REALISTIC TERRAIN AWARE MOBILITY MODEL

Conference Paper · February 2012

Sonja Filiposka
Ss. Cyril and Methodius University in Skopje

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Maja Dineska, Sonja Filiposka

Faculty of Computer Science and Engineering, Ss. Cyril and Methodius University, Skopje, Macedonia

Abstract - Among other simulation parameters, topology and mobility model are key factors for precise evaluation of ad hoc networking protocol characteristics. Because the movement of the nodes directly impacts protocol performance, it is essential to use realistic movement model that will provide improved simulation results. The majority of proposed mobility models in the current research literature do not provide realistic movement scenarios in a terrain modeled environment. They are often limited to random walk mobility models without considering real-world terrain. The work presented in this paper introduces R3D, an independent tool for generating mobility scenarios that follow a newly proposed 3D mobility model that includes nodes movements through real, irregular 3D terrain.

1. INTRODUCTION

In the next generation of wireless communication systems, there will be a need for the rapid deployment of independent mobile users. Significant application examples include establishing efficient, dynamic communication for emergency operations, disaster recovery or military operations. Such network scenarios do not rely on existing communication infrastructure and can be conceived as applications of Mobile Ad Hoc NETwork [1]. A MANET is composed of mobile devices capable of wireless communication, such as user-carried PDA devices and notebooks. Unlike wired networks which rely on routers or managed (infrastructure) wireless networks that rely on access points, wireless ad hoc networks perform routing by forwarding data between nodes. All mobile nodes act as mobile routers. Ad hoc networking protocols depend heavily on the routing mechanism and the movement of the nodes.

Network simulations are quite often the only research tool for understanding the operation of ad hoc networking protocols. Simulations provide feasible mean to compare different protocols and analyze their performance. Indeed, network simulations environments such as NS-2 [2], Qualnet [3] or Opnet [4] are the most commonly used tools for performance evaluation. There are a number of important simulations parameters, but topology and mobility models are two of the key factors for obtaining acceptable realistic results [5].

One important feature of MANETs is the dynamic behavior caused by node mobility. Thus, key challenge in the evaluation of such protocols is to conduct the performance analysis with realistic mobility models that accurately reflect the mobile users' movement. A realistic mobility model should include avoiding and getting around real-world obstacles that will provide conducting much improved analysis over real life scenarios.

Mobility models describe the movement pattern of mobile nodes and provide a definition for their location and velocity that might change over time. Once the nodes are initially placed, the mobility model is the one that defines movements over the simulation area. Many mobility models for the generation of synthetic traces have been presented (a survey is provided by Camp, Boleng and Davies in [6]). The first mobility model ever proposed was the Random Waypoint [7] movement model. Although it is the first it is also still the most widely used model. However the simulated behavior using this model does not resemble the natural movement of the nodes and point to several weaknesses [8]. Therefore, in attempt to improve movement patterns and to increase the realistic features, various researchers proposed large set of mobility models with different characteristics [9] [10].

The firstly proposed mobility models are the entity mobility models that are concerned with the individual node's movement. This individual movement is entirely independent of the movements of other nodes and the environment, although its changes in direction and speed in time interval (t+1) may depend on their values in the previous time interval t [10]. Models that demonstrate this feature are said to be models with temporal dependency [11]. A step forward towards realistic models is the ability of nodes to cluster and therefore the models are referred to as Group Mobility Models [12]. This means that node's movement may be influenced by neighboring nodes (e.g. ad hoc meetings, instant information sharing, etc.). Topographical models [13] [14] on the other hand integrate the environment in the simulation area following the necessity that the node's movement must be restricted by topographical characteristics.

It is fairly straightforward to conclude that all entity movement models generate behavior that is most unhuman-like. Having in mind that the most likely deployed scenarios for mobile ad hoc networks are found in outdoor scenarios for rescue missions, exploration and similar, one must emphasize the need for realistic mobility model that will integrate the environment which on the other hand can significantly restrict the movement of the nodes as well as the propagation of the wireless signals.

