A Mobility Management Tool -The Realistic Mobility Model

Joe Capka and Raouf Boutaba, *Member, IEEE*

Abstract— **This paper introduces a new mobility model which takes into account user motivation for mobility as well as geographic constraints on mobility.**

Index Terms— **Mobile wireless networks, mobility management, mobility modeling**

I. INTRODUCTION

Wireless networking is becoming more and more popular in research as well as in industry. While there are a number of successful systems already in existence, there is still much to be improved in this area of communications. Many of the problems that still require a solution spring from one underlying feature of wireless networks: mobility. When mobility is not present in a wireless network, the only true difference between the wireless and wired network is the access medium. Adding mobility of nodes in a network introduces a new level of complexity since the topology of such a network is no longer fixed. There are a number of scenarios where this type of behavior is seen or is expected to be seen in the future. The cellular network used primarily for mobile telephony is the oldest of such systems, however wireless LAN based on Wi-Fi is becoming mainstream very quickly. Mobility of nodes in any wireless network is dictated by factors external to the network itself. In other words, the movement of nodes within a network is not significantly influenced by the network and is not known to the network a priori. This causes difficulties when trying to gauge the resource requirements for specific parts of the network, or when trying to design an optimal paging and location management scheme. There is a large amount of research that focuses on solving many of the problems that spring from mobility in wireless networks, such as guaranteeing a level of service quality or studying connectivity due to network topology. In order to validate many of the mechanisms that have been proposed as solutions to various such problems, researchers have often used simulations. These simulations make certain simplifications and assumptions as is always the case with simulations, and then present results that should reflect with a certain degree of accuracy the success of any such mechanism in the proposed wireless scenario. While many of the assumptions are valid and necessary, there is one assumption made on a regular basis that may simplify many of these simulations too far. This is the assumption that mobility in a wireless network is uniformly distributed. Assuming uniform mobility, the simulations can be greatly simplified since a small portion of the network will experience behavior that is similar to that of the rest of the network. Although this makes the validation of various algorithms and mechanisms more convenient, it is not very realistic and may cause the validation to be incorrect in some scenarios. The main reason many researchers use the uniform mobility distribution in wireless networks is that there is no other simple alternative. Network simulation tools either expect the user to provide a mobility trace or to use the randomly generated trace based on uniform distribution. This paper presents such an alternative. The mobility model presented in this paper is based mainly on activity pattern theory [7] and while it is more complex than the uniform mobility model, it comes with an easy to use software tool that allows the user to generate mobility traces quickly and easily. The aim and main contribution of this work is to provide researchers with a tool that can create mobility traces that are much closer to reality than what is currently being used, without requiring those researchers to know much more about mobility than they currently do. Models similar to this one may exist in vehicular traffic engineering, but these are not available to researchers due to prohibitive costs, and are often difficult to understand and use. This paper is organized as follows: Section II gives an overview of mobility modeling research and attempts to classify existing mobility models. Section III describes the mobility model implemented in this work. Section IV discusses the forms of output provided by the model. Section V discusses the validation of the model and Section VI concludes the paper.

II. BACKGROUND

A. Mobility Modeling

What is a mobility model? A mobility model is a representation of a certain real or abstract world that contains moving entities. The world is said to exist for some finite amount of time during which each moving entity has one unique but changing location of presence as defined in the location granularity of the world [4]. In essence there are

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Joe Capka is Business Developer Analyst with Infusion Development (Canada) Corp. (e-mail: jcapka@infusiondev.com).

Raouf Boutaba is an Associate Professor with the School of Computer Science at the University of Waterloo, Canada (phone: +1 519 888 4820; fax: +1 519 885 1208; e-mail: rboutaba@uwaterloo.ca).

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mobile entities whose location is a function of time and some heuristics inherent to the mobility model. It is these inherent heuristics that differentiate the mobility models from one another. A number of various mobility models have been proposed in literature, some quite recently [2, 3, 5, 7]. There is a growing concern in the research community that the simplistic random walk and random waypoint models are no longer suitable for simulations with meaningful results for many problems [1, 8]. This is partly due to the fact that there are certain features of random mobility that are particularly difficult to justify. These would include the lack of geographic dependencies in the simulated environment and the purposelessness of the user motion. Another contributing factor to the abovementioned concern is that there are certain suspected properties of user mobility which are not reflected in any of the random models. It may be possible to exploit these properties and improve existing wireless systems, but any such potential improvements will not be visible when testing with a simulator that uses a random motion model. The properties spoken of are mainly expected to be some regularities in user movement. Thus various mobility models have been presented, each with a specific goal and suitable for a specific scenario. The following discussion attempts a brief overview of the various scenarios for which mobility models have been developed and presents a few examples of existing models.

