Chapter 6

SIMULATION METHODOLOGY

It is well known that the variability of node-to-node communication is a major challenge facing mobile wireless networks (mobile ad hoc and mesh networks). For example at one moment, high quality communication between two nodes may be possible while a short time later, communication between the nodes may not be possible. In the case of wide bandwidth communication, such drastic changes in link quality are typically the result of node mobility. For example, if a node moves around a corner of a building, then, since the signal is not easily able to penetrate through buildings; the communication between the two nodes may be severed. Thus, a combination of node mobility and complex propagation due to the environment results in rapid variability of communication links. However, while great strides have been made in protocols, there has been very little effort devoted to understanding how to best simulate them, specifically, how to best simulate the node mobility and signal propagation. This lack of effort contrasts the simulation of wired networks where there has been extensive work focused on simulation issues such as background traffic and topology (e.g., [70], [71], [72], [73]). This chapter focuses on the simulation methodology for realistic simulation of urban mesh networks.

In urban mesh networks, the study of topology is complicated by the dependence on the propagation characteristics of the environment and location of the nodes. Propagation and the location of nodes is not random, but is dominated by structure. For example, streets, especially well traveled, wide, and straight, have
high node density and excellent propagation properties. Thus, nodes on a major street will have a large number of other nodes within communication range. However, these nodes will not be able to directly communicate with nodes on parallel streets since such communication requires transmissions through buildings or over them; something that is difficult if the buildings are large. Hence, the topology in an urban environment with large buildings will consist of well-connected nodes along the streets. Nodes near intersections will provide connectivity between two streets. Hence, the topology of outdoor nodes looks like a street map of the city. Within buildings, nodes have a smaller propagation range. Thus, the local topology of indoors and outdoors is very different. Realistic topologies can be simulated only if the propagation and mobility simulations are realistic.

There is little doubt that the mobility models currently used in the simulation of mobile ad hoc networks are not realistic. To some extent, since open-space (i.e., free-space and two-ray) propagation models that neglect the impact of objects have been used in the past, there has been little reason to use mobility models where nodes avoid or interact with objects. However, when propagation in urban environments is considered, mobility must also be addressed. Specifically, the mobility model must take into account the structure of the urban environment such as streets, sidewalks and buildings.

One of the reasons that mobility models must not be overly simplified is that in reality pedestrians and vehicles tend to move in clusters [74], [75]. That is, the locations of nodes are correlated. Furthermore, there is a well-studied relationship between node density and node speed (e.g., recall the "two-second rule" that specifies the safe driving distance between cars). Since the spatial distribution of nodes has an important impact on the behavior of mesh networking protocols, mobility models must be realistic.

In summary, the objectives of the simulation approach discussed here is to
provide realistic simulation of mobility and propagation. Specifically, for mobility, the goal is to provide realistic
- node distribution,
- node clustering (i.e., correlation in node location),
- trips including trip lengths, paths, and generation rates,
- and node speeds.
For propagation simulation, the goal is to provide realistic
- propagation range,
- signal strength,
- and spatial variation of the link quality.
Together, the mobility and propagation simulators provide realistic
- topologies,
- and variations of topologies.
The mobility simulation objectives can be achieved by employing models and model parameters that have been developed and verified by the urban planning and traffic engineering research communities. The propagation simulation objectives can be achieved by verifying and by comparing the propagation model to observations. It would be a reasonable assumption that if the propagation and mobility models are realistic then the topology and the dynamics of the topology would be realistic.

It is important to note that the objective is realistic simulation, not accurate simulation. By this we mean that the simulation should provide mobility and propagation similar to what could occur in an urban environment, not necessarily what would occur in a particular urban environment. Accurate prediction requires in depth knowledge of the modeled urban environment. For example, accurate prediction requires precise knowledge of location and dimensions of buildings and other large to moderate sized structures, as well as knowledge of the building materials used and the layout of building interiors. Furthermore, accurate mobility simulation requires knowledge of details such as the types of establishments within each building (e.g., restaurant, office, shopping, etc.) and origin-destination flow matrices for
vehicle traffic. Realistic simulation, on the other hand, merely needs realistic dimensions and locations of buildings, building materials, layout of buildings interiors, and realistic trip generation for vehicles and pedestrians.

This first section of this chapter provides the overview of the different steps involved in the realistic simulation. The section 6.2 provides a brief overview of urban maps used for the propagation and the mobility simulation. Section 6.3 provides a brief primer on the UDelModels urban mobility simulator. Finally section 6.4 details the use of realistic population size (number of nodes) when conducting the simulation.
6.1 Simulation overview

There are several stages involved in realistic simulation of mesh networks. The first step detailed in 6.2 is to define the map of the urban region that is to be simulated. The stage involves editing the map to place the infrastructure nodes. The third step is to determine the propagation matrix for the city. The propagation matrix includes channel characteristics such as path loss, delay spread and angle of arrival for each source-destination in the city. This step has been dealt in detail in Chapters 2 through 5. Processed map information is used to generate mobility trace. The section 6.3 deals with this step. From the mobility trace file obtained from the stage 4 and the propagation matrix obtained from stage 3, propagation trace file containing the propagation characteristics between all pairs of nodes at every given time in the simulation can be generated. Finally the mobility and the propagation trace files can be used with any packet simulator such as QualNet, NS2, etc. to simulate protocols. The Figure 6.1 graphically depicts these different stages of simulation.