Based on this analysis, in this paper we propose a standalone tool that implements a newly defined realistic 3D mobility model that aims to realistically model the node mobility throughout a real three-dimensional terrain with realistic obstacles. The tool generates an output that defines the movement of the nodes during the simulation time in a format that can further be used as a mobility scenario script for the NS-2 simulator.

The remainder of the paper is organized as follows. Section 2 details related research in the area of mobility models. Section 3 describes the definition of the terrain over layer while the design and implementation of the model is presented in Section 4. Analysis of the properties of the model are provided in Section 5. Finally, Section 6 concludes the paper, outlining the future research direction.

2. RELATED WORK

There is a lot of literature that deals with the properties and descriptions of the proposed mobility models and their movement patterns. Categorization of mobility models can be found in [11], while a survey and a general comparison is provided in [6]. In this section we provide a brief description and an overview of the benefits and deficiencies obtained with the use of different mobility models and argue what is the missing puzzle in order to achieve more realistic behavior.

Random based individual movement models are still the most widely used and not because of their correct results, but primarily because of their simplicity. The Random Waypoint model [7] is used on a large scale when simulating protocols designed for mobile ad hoc networks. Because of its simplicity it is available with a large set of simulators. Mobile nodes move randomly in a two-dimensional system area without any restrictions in terms of the environment. In addition, parameters such as destination, speed and direction are all picked randomly. In brief, the order of the actions is as follows: each node picks a random destination uniformly and travels with speed v whose value is uniformly chosen in the interval $(0,Vmax]$. When a node reaches its destination point, it takes some pause time, after which it chooses a new destination and a new speed and resumes movement. The advantage of the model is its simplicity in implementation and performance evaluation and therefore is the most commonly used for simulation purposes.

On the other hand several studies [15] of this model have revealed unreliable results and many deficiencies. This model is expected to maintain the average speed as the simulation progresses, however in [8] it is shown that this model fails in providing steady state in a sense that the average speed of a mobile nodes constantly decreases with time. This is due to the fact that more and more nodes are "stuck" traveling to their destinations at low speeds. It was also shown that nodes distribution is higher in the center of the simulation area compared to the boundaries. Nodes traveling towards their destinations take sharp changes in directions and velocity [16] which on the other hand are chosen without consideration of their previous values. Almost all weaknesses discussed above are true for all random mobility models. The Random Walk Mobility Model [15] can be considered as Random Waypoint with pause time between two movements equal to zero. Random Direction [9] is proposed to overcome the unexpected issues that produce Random Waypoint regarding density waves.

While each of these models generates random mobility and can be used for the simulation study of ad hoc networking protocols, none of these models attempts to model the behavior of nodes in a realistic environment. All of the models assume open, unobstructed areas in which nodes are free to move according to the constraints of the mobility model. In real-world scenarios it is quite uncommon that people are located on flat terrains with no obstructions at all. In order to understand how a protocol will behave in an obstructed area, it is necessary to create mobility models that precisely model the environment.

There are a few mobility models that include the profile of the terrain when constructing the mobility scenarios, but these are often constrained by moving only on horizontal and vertical streets that represent the unobstructed area [14] or on the lanes of the freeway. Although these models incorporate sort of real terrains, they cannot be considered as realistic, because of their simplicity correlated with spatial dependency and inability to provide more complex realistic behavior. The Obstacle Mobility Model considers [13] the real-world urban topography, but only in a two dimensional system. The profile of the terrain used in this model includes obstacles like buildings and other objects that are target destination for the nodes. Several models have been developed based on this Obstacle Mobility Model. However one must bear in mind that while these models incorporate the environment in the mobility scenarios they are all models that try to model the urban node behavior.

On the other hand, because ad hoc network deployment scenarios are often placed in outdoor non urban environments, the R3D mobility model proposed and presented in this paper provides a mechanism for modeling movement in real world outdoor non urban scenarios that is based on irregular three-dimensional terrains defined using a standard terrain description according to the Geographical Information Systems.

