A Mobility and Traffic Generation Framework for Modeling and Simulating Ad hoc Communication Networks

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ABSTRACT

We present a generic mobility and traffic generation framework that can be incorporated into a tool for modeling and simulating large scale ad hoc networks. The basic framework consists of the following components:

1. A **Mobility Data Generator (MDG)** that generates positions and states of transceivers at specified times of the simulation clock. This module can support a variety of mobility models.
2. A **Graph Structure Generator (GSG)** that constructs the graph corresponding to the ad hoc network from the mobility data provided by MDG. This module can generate directed or undirected graphs depending on the radio range and propagation models.
3. A **Terrain Modification Tool (TMT)** that modifies the connectivity of the graph produced by GSG to allow for terrain effects or arbitrary obstructions.
4. An **Activity Data Generator (ADG)** that generates sessions (i.e., packet transmission activities) for a specified fraction of the transceivers that are active at specified times of the simulation clock.

The design allows a user to incorporate various realistic parameters crucial in simulating and modeling ad hoc communication networks. We illustrate the utility of our tool with two examples. The first example shows how purely synthetic movement patterns can be used in driving a simulation. The second example shows realistic movement patterns obtained via an urban population mobility modeling tool developed at Los Alamos.

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1. INTRODUCTION AND MOTIVATION

1.1 Definitions and Terminology

An *ad hoc wireless mobile network* is a collection of mobile transceivers that communicate via radio transmission. There is no wireline network to support the movement of packets. The communication network is formed spontaneously when transceivers activate their radios. Moreover, movement of the transceivers constantly changes the connectivity in the network. These networks are gaining popularity due to their applicability in a number of important situations such as battlefield communications, emergency management and response, etc. The topic of designing and building large scale ad hoc networks is an area of very active research.

The dynamic connectivity of the network that is induced by the constant movement of transceivers implies that the performance of the communication network depends crucially on how the underlying transceivers move. Indeed, as has been observed in the literature, parameters such as the velocity of transceivers, their mobility patterns and their spatial density significantly affect the network performance.

The goal of the *AdhopNET* project at the Los Alamos National Laboratory (LANL) is to develop a scalable simulation-based tool that can be used for the design and analysis of ad hoc communication networks being built as a part of SUO-SAS project at DARPA [3]. Here, we describe some modules of this simulation-based analysis tool. These modules produce mobility patterns and associated communication activities that drive the packet movement simulator. Although this tool was developed originally for AdhopNET, it can be used in conjunction with other simulation tools such as *ns-2* and *GloMoSim* [2, 1]. The flexible framework within which the modules operate allows us to create both synthetic and realistic mobility patterns along with appropriate communication activities (or calling patterns). Although our framework is designed for ad hoc networks, it can be used to obtain an understanding of the effects of mobility on a wired backbone network that contains mobile units and *base stations*. In such networks, each base station is a stationary unit that communicates with one or more mobile units. At any time, each mobile unit is assigned to a base station. A mobile unit can communicate directly with only its assigned base station. The base stations communicate among themselves through a wired backbone network. (The backbone may also involve satellite links.)

We now present some terminology that is used throughout this paper. The *range* of a transceiver is the geographic distance over which the packets sent by the transceiver can be received. Different transceivers may have different ranges. The distance metric used is the Euclidean (L_2) metric. Thus, if the range of a transceiver T is r, then a packet sent by T can be received only by the transceivers (or base stations) that are within or on the circle (or sphere in higher dimensions) of radius r centered at the point occupied by T.

In an ad hoc network, a *hop* refers to the movement of a packet from one transceiver T to another transceiver T' which is within the range of T. In a wired backbone mobile network, a hop may refer to either the movement of a packet between a mobile unit and its base station or between a pair of base stations.

The *out neighbors* of a transceiver T are those transceivers that can receive packets from T in one hop. Similarly, the *in neighbors* of a transceiver T are the transceivers from which T can receive packets in one hop. (The terms "in neighbor" and "out neighbor" arise from a natural directed graph representation of a network: the nodes of the graph correspond to transceivers (and base stations) and a directed edge (u, v) implies that the transceiver (or base station) represented by v is in the range of the transceiver (or base station) represented by u.)

A *session* is a complete sequence of packets sent by a source to a destination. The packets within a session are numbered 0, 1, 2, ..., $n-1$, where n is the total number of packets in the session. The source sends the packets for the session in the order $\langle 0, 1, 2, \ldots, n-1 \rangle$. In general, the sequence of packets received by the destination will be different from the sequence in which packets are sent by the source. The destination may not even receive all the packets sent.

