3D Simulations for Wireless Ad Hoc Networks in Grid Environment

Sonja Filiposka and Dimitar Trajanov

Abstract - In this paper the usage of grid environment for fast simulation of wireless ad hoc networks in 3D terrains is presented. The possibilities and gains of the grid environment have proven to be very resourceful when simulating wireless ad hoc networks using the NS-2 simulator especially when considering lengthy simulations for performance evaluation with a heavy traffic load involving computing intensive calculations like the estimation of received power in a 3D environment based on the radio wave diffraction.

Keywords – wireless mobile ad hoc networks, network simulator, Durkin's radio propagation model, performance evaluation, grid environment.

I. Introduction

One of the most popular and vibrant fields of parallel computing is the grid environment [1]. The idea of exploiting the unharnessed computing power of a heterogeneous mass of idle computers via the Internet caughts the attention of anyone who has faced an 'impossible' task that without the aid of parallelism will be finished long after the time it is acquired.

Using the grid environment a user can divide his huge task in a number of smaller pieces. These pieces are then distributed to a number of grid computing elements that work in parallel. After the subtasks are finished the user can collect the results which are obtained for a far lesser time than in the standard sequential approach that does not involve parallel execution.

There are a number of applications for this type of computing and we can find a number of different grid environments deployed in various institutions and countries. When considering the scientific community the largest grid community is the EGEE grid (Enabling Grid for E-science) that involves a great number of countries and offers huge amount of CPU resources to the disposal of scientists. The grid resources are mainly used for simulation applications that are very computing intensive and can be performed in parallel.

The process of network simulation has always been a computing intensive task that grows tremendously with the desire to bring the simulation scenarios closer to real life network deployment examples. There are many popular network simulators that are used in the scientific community for the purposes of protocol development, performance evaluation, behaviour estimation as well as many other similar objectives.

When simulating wireless mobile ad hoc networks one of the most popular simulators is the NS-2 network simulator [3]. This simulator enables a creation of a wireless scenario for a 802.11 enabled ad hoc network with mobile nodes, a special routing protocol and a fully specified network traffic.

However, the radio propagation models offered in the NS-2 simulator are treating the simulation environment only as a flat rectangular area wherein the nodes are on the same height relative one to another and there are no obstacles between them.

In order to bring our simulations a large step closer to real life scenarios, we developed an extension for the NS-2 simulator that enables us to place and move the ad hoc network nodes in an irregular 3D terrain defined by the means of a DEM [10][11] file that holds the digitalized elevation values for a specified terrain. The radio propagation is then calculated according to the Durkin's propagation model [9] that is based on signal diffraction.

On the other hand, the introduction of 3D terrains and the terrain aware radio propagation had a great impact on the duration of the simulations since the Durkin's calculations have proven to be very computing intensive. Thus, in order to be able to get results from our simulations in a reasonable amount of time, we ported the Durkin's extended NS-2 simulator to the SEEGRID environment [2] which is the South-Eastern Europe part of the EGEE grid.

In this paper, we present the results that show how the grid environments can tremendously speedup the process of obtaining simulation results when using the NS-2 simulator. Via a number of different simulation scenarios we investigated how the traffic load, node speed and terrain complexity influence the duration of the simulations.

The rest of the paper is structured as follows. In Section 2 we present a small introduction to MANETs and our extension of the NS-2 simulator with the Durkins radio propagation model and 3D terrains. In Section 3 we present the way we ported the simulator to the grid environment. Section 4 presents the results that show the impact of the extension of the NS-2 simulator on the time duration of the simulations. Also a comparison of the influence of different factors on the duration of the simulations is presented. Finally, Section 5 concludes the paper.

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II. MANETs and the Durkin’s Propagation Model

A. Wireless Mobile Ad Hoc Network

The ability to communicate with people on the move has evolved remarkably during the last decade. The mobile radio communications industry has grown by orders of magnitude and made portable radio equipment smaller, cheaper and more reliable [4]. The large scale deployment of affordable, easy-to-use radio communication networks has created a trend of a demand for even greater freedom in the way people establish and use the wireless communication networks [5].