3. TERRAIN OVER LAYER FOR MOBILITY MODELING

In order to create a 3D terrain aware mobility model the first step is to be able to read in the terrain configuration from a standardized GIS terrain format. Regarding the mobility modeling of outdoor non-urban scenarios, the existing approaches are neither suitable nor complete. In order to achieve high degree of realism geographic restrictions must be considered. Defining geographic restrictions means implementing topology sub-model that influence node movements regarding the terrain.

The terrain definitions that can be used in our model are based on the standard formats for terrain description: Digital Elevation Model (DEM) [17] or Triangular

Irregular Networks (TIN) [18]. The R3D tool accepts the TIN terrain description as an input argument as defined through the use of the Virtual Reality Language (VRL) [19]. However since the access to a freely available DEM definition of a real world terrain is much easier, one can use these DEM terrain format with an extra step of converting the DEM to TIN (without any information loss) using some freely available software such as Landserf [20].

The TIN vector model represents a surface as a set of contiguous, non-overlapping triangles associated with 3-dimensional data (x, y, and z) and topography. Within each triangle the surface is represented by a plane. The points that define all the triangles and planes that describe the terrain are the data that the VRL file contains. For a comparison the DEM format is a raster based format that holds the terrain information as a matrix of terrain heights. An advantage of using a TIN over a raster DEM in mapping and analysis is that the points of a TIN are distributed variably based on an algorithm that determines which points are most necessary in order to provide an accurate representation of the terrain. Data input is therefore flexible and fewer points need to be stored than in a raster DEM, with regularly distributed points.

The R3D mobility model is based on the random waypoint mobility model while making the nodes aware of the terrain they are moving on. This terrain awareness is primarily done using a second layer over the terrain that defines the allowed approachable movable areas for the nodes and denies node movement in the forbidden non-approachable areas. This second layer over the terrain is defined in 2D and can be obtained automatically based on the steepness and roughness of the terrain or can be defined by the mobility scenario modeler. The main idea of the model is to transform the simulation area in such a way that will not allow the nodes to climb too steep paths (like canyons or steep rocks), or will not allow the nodes to enter natural obstacles (like rivers, lakes, creeks and alike).

The non-approachable areas for the nodes that are automatically recognized via their high slopes are obtained using the coordinates of the points that define the terrain triangles from the TIN file. Using this coordinates it is fairly straightforward to form a connected flat surface plane that represents the triangle extending in three directions and to calculate its normal vectors a, b and c. After determining the values of these vectors, the slope of the plane can be calculated. After each slope is defined, the input terrain is overlaid with a two-dimensional layer that marks each part of the terrain as approachable on not approachable according to the slope of the terrain and the outside input from the user who defines what is considered as an acceptable slope. The user is allowed to define different slope for each scenario, depending on what are the observed properties and the definition of the scenario by itself. Note that the slope is presented in percents and not in degrees.

The detailed terrain modeling process is as follows. For each cell in the two-dimensional layer the central cell point equally located from both ends is selected and then the slope of the triangle containing this central point is observed in order to compare it with the acceptable slope range. If the value of the slope is greater than the one defined by the user as maximum acceptable, then the cell is modeled as unapproachable and vice versa. For an example, let's assume that the user defines max acceptable slope of 30%. It means that all the cells for which their central point belongs to triangles with a slope lower than 30% will be marked as approachable and vice versa. The result of this process is a two-dimensional layer representing the terrain that is modeled depending on the three-dimensional description and the user input for the slope.

The described modeling process introduces the problem of too many small approachable areas surrounded by unapproachable areas which allows for the nodes to be stuck in a kind of isolated small islands of non-steep terrain. It is unlikely that one can carry out an efficient analysis and extract proper results, because of the constrained node movements with similar characteristics. The number of moves and pauses performed by the trapped nodes are significantly bigger just as the number of failures realized in order to find a valid destination.