6.2 City maps

In order to model urban mesh networks, it is necessary to have a model of the urban area. There are several ways that maps suitable for simulation can be developed. First, a random city can be built as was done in [37]. In this case buildings are placed at random and a Voronoi diagram is used to construct sidewalks between the buildings. One drawback of such an approach is that important aspects of cities such as long thoroughfares and big intersections are neglected. It is well known that streets play an important role in mobile phone communication and it has been shown that streets play an important role in urban mesh networks [76].

A more realistic way to generate cities is to utilize the detailed GIS datasets [77]. These datasets include 3-dimensional building map information that provides enough detail for realistic simulation. There is an abundant number of such datasets.
For example, there are GIS datasets for most, if not all, American cities. Our map building suite of tools converts GIS datasets into format suitable for a specialized graphical editor. The graphical editor is used to "touch-up" the GIS map (e.g., remove spurious buildings, add roads, sidewalks, traffic lights, and fixed base stations). The graphical editor is also used to define locations where vehicles enter and exit the modeled area.

A third way to generate city maps is to develop a map directly in the editor. For example, idealized grid city could be generated within the editor. And finally, there has been some work on generating random, yet realistic cities [78]. Often, random cities produce GIS datasets, and hence can easily be used for propagation and mobility simulation. These realistic random cities are often generated to meet certain aesthetic requirements. It is unclear if these random cities would span a relevant range of mobility and propagation.

While GIS datasets have details of building heights and position, they typically do not provide any details about the interiors of the building. In lieu of actual interiors, they must be automatically generated. Our suite of tools assumes that all buildings are office buildings with offices that are 3.5 meters wide and 3/8 of the building depth deep and the width of hallways is 1/4 of the depth of the building. The hallway runs in the center of the building and stairs are on each end of the building. Incorporating automatic generation of heterogeneous building interiors will be left for future work.

6.3 A brief primer on UDelModels urban mobility simulator

The performance of mesh networks is clearly impact by the distribution of nodes. The majority of mobility simulators assume that the nodes are uniformly spread or at least distributed according to a smooth distribution. For example, the popular random way-point mobility model leads to a smooth distribution where
nodes tend to be at the center of the modeled area [79]. Such distributions differ significantly from those that arise in realistic mobility in two ways. First, nodes are restricted to sidewalks, buildings, or roads, and second, the positions of nodes are correlated, specifically, nodes often move in groups (i.e., node arrivals are bursty). Such groups of nodes are called platoons and are well known to have an impact on the capacity of roads and sidewalks [75]. Platoons of vehicles and pedestrians can arise from traffic lights and from faster nodes catching-up, but not passing slower nodes. In the case of pedestrians, the second cause is increased by nodes that are in groups by choice. Such groups move slower than solitary nodes and limit the ability of faster nodes to pass, thus expanding the size of the group.

In this section a mobility model of people in urban areas for mesh network simulation is presented. Unlike most mobility models found in the literature, this model attempts to provide realistic mobility of people in an urban setting. This simulator is based on the data collected by various surveys including the time-use study conducted by the US Department of Bureau of Labor Statistics and several transportation departments (San Francisco, Connecticut, etc.). The simulator is primarily organized as a three tier model as shown in Figure 6.2. The highest layer is an activity model that determines the high level activity that the node is performing (e.g., working). The second layer is a task model that determines the specific task within an activity (e.g., meeting with three people). And the third layer is an agent model that determines how the person moves from one location to another (e.g., how a node navigates down a crowded hallway). The activity model is based on a recent US Department of Bureau of Labor Statistics time-use study. The task model focuses on mobility of office workers and is based on the current findings by the meetings analysis research community. The agent model is based on the work from urban planning that has extensive knowledge of pedestrian flow. This section provides a very brief introduction to the mobility model. More about
Figure 6.2: The figure illustrates the three tier model employed in the mobility simulation.

The simulation overview can be found at [7] and more about the mobility model can be found at [52] [80] and [51].

6.3.1 Activity model

This part of the mobility model is based on the US Bureau of Labor Statistics 2003 time-use study [81]. This study identifies a large number of activities. We focus on those activities that indicate location and group activities together that are performed in the same location (e.g., all activities performed at home are grouped together into the at home activity). While the BLS study also collected coarse location information, both activity and location information were used to determine the location used in the modeling effort.

This model effort focuses on the work day which consists of being at home, going to work, working, and perhaps taking a break and returning to work and then leaving work and returning home. The model neglects activities before and after work. Future work will include the rest of the day. For each person, the following steps are taken to determine the activities that they perform.
1. Select a home and office.