1.2 A Brief Review of Known Mobility Models

A number of mobility models that can be used in the simulation of ad hoc networks have been proposed in the literature. A commonly used model in this context is the *random mobility model* [14]. In this model, the position of each transceiver at time $(t+1)$ is a random displacement from its position at time t. This implies in essence that the speed and direction are both random variables that have no correlation with their current values. As discussed in the literature, this model tends to produce unrealistic choppy motion with sharp turns, sudden stops, etc.

Other related models include: Basagni et. al. [5], Ko and Vaidya's model [11], Das et. al. [7], and the *random waypoint mobility model* [12, 8, 9].

All the above models have one common theme: they specify mobility rules for individual transceivers. Recently however, researchers have identified another type of mobility model which is referred to as the *group mobility model.* In such a model, sets of transceivers form groups. The movement of individual transceivers within a group are strongly correlated. Such models aim to provide realistic mobility data when ad hoc networks are used in an emergency response or a military setting. Two basic models of this type have been proposed in the literature.

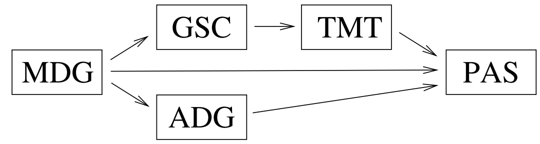

Figure 1: Simple schematic diagram of the simulator, showing only "feed-forward" paths and a trivial composition of the modules.

The first is the *Exponential Correlated Random* (ECR) model studied in [6, 13]. Using this model, one can control the movement of a group independently of the movement of the other groups and the nodes within the group. At each step, a group undergoes a randomly chosen displacement along a randomly chosen direction.

A more sophisticated model referred to as the *Reference Point Group Mobility* (RPGM) model is proposed in [10]. By an appropriate setting of the parameters, RPGM can mimic many other known mobility models. An informal description of this model is as follows. The transceivers are partitioned into a specified number of groups. Each group has a logical center which can be assigned a specific movement model. Transceivers within a group move together as a group within an annulus around the group center, with a small amount of random movement. Such movements can be readily implemented (for instance) by maintaining prespecified lower and upper bounds on the distance of each point from its group center.

2. PROTOTYPE SIMULATOR

We have developed a prototype software tool that allows a user to generate mobility data using different models. As in [10], our tool is flexible enough to support group and individual mobility models as well as to mimic other models. We present some results generated using this tool.

We also report some preliminary results obtained using a more realistic mobility model. These results were obtained from a large scale microscopic mobility simulator called TRANSIMS, also developed at Los Alamos [4]. Using TRANSIMS, one can produce extremely high fidelity mobility models that have been validated against realistic road traffic (and many other population mobility characteristics) in present day urban areas.

Finally, we indicate how the mobility models can be combined with a communication activity generator that produces synthetic calling patterns in which parameters such as size and number of packets, level of burstiness, etc. can be controlled. As in the case of mobility models, the activity patterns can be generated so that the synthetic patterns match realistic patterns in a statistical sense.

The mobility data and activity generators have been designed with the goal of providing data to large scale ad hoc network simulators.

A Functional View of the Prototype Simulator:

A schematic diagram showing the various modules of the prototype simulator is presented in Figure 1. This schematic diagram represents a functional view of the system, connected in its most simple configuration. A brief discussion

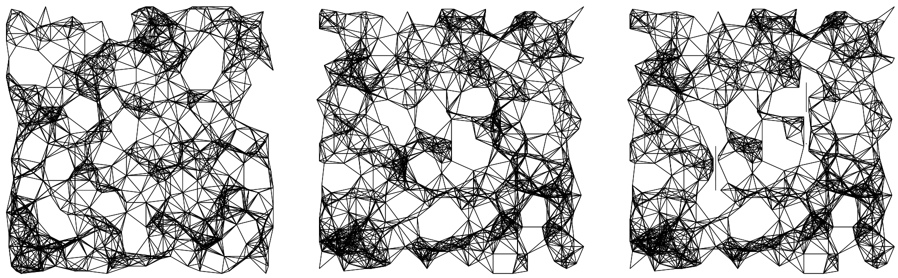

Figure 2: Time evolution of connectivity pattern for a graph derived from MDG with and without TMT. The three panels are: $t = 0$, $t = 500$, and $t = 500$ with two barriers.

of the functions carried out by the various modules is presented below.

