks using the random waypoint and Manhattan mobility models using the ns-2 network simulator. This work models the effects of buildings without restricting radio propagation distance, first by increasing block size to prohibit direct communication between nodes across blocks, and then by implementing a new radio propagation model in ns-2 that simulates the urban canyon effect of metropolitan areas. While there is little impact on network performance between mobility models without these enhancements, when modifications are made to simulate buildings and urban canyons, network performance suffers greatly and it is clear that the mobility model has a significant impact on simulated network performance. In addition, the results show that the impact of the choice of mobility model lies in the geographic constraints placed on node locations, not necessarily the nodes' mobility.**

Key words: Mobility models, ad hoc networks, simulation

1. Introduction

Mobile ad hoc networks (MANETs) differ from traditional networks in two fundamental ways. First, each host must act as a router and may be involved in forwarding packets for other nodes. Second, nodes move relative to each other so routes between nodes change frequently. The manner in which nodes move in a MANET simulation is dictated by the mobility model. Various mobility models are used to simulate these changing topologies and the way in which nodes move can impact the efficiency of the network. Recent debate has focused on the realism of these mobility models [1]. Many researchers use the random waypoint model, but it is likely that randomly dispersed nodes would artificially improve network performance because nodes would be more likely to be evenly distributed throughout the simulation area, allowing the network to more efficiently share wireless spectrum.

Using the ns-2 [2] network simulator to simulate an ad hoc network, this research measures network performance under two different mobility models, the random waypoint model and the Manhattan model, to determine how the mobility model affects network performance. The Manhattan model resulted in degraded throughput only when the distance between parallel "streets" was wider than the radio propagation range of the mobile nodes. Furthermore, the restrictions imposed on the placement of the nodes, rather than the movement of the nodes, significantly affect the performance of the network. More accurate simulations of network performance in an urban environment, using a radio propagation model that simulated the urban canyons created by city blocks with densely-packed buildings, were also conducted. This modification, which more closely models realistic node communication in an urban environment, degraded network performance considerably.

Results of this simulation study indicate that the random waypoint mobility model does not result in worst-case ad hoc network performance. Simulated network performance under a more realistic urban model is significantly worse when the distance between streets is greater than the radio propagation range of the communicating devices. When the model is changed to more realistically take into account the impact of buildings on radio signal propagation, network throughput is reduced by almost two-thirds.

2. Background and related work

In traditional networks, host computers are connected to a hierarchal infrastructure of routers that forward packets from one host to another. This infrastructure does not exist in ad hoc networks. Network nodes must, therefore, act as both hosts and routers and they must work cooperatively to route traffic. The advantage of such networks is that they can be rapidly deployed in areas without existing infrastructure, configuring themselves to move packets between hosts.

When network nodes are mobile, the network must not only be able to self-configure, but must also adapt to changes in network topology over time. There has been significant work in recent years to develop MANET routing protocols that are able to both self-configure and efficiently adapt to changes in the network.

2.1. Random waypoint and Manhattan mobility modeling

Modeling the mobility of nodes in ad hoc networks is an immature science, primarily because there are few real-world ad hoc networks with which models of node mobility can be compared. When simulating ad hoc networks to measure the performance of various protocols, most studies use the *random waypoint* mobility model [3]. In this model, nodes are randomly distributed in a fixed simulation area. Each node chooses a random destination within the simulation area and a random speed from within a given range. Each node moves to its chosen destination and pauses for a random period of time from within a specified range before selecting a new destination. While this mobility pattern causes the network topology to change over time, it is often criticized as being unrealistic because actual network nodes are not likely to move about in such a random fashion. More realistic models have been proposed that model mobility in different circumstances [1]. The Manhattan Model [4] is used to simulate movement of nodes in an urban environment where movement is restricted to north-south and east-west grid lines representing city streets as depicted in Figure. 1. This model restricts node positions to specific routes within the simulation area which could lead to a concentration of nodes at intersections. While this would likely improve connectivity between the clustered nodes, the increased concentration might also cause interference which would reduce overall network throughput.