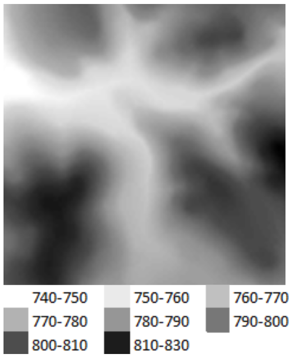

Figure 1. Example terrain and directions for interpreting (height is given in meters)

Figure 2. 2D over layer with approachable and non approachable areas for the example terrain (white approachable; black non approachable areas)

Since it is not a realistic node behavior for the nodes to come to be and remain captured in these areas, this problem was solved in the following way: before the simulation starts, the user is prompted to input the maximum size of the enclosed areas (islands) that will be set as unapproachable. After the initial definition of the over layer with the approachable and non approachable parts of the terrain, the algorithm then includes a calculation that seeks out all enclosed areas and if their surface is smaller than the one defined by the user, it models the whole island as a non approachable terrain. In this manner, the end user can be certain that the nodes can perform movements that are distributed across the whole simulation area, or can be confined on large isolated planes (i.e. mountain plateau).

For a visual example of the construction of the terrain over layer consider the following: the terrain presented in Fig. 1 is a 1000 x 1000 m terrain with a minimum of 730 and maximum of 830 meters height. Using our R3D mobility model we obtain the terrain over layer as it is presented in Fig. 2. The obtained terrain over layer is defined with maximum acceptable slope of 25% while the minimum acceptable size of the isolated closed areas of 400 square meters.

The inability of the generator to conclude what is the ideal size for manipulation may be conceived as deficiency. The user must perform detail observation of the terrain and maybe use the generator for a couple of times in order to come to the conclusion of the ideal size. Please note that such algorithm is difficult to provide since different scenarios define different parameters and may use many kinds of terrains with varying size. Thus, this feature remains to be improved in the future versions of the mobility model.

The terrain over layer given in Fig. 2 can further be changed by additional markings of non approachable areas by the user. In this way the user can input other non approachable areas like water bodies and alike.

Another important remark regarding the R3D mobility model is towards the variety of applications. Please note that the mobility model can actually also be used in a 2D environment only. In this case the user alone defines the non-approachable areas and is not concerned with the accessibility of the steep terrain because it is simply not present in this type of scenario.

4. DESIGN AND IMPLEMENTATION OF THE MOBILITY MODEL

The R3D mobility model and tool proposed in this paper generates realistic movement pattern for non-urban scenario where irregular terrain is considered. Therefore nodes must follow a proper mobility algorithm avoiding obstacles and only progress towards approachable points.

Based on the over layer of approachable and non approachable areas, the basis of the R3D mobility model is on top of the Random Waypoint mobility model in combination with the A* algorithm [21] used for pathfinding. This algorithm allows the node to find its way around the non approachable areas towards its goal.

Before the simulation starts, the user is allowed to set a few parameters that will define the scenario. Parameters enabled for user definition are setting the minimum and maximum values for speed and pause (also the user can decide upon enabling pauses for the simulation). The user defines the number of nodes that will be distributed over the simulation area and sets the maximum simulation time. As mentioned in section 3, the size of the maximum acceptable slope and the size of the enclosed areas can be also defined by the user before the simulation starts.

The nodes are initially randomly distributed in the approachable areas. Their potential initial locations are only the cells that are assigned as approachable with the process of terrain modeling. If pauses are enabled by the user, than each node may choose whether to move or pause as its first action. If the pauses are not enabled it is certain that all nodes will perform movement as the simulation begins. If the node will perform movement, it randomly selects one location (cell) in the simulation field as its destination. Then the nodes moves with a randomly chosen speed within a given [Vmin, Vmax] evenly distributed interval towards the randomly chosen goal that has to be positioned in an approachable area while there has to be a path from the node present position to the approachable destination. Valid destination selections are only the cells that are assigned as approachable and there exists a valid path obtained using A* avoiding all the non approachable areas.