Mobility Data Generator (MDG): The function of this component is to generate the positions of transceivers at various times of the coarse clock. (There are many packet hops per graph change.) This module also allows transceivers to become idle for some period of time and rejoin the network at a later time. Further, the module also allows new transceivers to join the network and existing transceivers to leave the network permanently. The design is flexible enough to incorporate various mobility models discussed earlier and also to incorporate mobility models derived from realistic mobility data.

Graph Structure Generator (GSG): The function of this module is to construct the directed (or undirected) graph corresponding to the ad hoc network from the mobility data provided by MDG. The type of output that is be produced by this module is as follows. At each time when mobility data for transceivers is available, GSG constructs the out neighbors of each active transceiver T knowing the range of T and the positions of all other active transceivers. The module has been decoupled from MDG so that it can be made compatible with many different simulation tools. Moreover, the module is flexible enough so that the existence of a directed (or an undirected) edge between a pair of transceivers A and B can be a function of a given radio propagation model. For example, we can use the line of sight model or a two way path loss model [6] to decide whether or not two transceivers can talk to each other.

Terrain Modification Tool (TMT): The inputs to this module are a graph (as produced by GSG) and information about barriers in the terrain. At an abstract level, the effect of terrain can be seen as deleting a subset of edges in the ad hoc network formed by the transceivers. The module uses the information about barriers to remove the edges in the graph which cross barriers. Information regarding barriers is given as a list of point pairs. The name of the module includes the word “terrain” because the initial use of the module was to handle constraints due to different types of terrain. In its current form, it supports many forms of obstruction, including buildings, stationary electronic interference, etc. Again, the reason for making this a separate module is that the effect of terrain on the existence of an edge can now be decided post hoc.

Activity Data Generator (ADG): The purpose of ADG is to generate sessions for a fraction of the transceivers that are active at a given time. For each session, the data generated by the ADG specifies the source, the destination, the number of packets in the session, the size of each packet and the rate at which the source generates the packets. If the user wishes to simulate a session of varying packet sizes, rates, etc., then it can easily be done using multiple “logical” sessions to emulate a single “actual” session.

Packet Activity Simulator (PAS): This module is the heart of the ad hoc network simulator. This module simulates the packet flow in the system using the activity data and the graph structure generated by ADG and GSG respectively. Thus, this module can begin to execute only after all the other modules have finished their execution. It is this module that simulates the interaction of packets with the network and each other, and resolves the contention for resources. Since the focus of the current paper is on modeling user mobility, we have not included a detailed discussion of this module.

Composition of modules: The modular nature of the components and our modeling methodology provides the ability to simulate a variety of scenarios by appropriate compositions of modules. Figure 1 illustrates only the most simple feed-forward-once configuration of the simulator. The real power of the methodology is realized only through the use of feedback and sophisticated combinations of the modules. We present two simple examples below to illustrate the idea.

A troop movement exercise could be simulated by running a clustered random waypoint model once for each unit of soldiers, then running each group independently through the graph connection module, and finally merging all files. So long as there are no duplicate transceiver IDs, this emulates troop deployment where each unit has its own non-interfering channel of communication and pattern of movement. For a simple modification, one member of each unit could be selected to have all other selected transceivers (one from each unit) added to its connected node list, whereby commanders of units have a second common channel amongst themselves.

A second example is in the modeling of a self-adapting

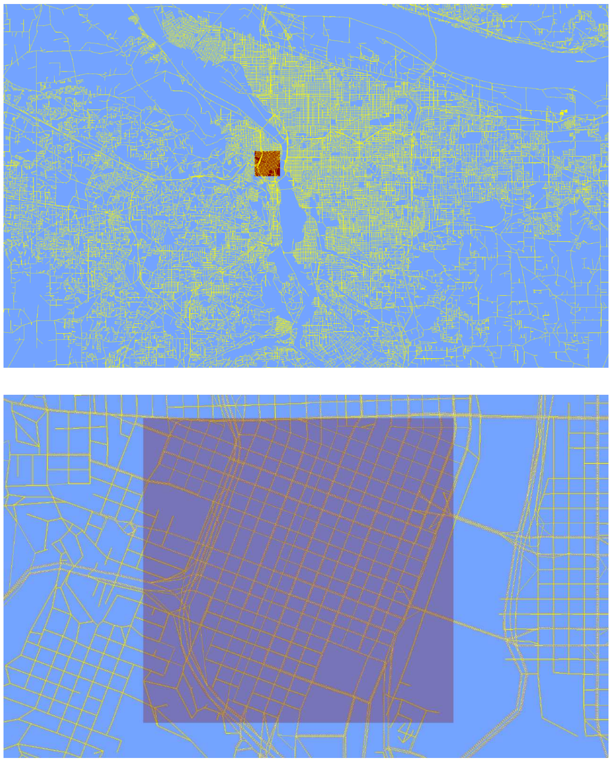

Figure 3: A map of Portland, OR, and a zoomed-in version of the part of downtown from which a subset of travelers was selected in Figure 4.