B. Geography

There exist two classes of mobility models when geography is concerned. What is meant by geography are the underlying geographic constraints that any mobile user in the real world has to deal with, such as roads, rivers and walls. The two classes are those that include geography and those that do not. While this seems obvious, it is important to keep in mind. There are a number of complex mobility models that exist which have no mention of any geography [10], and may be quite incomplete for validation of certain studies.

C. Mobility Scale

One of the main classification mechanisms for mobility models is the scale for which they are designed to function. The smallest scale mobility models are designed for the indoor environment. While the indoor environment is often labeled as the most appropriate environment to be modeled by a random model, there are models such as the picocellular model presented in [9] that are specifically designed to handle such small scale mobility. This model by Voigt and Fettweis presented in [9] allows users to move among a set of locations within a room, one of which is a special location by the door that allows movement out of the room. There are probabilities associated with different movements. The next size up is the street unit model such as presented in [4]. This model allows for modeling streets with such a level of detail that stop signs and traffic lights are included. The next scale up are models that deal with area zones, these models are primarily concerned with the idea that certain mobility, such as vehicular mobility, only happens on streets and certain areas are more densely populated than others. [4, 8] present such models. Then there is the last scale which is the city area type of model. This model is concerned with the different parts of a city area and the mobility of users between these parts. There is a lot of variation between models of this scale, as there are a lot of simplifications or complications such a model may involve. Most mobility models fall into this category [2, 4, 5]. The scale of the model is important to note since different problem studies require different granularity of mobility. For example, studies that deal with location management often deal with sections of the network as opposed to individual access points and thus require no more detail than that provided by a city area scale model.

D. User individuality

Another main classifier when making distinctions between mobility models is the treatment of users, or mobile terminals. The simplest user treatment consists of aggregating the users into a density function that defines how many users are in a given location at a given time. The next step involves the definition of multiple user classes. Each class differs from the others in some was, such as the speed the users in that class travel at. This approach can be seen in the work involving poles of gravity [1, 2], where the users are modeled as a flow from one location to another. Users are still represented by a density function, however there is a number of different density functions, each representing user class. The next step is to make each user an individual entity. This increases the complexity of the model considerably since each user has an individual state. An example of this can be seen in [5] where individual users move around various world maps. Once individual users exist, there are a number of ways to make each user differ from the others. Most models will still classify uses such that they belong to one of a small number of classes such as highly mobile users, business users or residential users [3, 7]. However, each of these users can have different behaviour that is unique to that user by some randomization of that user’s properties, such as speed of motion, or the location the user considers home. These are the most complex user models. There is one last feature of a user that can be used to classify the mobility model, this being the persistence of the user. In essence, persistent users stay present in the mobility model throughout the lifetime of the world. This means that any behaviour specific to this user will have an impact on the world for the existence of the world. Non-persistent users [8] may disappear from the world and be replaced by similar users throughout the existence of the world. Persistent users can be found in [7], where the activity based model requires a user to return to its work and home locations every so often. This type of behaviour would be meaningless if the users were replaced by similar users whose general behaviour would be the same but who would have different home and work locations, since the regularity that the model aims to offer would be lost.

III. THE REALISTIC MOBILITY MODEL

While there are a number of good mobility models to start from when creating a new one, there is a particular that was used as a basis for the RMM. The mobility model presented in this work is mainly an extension of the activity based mobility model by Scourias and Kunz [7]. The reason this model was chosen as the staring point for the RMM is due to the features already present in the activity based model. While other models have a more detailed treatment of mobility, the activity based model is one that offers user persistence. For applications that aim to exploit any regularity in user behaviour, this type of model is very desirable. While the activity based model is useful and sufficient for the study it was designed for [6], it has a number of shortcomings that have made its usefulness limited. The aim of the RMM is to improve upon these shortcomings. Note that while some of the shortcomings discussed in the following paragraphs are shortcomings of the design, some are only shortcomings of the implementation.

A. No geographic layer

The model does contain a geographic constraint layer. There is no method to encourage or prevent users from moving in certain ways that is related to some physical constraints. Thus for example there would be no way to test the impact a new highway in a city would have on they network.