If the node's first action is to pause it will only choose a value from the interval [Pausemin, Pausemax] that presents the amount of time that the node will pause after the simulation begins. After the pause time ends nodes are not allowed to perform another pause and are forced to move towards another randomly chosen valid destination in the simulation area with a randomly chosen speed. After each movement the node chooses whether to pause or continue moving toward another reachable randomly chosen goal with randomly chosen speed. The speed and destination goal of a node are chosen independently of other nodes. If the pause time is equal to zero or pauses are not enabled at all, this leads to continuous mobility. The whole process of pausing and moving for all nodes is repeated over and over again until the simulation time reaches the maximum simulation time parameter defined by the user before its start.

As previously commented, the presented mobility model design reminds of the random Waypoint model if the terrain is completely flat. If this is the case, then the tool will act as two-dimensional mobility generator and the movement is not constrained by any obstruction. This leads to the fact that the model may be also used in scenarios that doesn't consider the terrain at all. Regardless of the terrain oblique, we remind that the user is also allowed to define its own obstructions in the simulation field. These obstructions are types of obstructions that somehow are not incorporated with the terrain description. These unapproachable zones will be treated in the same manner as all other cells assigned using the terrain modeling process.

The R3D generator also includes a mechanism for collision avoidance. Nodes traveling towards their destinations may be determined to pass the same cell at the same time and to perform collision. The node collision avoidance works as it is given in [22], but include collision detection before the move even starts. After the node chooses its next destination, the pass time interval is determined for every cell on the path. Then, the node checks if there is another node that will pass any of its cells on the path to the destination in the same time. If this is true, the cells where the collision occurs are assigned as unapproachable for the given time moment and a new path is found. The process is repeated until a path with no collisions at all is found.

5. MOBILITY MODEL CHARACTERISTICS EVALUATION

The primary objective of the simulations given in this paper is to understand the impact of the terrains in a simulation environment. We tested the proposed mobility model using several runs generating different scenarios and making a comparison among the evaluated performances so conclusions could be drawn. Results of multiple scenarios are presented in this section, each one characterized by different parameters, in order to cover all the aspects.

The first group of results is obtained utilizing the square 1000 x 1000 m terrain given in Fig. 1 and appropriately in Fig. 2. The aim of these simulations is to present the impact of the changes in the value of the acceptable terrain slope parameter on the generator performances. We compared the same scenario, first with maximum slope of 30% and second with maximum acceptable slope of 35%. As expected, as the maximum acceptable slope rises, the percent of approachable cells follows. Indeed, 72,3% of the cells in the first run are assigned as approachable despite 87,7% approachable cells after the second run. Our analysis shows that the number of failures to find an approachable destination, and a correct path to it, is directly dependent on the terrain accessibility. As the terrain is more accessible, the less is the number of failures.

The number of collisions avoided is also dependent on the terrain accessibility and also the number of nodes in the simulation area. If the simulation area is less obstructed, more of the area is approachable and nodes prefer to move across different paths to reach the destinations, so the chance to collide is reduced.

Another parameter that can be indirectly controlled by the user refers to the number of triangles that are used to describe the terrain. The more triangles are involved in the terrain description, the more precise the evaluation gets since the generator works with a more detailed terrain. Through several scenario runs where the same terrain is defined by a different number of triangles we concluded that as the number of triangles decreases the terrain accessibility increases. This is due to the fact that if the terrain description is less precise (in term of number of triangles used to describe the terrain) it means that the average slope of few triangles now merged as one is less than the slope of the previous triangles having the steepest plane and the chance to belong to the defined interval by the user are greater.

For an example, an evaluation was made using another square terrain sized as the previous, with similar characteristics and the following results are obtained: If the terrain is described using 12019 triangles the terrain accessibility is exact 70%, while when the terrain is described using 9843 triangles we get accessibility of 70,5%, while 6862 triangles description that lead to a accessibility of 71,5%. As the number of triangles increases, the number of approachable cells is decreasing leading to more failures in order to find correct destination and more collisions avoided. However, one can observe that the change in accessibility is not very prominent.