Table 1: The degree sequence of the three graphs obtained from realistic traffic (Figure 4) by changing the transmission range bounds in GSG. The first column denotes the degree bound. The second column tells number of nodes with that degree when the transmission radius is 10 units. The third and fourth coloumn denote similar bounds when the range is 50 and 100 units respectively.

Degreee Value d	#Nodes ($r = 10$)	#Nodes ($r = 50$)	#Nodes ($r = 100$)
0	481	68	3
1	121	113	7
2	33	107	21
3	3	110	19
4	13	66	21
5	19	48	42
6	3	22	49
7	3	13	49
8	0	19	51
9	0	14	54
10	0	17	42
11-14	0	49	155
15-19	0	14	72
20-29	0	33	82
30-49	0	0	51

network where each transceiver maintains its power so that it has a constant number of neighbors. In this case GSG would need to be iterated with each node at each timestep searching for the range that yields that number of neighbors.

3. RESULTS

As discussed earlier, the synthetic mobility pattern generator allows us to generate a wide variety of movements. Here, we describe an example illustrating its capabilities. For this illustration, we used 500 transceivers spread uniformly over a grid of size 110 $\times$ 110 units. The range of transceivers was chosen as 10 units so that two transceivers whose Euclidean distance is less than or equal to 10 units can communicate with each other. Since the ranges of all the transceivers are identical, the communication network formed by the transceivers at any time can be represented by an undirected graph.

Figure 2 shows two snapshots of the generated graphs as the points move over the grid. The first two panels were produced with no barriers. These show the communication network at times $t = 0$ and $t = 500$ simulation time units. As can be seen, the connectivity of the network changes significantly as the transceivers move slowly along the grid. The final panel of the figure was produced from the same mobility data snapshot as the second panel, except that the terrain included two vertical barriers. The first barrier is the vertical plane defined between the two points (36,28) and (36,64). The second barrier is defined by the two points (73,46) and (73,82). By comparing the last two graphs, one can see the effect of barriers on the connectivity of the network.

Next, we present some preliminary results on incorporating realistic mobility patterns. By “realistic”, we mean movements that are likely to arise in operational ad hoc networks. The tool we used to generate these mobility patterns is TRANSIMS, a large-scale microscopic transportation simulation environment [4]. TRANSIMS produces realistic traffic patterns (position of all travelers on a second by second basis) on the scale of a large metropolis. The top panel of Figure 3 shows the transportation network spanning the city of Portland, OR, used in TRANSIMS. TRANSIMS has the ability to carry out highly detailed simulations of very large transportation networks. Thus, it can be used to produce mobility patterns on an extremely large scale (1.5 million people with 1 million links). Current ad hoc network simulations can handle no more than a few thousand transceivers. So, we selected a part of downtown Portland (shown as a small dark area in the middle of the top panel of Figure 3) for generating experimental results. The bottom panel of Figure 3 shows the chosen area more clearly. The traveler occupancy (i.e., the transceiver occupancy) snapshot is taken around 7.30 AM on a normal day.

Figures 4 show how the connectivity of the communication network formed by the transceivers changes as we increase the transmission ranges. ¿From left to right, the three range values used are 10, 50 and 100 meters respectively. As can be seen, the connectivity of the network increases substantially as the transmission range is increased. Again, for simplicity, all transceivers were assumed to have the same range. A summary of the degree sequence corresponding to the three graphs is shown in the table. The flexibility to change the range of transceivers independently of the distance between them allows to use the tool in situations where we want to study power aware protocols. Such protocols dynamically control the range of the transceivers. It is easy to accommodate transceivers of different ranges in this setting.

Figure 4: Variation in the connectivity of the graph as one increases the radio ranges of the transceivers. The respective thresholds for existence of edges are 10, 50 and 100 meters. The figures are for a subset of approximately 600 travelers in downtown Portland.

4. ACKNOWLEDGMENTS

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