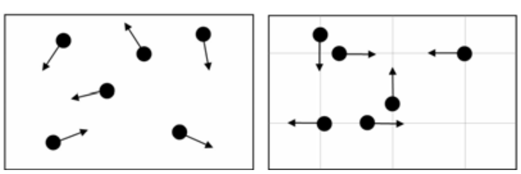

Figure. 1. Random Waypoint (left) and Manhattan Mobility Models

2.2. Related work

Simulation of mobile nodes was originally begun by the Monarch project [5] to study the effectiveness of different routing protocols for mobile networks. This project contributed extensions to the ns-2 network simulator to emulate wireless interfaces and routing protocols for mobile ad hoc networks. The IMPORTANT evaluation framework developed at USC [4] focused on the impact of mobility patterns on routing performance, developing ns-2 extensions for Manhattan, Freeway, Group and Random mobility models. This work showed that the choice of mobility model has a large impact on network routing performance. We extend their analysis to take into account signal attenuation caused by obstacles, in our case, buildings, on the performance of ad hoc networks in urban terrains. Furthermore, we characterize performance in terms of network delay and packet drop rate, in addition to overall network throughput. Average packet delay is an important measure of network performance, especially in delay-sensitive applications, such as streaming audio or video. Packet loss also gives insight into the performance of the network. Networks with high rates of packet loss might have artificially high throughput due to packet retransmission.

Camp, et al. [1], compare the performance of ad hoc networks under several different mobility models and also conclude that the choice of mobility model affects network performance. Their survey of mobility models considers variations on the random waypoint model along with several group mobility models. None of the models studied include the impact of obstacles on radio signals.

Jardosh, et al. [6], attempt to create a more realistic *Obstacle Mobility (OM) Model* by including obstacles. Polygon-shaped obstacles are created to represent buildings, which serve as node destinations. Nodes move along the shortest path to the destination. The effect of obstacles on wireless transmissions is calculated, creating ‘obstruction cones’; areas in which a building can block transmissions between nodes. Their simulation results agree with previous conclusions that the characteristics of the mobility model greatly influence network performance.

3. Simulation environment

In this research, network performance under the random waypoint and Manhattan mobility models was simulated using the Network Simulator 2 (ns-2) [2], version 2.29. The ns-2 *setdest* utility was used to generate random mobility. Manhattan mobility was generated using code from the University of Southern California, developed as part of the IMPORTANT project [4]. Manhattan mobility, which is much more structured than random movement, confines the nodes to “streets.” Under Manhattan mobility, the nodes often tend to gather in small clusters near intersections, which reduces distribution of nodes throughout the rest of the simulation area. This behavior may manifest itself in less favorable network conditions than the purely random movement of nodes.

3.1. Network node model

For all of the simulations described here, the physical layer model simulates the Lucent WaveLAN network adapter, with a maximum transmit/receive range of 250 meters. This is the default physical layer model for wireless simulations in ns-2.29. The MAC layer uses the IEEE 802.11b model in ns-2, which simulates the 802.11 carrier-sense, multiple access protocol with collision avoidance (CSMA/CA) described in the IEEE 802.11 specification [7].

The ad hoc, on demand, distance vector routing protocol (AODV), as described in Internet RFC 3561 [8], was used for the MANET routing protocol. AODV was selected because of its reliable performance in high-mobility situations, its ability to scale well to large networks, and its low control-packet overhead compared to other MANET routing protocols [9].

4. Simulation methodology

The simulation scenarios in this study all used the same number of nodes, the same types of nodes, the same random network traffic and the AODV routing protocol. Performance metrics used in the analysis of simulation results were average throughput, average packet delay and average drop rate. Average throughput was calculated by accumulating the total amount of data received in the network and then dividing by the time the simulation was in steady-state, which was determined as described in Section 4.3. Average packet delay is the average time between transmission and reception of successfully transmitted packets. Drop rate is the number of dropped packets divided by the total number of packets transmitted in the network.

4.1. Mobility parameters

The simulations described here include 20 simulated ad hoc network nodes moving in an 800 X 800 m^2 area. The Manhattan mobility models used a map with three "streets" running north-south and three running east-west. Table I gives the mobility parameters used for both random and Manhattan mobility simulations. Ns-2 has no facility for simulating terrain or buildings and the distance between the streets has a significant impact on network performance. Two different block widths were modeled, 200 meters and 250 meters. Initially, 200 meter block sizes were chosen to approximate the distance between main streets in a U.S. metropolitan area. However, the radio range of the simulated network devices is 250 meters, so with no built-in mechanisms for modeling topography in ns-2, nodes could unrealistically communicate from parallel streets across 200 meter blocks. Simulations were then repeated using block sizes of 250 meters so that nodes could not communicate across a block. This model is more realistic because nodes in a true urban environment cannot transmit through buildings to nodes on the other side of a city block.