2. Determine the arrival time at work.

3. Determine the duration at work.

4. Determine if a break from work is taken. (The next 5 steps assume a break is taken.)

5. Determine the break start time.

6. Determine the number of activities performed during a break.

7. Determine which activities are performed during the break.

8. Determine the duration of each activity.

9. Determine the arrival time back at work and determined if a break is taken again. If so, steps 5-9 are repeated.

**6.3.2 Task model**

Some activities consist of a single task. For example, eating consists of going to a restaurant. However, shopping and working consist of multiple tasks. We model shopping as a simple random walk inside the store. However, work is modeled in a more complicated manner that focuses on modeling meetings. Specifically, [82], [83], [84] have collected data on the frequency, size, and durations of meetings; [83] includes two person meetings. These studies allow the model to include worker interactions. Thus, we model mobility while at work as a sequence of meetings followed by working in the node’s office. This process repeats until the work activity is complete.

More specifically, meetings are simulated as follows. The time between meetings is assumed to be exponentially distributed. When a meeting begins, a random
number of people are selected to attend the meeting. Based on the number of people attending, the duration of the meeting is determined. The duration is assumed to be exponentially distributed.

The model parameters of the model are the mean time between meetings, the distribution of the size of meetings, and the relationship between number of meeting participants and the mean meeting duration. These parameters are determined from [82], [83], [84].

6.3.3 Agent Model - Node Dynamics and Interactions

The agent model focuses on the dynamics and interaction between moving people. More specifically, the agent model consists of enforcing a distance-speed relationship between nodes and lane changing rules. The following aspects are considered in the agent model

1. Inter-node distance speed relationship: When a node with a higher desired speed catches up with a slower moving node, it will either follow or pass. To understand the dynamics of catching up, it is necessary to understand the distance-speed relationship. The impact of this relationship is that nodes can and will be tightly packed (i.e. high density) if their speed is low (congestion), but if the speed is higher, then the nodes must be further apart (low density). Since the density of nodes plays an important role in mesh networks and MANET performance, the distance-speed relationship must be understood and realistically modeled.

2. Probability of a node changing lanes: While traffic lights are an important cause of platooning, lane changing also plays an important role [74]. A node will certainly not pass if there is no room (e.g., if the other lanes are full). Even if there is room, both pedestrian and vehicle nodes might not pass out of choice and select to slow down and follow the node ahead [85]. Such decisions
lead to platooning. Platooning can change the node density at a particular place which in turn affects the communication pattern of the nodes in or near the platoon.

Another important aspect of mobility is the mode of transportation and the arrival rates in relation with the time of day. Detailed explanation of mobility model is out of scope of this thesis. More on mobility model could be found at [52], [80] and [51].

6.4 Urban Population Size

It is well known that the number of users has a major impact on the performance of the network. Thus, realistic node population sizes are an important part of realistic simulation. While the number of nodes in a network depend on the number of people in the simulated region, it also depends on the fraction of people that subscribe to the network. Today, mobile phone penetration in Europe exceeds 80% while in the US the fraction of subscribers is approximately 60%. Of course, in the early period of mobile phone deployment, the fraction of subscribers was much smaller. Hence, a wide range of penetration rates are realistic.

As expected, realistic population size in an urban region can be quite large. For example, 1 km$^2$ of Manhattan may contain 10,000 people outdoors [74], a number that is far larger than most simulations currently found in the literature. However, in a less dense city, if 10% of the population participates in the network, then a nine block region of Chicago would contain about 4000 nodes, a number that can be supported by protocol simulators such as QualNet [34]. The following presents guidelines for determining the population size in an urban region.

In the urban core, most of the indoor space is used for commercial purposes, including offices, stores, and restaurants, with office space being the most prevalent. As one moves away from the core, a larger fraction of the indoor space is used for
residences. However, it is assumed that the map specifies which buildings are office, retail, residential, or mixed usage. For office space, a survey of office use in the UK found that typical densities are approximately 15 m.$^2$ per person [86]. Thus the total working population can be determined by computing the total area of office space and dividing by 15.

The US Census American Housing Survey finds that in urban areas there is approximately 1 person per 65 m.$^2$ of residential space. The size of the residential population can be found by determining the total area of residential space and dividing by 65. However, in simulation, we assume that 92% of the people that live in the city will also work within the city, and hence are counted in the working population.

The simulator sets the population as follows

\[
\text{Number of office workers} = \frac{\text{total office area}}{15},
\]

\[
\text{Number of people living locally} = \min \left( \frac{\text{total residential area}}{65}, \frac{\text{number of office workers}}{0.92} \right),
\]

\[
\text{Number of people simulated} = \text{number of office workers} + \text{number of people living locally} \times 0.08 + \text{number of nonworking visitors},
\]

\[
\text{Number of people who commute via subway} = (\text{Number of office workers} - \text{Number of people living locally} \times 0.92) \times \text{MassTransitRatio},
\]

\[
\text{Number of people who commute via car} = (\text{Number of office workers} - \text{Number of people living locally} \times 0.92) \times (1 - \text{MassTransitRatio})^{1}
\]

where the values are such that the office worker density is maintained even if there is an abundance of residential space. Note that we allow for some nonworking visitors. However, further work is required to determine realistic sizes of the nonworking visitor populations.

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1 The MassTransitRatio is the fraction of commuters that take the subway.