One of the consequences to this ever present demand is the rising popularity of the ad hoc networks. A mobile wireless ad hoc network (MANET) is an infrastructure-less network that can be established anywhere on the fly [6]. It consists of wireless mobile nodes that communicate directly without the use of any access point or base station. Thus, the nodes are supposed to establish a network environment by the means of self organization in a highly decentralized manner. In order to achieve this goal every node has to support the so-called multihop paths. The multihop path concept is introduced to allow two distant nodes to communicate by the means of the intermediate nodes to graciously forward the packets to the next node that is closer to the destination. This is controlled by a special ad hoc routing protocol [7] that is concerned with discovery, maintenance and proper use of the multihop paths.

The independence of existing infrastructure, as well as the ability to be created instantly, that is, on demand, has made the ad hoc networks a very convenient and irreplaceable tool for many on-the-go situations like: rescue teams on crash sites, vehicle to vehicle networks, lumber activities, portable headquarters, late notice business meetings, military missions, and so on. Of course, every one of these applications demands a certain quality of service from the ad hoc network and usually the most relevant issue are the network performances in terms of end-to-end throughput. However, the trade-off of having no infrastructure and no centralized manner of functioning has influenced the ad hoc networks performances greatly on many aspects.

B. Terrain Aware Radio Propagation Models

As for all wireless mobile communications the mobile radio channel places fundamental limitations on the performances of the ad hoc network. Modelling the radio channel has historically been one of the most difficult parts of mobile radio system design. Propagation models have traditionally focused on predicting the average received signal strength at a given distance from the transmitter, as well as the variability of the signal strength in close spatial proximity to a particular location.

When simulating wireless mobile networks habitually we come to use one of the large-scale propagation models that estimate the radio coverage area of a transmitter for an arbitrary transmitter-receiver separation distance [8]. These practical and fast, yet terrain unaware, frequently used propagation models are the free space propagation model or the ground reflection (Two-ray) propagation model.

The free space propagation model is used to predict received signal strength when the transmitter and receiver (T-R) have a clear, unobstructed line-of-sight path between them. In a mobile radio channel, a single direct path between T-R is seldom the only physical means for propagation, and hence the free space propagation model is in most cases inaccurate when used alone. The two-ray ground reflection model is a useful propagation model that is based on geometric optics, and considers both the direct path and a ground reflected propagation path between T-R. This model has been found to be reasonably accurate for line-of-sight microcell channels. At large distances, the received power falls off with a rate of 40 dB/decade. This is much more rapid path loss than is experienced in free space.

However, radio transmission in a mobile communications system often takes place over irregular terrain. Therefore, the terrain profile of a particular area needs to be taken into account when estimating the path loss since the transmission path between the transmitter and the receiver can vary from simple line-of-sight to one that is severely obstructed by buildings, hillsides or foliage.

In order to bring our observations a large step closer to the real-life ad hoc network deployment, we decided to use a propagation model that incorporates the nature of propagation over irregular terrain and losses caused by obstacles in the radio path. We created an implementation of the Durkin’s model [9] as an extension for the NS-2 simulator [3], thus allowing us to conduct more realistic simulation scenarios and analyze the way the terrain profile affects the ad hoc network performances.

The definition of the terrain is given by the USGS DEM standard [10], [11], which is a geospatial file format developed by United States Geological Survey (USGS) for storing raster based digital elevation models (DEM). The raster type of data consists of rows and columns of cells wherein a unique value is stored. Each cell gets a numeric value that can be represented by a unique identifier. The resolution of the raster data is the cell width and length in earth units. Usually the cells are square terrain areas, but other shapes can also be used.

The Durkin’s model is based on one of the basic mechanisms of radio propagation, diffraction. Diffraction allows radio signals to propagate around the curved surface of the earth and to propagate behind obstructions. The concept of diffraction loss as a function of the path difference around an obstruction is explained by Fresnel zones. Fresnel zones represent successive regions that have the effect of alternately providing constructive and destructive interference to the total received signal. In mobile communication systems, diffraction loss occurs from the blockage of secondary waves such that only a portion of the energy is diffracted around an obstacle. That is, an obstruction causes a blockage of energy from some of the Fresnel zones, thus allowing only some of the transmitted energy to reach the receiver. Depending on the geometry of the obstruction, the received energy will be a vector sum of the energy contribution from all unobstructed Fresnel zones.