It is very important to stress that our analysis has shown that none of the parameters used to define the terrain impact the speed of the nodes. Once the nodes are distributed over the simulation area, each node selects its speed from the given range defined by the user. The speed and the duration of pauses are distributed randomly and uniformly from the given range and their values do not depend on other parameters. As a concluded result from all observations and simulations analysis we may say that the average speed stabilizes a bit lower than the middle of the range defined by the user (Vmin + Vmax)/2. This kind of behavior of the mobility model is expected and encouraged by the existing mobility model analysis [7].

Yet, the number of pauses and the number of movements certainly depend on the duration of the simulation, but also from nodes initial position. If the node is initially located in some enclosed area (island) or maze that is not connected to the rest of the simulation field, then the number of performed movements and pauses will be much greater just as the number of failures to find a valid destination.

The bigger the terrain is, the duration of simulation run should be longer in order to have a more even distribution of the visited approachable cells in the simulation field.

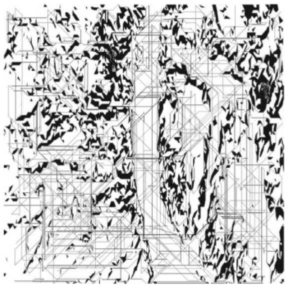

Figure 3. Movement distribution

Previous simulations using the smaller field of 1000 x 1000 meters were run for 1000 or 1500 seconds. However, if the simulation is run for 1000 seconds incorporating a terrain with size 7000 x 3000 meters, the results show that during this time some of the nodes did not manage to finish even the first movement and some of them barely perform maximum of two movements. The 2D over layer of this terrain is presented in Fig. 3 where are shown all the movements throughout the entire simulation area performed by 50 nodes for 5000 seconds. To conclude, if the tool is about to be used for generating scenario over a large terrain it is a must to perform the simulation several times in order to analyze obtained results. Towards it, we consider that correct results are obtained when the simulation is run long enough to provide velocity stabilization a bit lower than the middle point in the defined range, also for the average pause time (if are enabled). In this way the nodes will perform at least a number of moves and pauses so that correct average numbers may be extracted.

6. CONCLUSION

Researches indicate that the behavior of simulated routing protocols varies widely depending on the mobility model. The definition of realistic mobility model is crucial since the simulations should provide reliable results for ad hoc networking protocols performance.

It is shown that random mobility models do not provide such results, since the topology map doesn't consider environment at all. Some augmented models as Mobility Model founded on social network theory or 3D signal obstruction model are step forward towards realistic, but still cannot be taken into consideration since they do not implement geographic restrictions and spatial dependency respectively.

This paper proposes a new mobility model that enables inclusion of 3D irregular terrain and generates movement pattern that is in accordance with the terrain profile. The tool may also be used to generate scenarios that incorporate 2D flat terrains, where the area that is approachable is defined by the user only and nodes movement is not also restricted by the terrain profile. In such case, the proposed model will behave just as Random Waypoint model and the model for radio propagation will only consider the distance between nodes.

Regardless of the terrain existence, the user is allowed to define its own unapproachable zones that are not included into the terrain description and to further restrict movements of the nodes.

The R3D mobility model includes a terrain modeling mechanism plus an algorithm for finding the shortest path from the source to destination while providing a mechanism for avoiding all obstructed cells, a mechanism for avoiding collisions and manipulation with small enough closed areas. The results from our simulation analysis show that the model does not have a problem with a continuous decreasing velocity while it is independent on the terrain parameters.

Our future work will be focused on improving the model with a better algorithm for seeking out and defining enclosed unapproachable areas as well as more transparent definition of additional natural or manmade obstacles using a GIS defined over layer of the terrain. Another addition will be incorporating possibilities for social group node behavior in our model.

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