Table I Mobility Parameters

Mobility parameter	*Value*
Number of nodes	20
Simulation time	2000 seconds
Simulation area	800x800 m^2
Minimum node speed	5 meters/second
Maximum node speed	10 meters/second
Pause time	0

4.2. Data traffic modeling

Network traffic was modeled as constant bit rate (CBR) sources. CBR traffic imitates User Datagram Protocol (UDP) traffic at the transport layer, providing best-effort datagram delivery with no transport-layer acknowledgements or retransmissions. The other option was Transmission Control Protocol (TCP) traffic. TCP, however, increases variance in all three performance measures since it adds the network overhead of connection set-up, packet-level acknowledgements, and retransmissions while providing the same relative performance as UDP under the three simulation scenarios. UDP (CBR) traffic between nodes was, therefore, selected to reduce the overall number of replications required to achieve statistically sound results.

The ns-2 utility *cbrgen* was used to create network traffic. The same traffic, consisting of 14 source/destination pairs randomly chosen by *cbrgen*, was used in all simulation runs. Each CBR stream sent four 64-byte packets per second beginning at one second of simulation time and continuing until the end of the simulation.

4.3. Other simulation parameters

The traffic generation and mobility model generation utilities were modified to all use the same random number streams with specified seeds to ensure that the varied outcomes from the different models were not due to variations in random number generation.

Welch's Procedure [10] was used to determine when to begin collecting statistical data in the simulations. A 200 second warm-up period was used before statistics collection began and data was collected for another 2000 seconds of simulated time per replication.

A 95% level of confidence that all of the performance measures (average throughput, average drop rate and average delay) were within the chosen confidence intervals was desired. To calculate the required number of replications to obtain an overall 95% confidence level, Bonferonni's inequality [10] was used to calculate the required confidence level for each performance measure.

The maximum of the number of replications calculated for each measure was selected as the overall number of replications required Based on these calculations, we ran 26 replications of the random waypoint simulations, 21 replications of Manhattan mobility with 200m blocks, and 94 replications of Manhattan mobility with 250m blocks.

5. Simulation results

5.1. Network performance versus mobility model

Figure 2 shows the difference in throughput between the three mobility models. The mean throughput for Manhattan mobility with 250m blocks was 3895 bytes/second. This value is significantly lower than throughputs for random mobility (4507 bytes/second) and Manhattan mobility for 200m blocks (4494 bytes/second). Figure 3 and Figure 4 show differences in drop rate and average packet delay for the three mobility models. In each case, network performance for random mobility and Manhattan mobility with 200m blocks is similar. In fact, for all three performance measures, confidence intervals for these scenarios overlap, indicating a statistically insignificant difference between the two. However, for all three performance measures, random mobility and Manhattan mobility with 200m blocks significantly outperform Manhattan mobility with 250m blocks. Recall that the larger block size limits communication by preventing direct communication between nodes on parallel streets. These results, therefore, imply that the mobility pattern of the network devices has less to do with performance than the limitations that the mobility model imposes on node placement within the movement area.

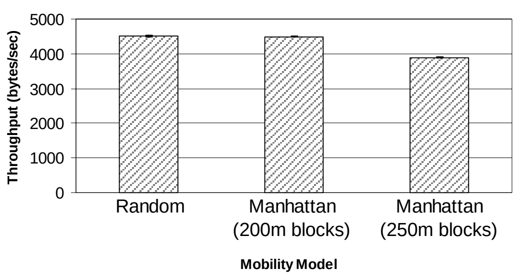

Figure 2. Throughput versus Mobility Model. Error bars on graph depict confidence intervals.

5.2. Network performance with stationary nodes

To measure the performance impact caused solely by the placement of nodes, a series of simulations in which nodes were placed in the simulation area according to each of the three mobility patterns were executed with the nodes remaining stationary for the duration of the simulation. Figure 5 shows the results of these simulations compared to the results of the simulations in which the nodes moved. When nodes were moving, throughput was improved slightly because nodes were able to gain a connection during portions of the simulation, even if they were not connected long enough to transmit all of their data. When nodes did not move, either all data were passed or none were. This affect resulted in slightly lower performance.

The relative performance of the three models is the same with stationary nodes as with moving nodes, which supports the hypothesis that declining network performance is caused primarily by the limitation imposed on node placement by the mobility model and not by the mobility itself.