B. Granularity

As presented, the activity based model has no way to separate the motion of the user in a geographic sense from the motion of the same user as seen from the perspective of the network. This means that the activities users are engaged in are located at locations with granularity of the network as opposed to geographic locations. There is then no way of knowing the difference between a user that is at a location quite far from a network access point (NAP) or one that is directly underneath the NAP.

C. Fixed routes

Users move from location to location based on the activities they are involved in. The selection of the next activity location is quite elaborate, but the route which the user follows to that next activity is simply the shortest route from the current location, which is obtained from a fixed routing table that is the same for all users. Thus it is impossible to have users that choose their own path, depending on some user based criteria. There may exist two equidistant paths, and it would seem likely that all users would not choose the same path.

D. Activity locations

The shopping activity is the only activity that is limited to certain locations. The rest of the activities can and do happen with equal probability at any location in the model. This is quite unrealistic as geographically there would be locations that are primarily residential, primarily business, etc., and activities would have different probabilities of happening in different kind of locations.

E. Fixed User Speed

Each user moves through the entire network with exactly the same speed. In essence the mobility of users consists of calculating the time that the crossing of the number of network access points between the source and destination takes based on a universal fixed speed. This does not allow for the differentiation of vehicular versus pedestrian users for instance.

F. Only one topology

The implementation of the activity based model comes with a network topology of 45 cells that is a representation of one specific physical region. There is no straightforward way to change this to a different network topology; conversely modifying the source code is necessary. The mobility model should be able to easily handle multiple network topologies. The aim of the RMM is to remedy the shortcomings listed above. The main difference noticeable between the RMM and any other mobility model referred to in this paper is that the RMM does not include a network. It was decided that user mobility is not influenced by the network in any significant way (the number of users that will choose a different movement due to network behaviour such as signal availability is relatively small) and thus there is no need to include the network in the mobility model. The aim of the RMM is to produce a mobility trace of users that conforms to the definition of a mobility model [4]. From the trace it is possible to derive the location of any user at any time the modeled world was in existence. This allows a wider use of this mobility model, since any simulator that is capable of reading a mobility trace will be able to make use of the RMM. Some formatting issues may exist, but these should be trivial to solve. Other mobility models are developed as part of a simulator and are thus more difficult to use in other simulation scenarios. There is no need for this as there are numerous quality simulators in existence already. Since there is no network involved in the RMM, all the user mobility occurs on a geographic scale. The world is created to be of a certain size, and the granularity of user movement is defined using the same scale. This constitutes the basis of the geographic layer. The model then allows for the definition of geographic regions such as roads, cities, and rural areas. These impose different physical constraints on the movement of the user. See the next section for specifics. Motion in the RMM is based on a routing table that contains the result of an ‘all-pairs shortest-path’ calculation. The costs of motion from one location to another adjacent location are determined by the geographic type those locations represent. These costs are chosen when the world is created. A user that needs to move from one location to another can thus lookup the next hop on the shortest path to the destination and proceed. This seems to be similar to the method used in the activity based model. There are however two differences. The routing is now happening on a scale that is independent from the network, and if there is more than one equidistant path between two destinations, the user is free to choose any of them. This reflects a more realistic scenario where users will observe the geographic constraints and choose the shortest path possible, but will be free to speculate as many real humans do, which of all the available equidistant paths is the best one. Most activities that users undertake can still be located pretty much anywhere in the world as it is defined. Work, home and shopping are limited however. The zoning layer allows the model to define four types of zones. The default zone is a no-zone, which means this location is not any of the following three special zones. The first special zone is the business zone. A user is by default only allowed to work in locations that have been zoned as business zones. The second type of zone is the residential zone, which is the only zone that a user is allowed to have a home in by default. The last special zone type is the shopping zone which is by default the only zone where a user is allowed to shop. The zone adherence can be set to less than 100% however, which means that a certain percentage of users will reside in non residential zones and work in non business zones. This is motivated by real-world people such as farmers who do not live nor work in residential or business areas. As mentioned above, the activity based model does not provide a mechanism for users to move with different speed. The RMM resolves this problem in the following way: The speed of a user is based on the type of geography they are moving through. A user moving along a highway will move faster than one moving through the city or through a field. In order to make the users unique however, the actual speed of motion is chosen randomly from a range that corresponds to each location type. This method allows each user to move at a unique speed, but preserves the notion of similar user speeds being observed in any given area. With the features mentioned here, the RMM provides a mobility model that not only captures the useful features of the activity based model, but also improves on it. The model is designed so that it can be used in many scenarios and in combination with many simulators. Since the model is network independent, it can be used with any of a number of networks, and many experiments can be run with the same mobility trace to ensure fair testing. The RMM was designed with usability in mind and thus includes an easy to use implementation which is not described due space limitations.

IV. MODEL OUTPUT

In order for this model to be useful, it has to produce output that can be used as a mobility trace. This output is generated in the form of motion segments. Mobility segments comprise of a source (x,y) location, a source time, an (x,y) destination location and a destination time. The mobility trace that is the desired output is therefore a file that contains entries consisting of the user ID, the start time, the start location, the end time and the end location. Having this information enables the researcher to determine the location of any user at any time during the simulation. The output thus corresponds to the output requirements set forth in [4]. Another form of output that is provided in the RMM are periodic snapshots of the user distribution throughout the model. These snapshots are generated at a specified interval, and represent the number of users present in all locations at that time instant. There are two representations of any one snapshot, a numerical representation and a graphical representation.

V. VALIDATION

It is difficult to completely validate such a mobility model, since no mechanism of proof exists that could prove this model to be correct. There are however a number of arguments that can be stated, which reinforce the validity of the RMM. The RMM is based in large part on previous work that has been validated and accepted. This is the activity based model presented in [7]. The drive for users to move around the RMM is provided by the activity selection mechanism proposed in the activity based model, and can therefore be taken to be at least as correct as that work. The new features that the RMM provides are features that influence the mobility of the users between the activities, and the constraints on the location of some activities. The main new features are: • Addition of geographic constraints - Users are now motivated to move along certain structures of the simulated world and avoid others. • Varying user speed – Users move with speeds that are dependent on the type of geography they are moving through, and speeds that vary from other user speeds. • Equidistant paths exploited – Users can choose motion along any path from a set of equidistance shortest paths when such a set exists. • Zoning – Users cannot live and work where they choose to, there are zoned areas that are designated business areas and residential areas where these activities must take place. The reasons for adding the above stated features should be clear from the previous discussion. The validation of each one of these features was performed by careful analysis of various test scenarios created using the tool that implements the RMM. Geographic constraints were shown to influence user movement when users did not take direct routes between two points, but instead took routes with the lowest cost. The cost was a reflection of geographic constraints. In short, users preferred using roads to travel and avoided water areas. Varying user speed was verified by observing numerous trips by various users that had the same origin and destination. The length of time these trips took varied, thus showing variable user speeds. A scenario where multiple equidistant paths existed showed that different users did indeed choose different paths to travel from the same source to the same origin, thus showing this feature to work. Finally, the snapshot output method showed that users did adhere to zoning restrictions as most users would start the day in the residential zones, then spread out in the world with a slightly heavier concentration in the business zones and finally return to the residential areas at night. Thus the newly introduced features do work as intended, and it is difficult to prove that they are useful. However the arguments for introducing these features are strong and there is no argument against using such a model.

VI. CONCLUSION AND FUTURE WORK

In this work, a new user mobility model is presented. This model is defined to be more realistic in many ways than any other model available to the wireless research community. The model builds on work presented by Scourias and Kunz in [7], where they present the activity based model. The model is extended to include a number of features making the mobility trace it produces more realistic, such as geographic constraints and zoning of area types. A GUI is included in the implementation of the model such that the worlds where the users are to be simulated in can be drawn, and the parameters for the simulations can be easily entered using user friendly menus. The goals for this mobility model are met by having created a model that is easy to use and is able to produce user mobility traces without the researcher needing to have much background of mobility modeling. Validation of the model is difficult, but tests have shown that the behaviour generated is as expected and is representative of real world behaviour. This model can be improved upon in the future in a number of ways. One major improvement would be including temporally dependent attractions. An example of such an attraction would be a sports event. Another improvement would consist of adding route preference to users. A user that is presented with equidistant paths may choose the same one the second time they are in this situation. This would be representative of the habitual nature of human beings. The activity transition probabilities and activity durations are currently based on one survey. Any additional surveys as this one would be useful in making the model more robust. The RMM is currently designed to model user movement on the scale of kilometers or hundreds of meters. It would be useful to create a similar model that is focused on much smaller scales, since such a model would be useful for much of the wireless LAN technology that is becoming so popular.

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