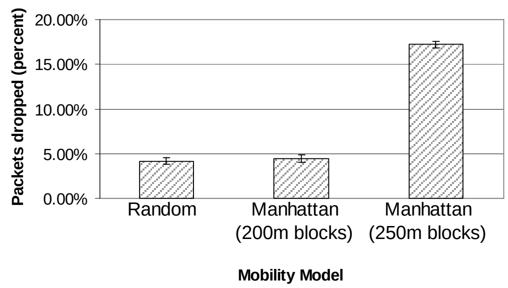

Figure 3. Average Packet Drop Rate versus Mobility Model

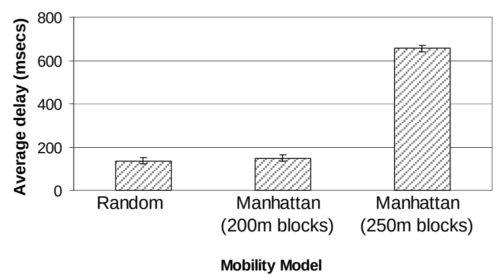

Figure 4. Average Packet Delay versus Mobility Model

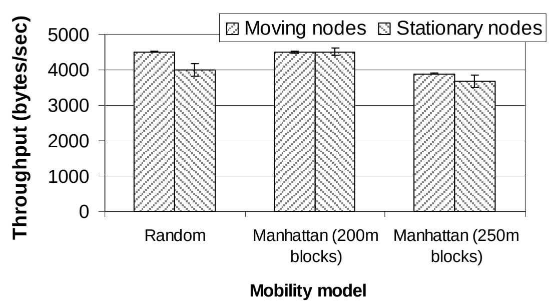

Figure 5. Moving versus Stationary Node Throughput

5.3. A new radio propagation model for ns-2

The above results show that simulated ad hoc network performance is greatly impacted by restrictions on node placement. The results do not, however, give an accurate picture of performance reduction caused by urban terrain.

The simulations using 250m blocks are a better indication of actual network performance in an urban area than the 200m block simulations because the larger block size prevents communication between nodes on parallel streets, thus simulating the buildings that would prevent this communication. These wider blocks, however, are unrealistic because they also prevent communication between network devices at adjacent intersections that would normally be possible between the wireless network devices. It also allows for communication between nodes that are on perpendicular streets but far away from intersections that would normally be blocked by buildings. Unfortunately, there was no straightforward way to simulate restrictions on node communication in the urban canyons created by buildings in an urban area. Ns-2 was originally designed to simulate wired networks and it does not support topographical information. To run simulations that modeled buildings, the simulator had to be modified to take wireless signal attenuation caused by buildings into account.

To model signal attenuation as described above, the TwoRayManhattan radio propagation model was developed, based on the TwoRayGround model included with ns-2. This model only allows communication down city streets and around a corner if both nodes are within 5 meters of the same intersection. Twenty replications using this radio propagation model and Manhattan mobility on 200m blocks were executed to determine the impact of this new propagation model on network performance. As expected, performance suffered greatly. Figure 6 shows throughput compared to the other three simulation scenarios. The mean drop rate in these simulations was 64% and the mean packet delay was over two seconds.

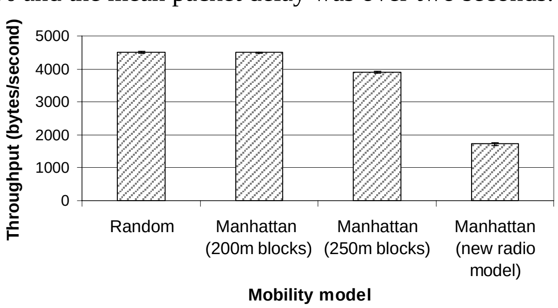

Figure 6. Throughput versus Mobility Model with New Radio Propagation Model

6. Conclusions

The results of this ad hoc network simulation study indicate that the mobility model has a large impact on simulated ad hoc network performance and that random mobility does not result in worst-case MANET performance. The lack of restrictions on node placement under the random waypoint mobility model allows for an even distribution of nodes over the simulation area, providing more routing options and reducing the node clumping that can increase packet collisions in the Manhattan mobility model. As the Manhattan model is improved to more closely model urban mobility, first by increasing block size to prevent direct communication across blocks and then by restricting radio propagation to simulate urban canyons, network performance suffers greatly.

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