When shadowing is caused by a single object such as a hill or mountain, the attenuation caused by diffraction can be estimated by treating the obstruction as a diffracting knife edge. This is the simplest of diffraction models, and the diffraction loss in this case can be readily estimated using the classical Fresnel solution for the field behind a knife edge.

The execution of the path loss estimation according to the Durkin's model consists of two parts. The first part addresses a topographic DEM file turned into a topographical database and reconstructs the ground profile information along the path between T-R. The second part of the algorithm calculates the expected path loss along that path.

Specifically, we move along the line that connects T-R in discrete steps. The first step is to decide whether a LOS path exists between T-R. The LOS condition is violated whenever there is an obstacle higher than the T-R line. Second part of the algorithm is checking to see whether first Fresnel zone clearance is achieved. If the Fresnel zone of the radio path is found to be unobstructed, then the resulting loss mechanism is approximately that of free space. The method for determining first Fresnel zone clearance is done by first calculating the Fresnel diffraction parameter v, for each of the ground elements.

If the terrain profile failed the first Fresnel zone test, the algorithm calculates the free space power and the received power using the plane earth propagation equation. The algorithm then selects the smaller of the powers as the appropriate received power for the terrain profile. If the profile is LOS with inadequate first Fresnel zone clearance there is loss that is added (in dB) to the appropriate received power. The loss is evaluated using the highest value of the diffraction parameter v, which means that we settle for the worst case of all existing diffraction knife edges.

Our first implementation of the Durkin's model as presented in [12] has proven to be very slow when trying to simulate mobile networks and has been redesigned and optimized in order to provide a much faster estimation of the received power. The main reason for optimization was the overwhelming number of times the algorithm needed to access the topographical database. This behaviour was due to the large amount of interpolations done for points inside the Fresnel zone.

Also, the other calculations mainly consist of time consuming functions like square roots and logarithms that also add to the time needed for processing one pair of transmitting receiving nodes. When taking into consideration that in NS-2 this is done in a way that for each transmitting node the receiving power level at every other node that is part of the network has to be calculated in order to decide whether there is interference or no, we came across a performance problem since the simulations were taking a tremendous amount of time.

In order to lessen the computing time, at the beginning we discard the 'impossible' situations, that is we immediately calculate the receiving power according to the free space propagation model and if it is below the interference threshold we do not need to check whether the signal is even less stronger than our first order optimistic approximation. Also, whenever the diffraction parameter reaches its "highest" value, we no longer need to search for another knife edge since the one encountered is "bad enough".

Another performance enhancement is introducing a cache in the case of simulation of static nodes. Since for static simulations the once already calculated received powers for a given transmitter cannot change, we decided to keep these values in a cache in a form of a N x N matrix where N is the number of nodes in the simulation. At the beginning of the algorithm we first check to see whether we already have the necessary values in the cache. If they are available we simply reuse them, otherwise we calculate and add the new values in the cache. In this way, the speed of completing our simulation sets was brought back to the original when simulating in the usual 2D environment.

As for the cases of mobile nodes, the careful code optimizing by reducing the call of the topographical database to the minimum and by reducing the number of time consuming complex calculations, i.e. the square root whenever calculating the distance between two points, have proven to be satisfactory. The optimized Durkin's propagation model for NS-2 now runs with speed that is comparable to the popular two ray ground model.

III. SIMULATING MANETS IN GRID ENVIRONMENT

A. Using the SEEGRID Infrastructure

In order to make the necessary set of simulations for observing the relationship between the two ray ground and the Durkin's model, as well as for the relationship between the influence of the terrain and the mobility and traffic model on the network performances with nodes that move with different node speed, the number of distinct simulations that need to be run is close to 600 for only one iteration. When striving to obtain average results from multiple runs the number rises up to 6000. Given that the time for execution of one heavy load simulation is 5 to 7 hours, the time needed to make the necessary simulations starts to be measured in terms of months. This was the main motivation for our need to port the simulator to a grid environment that will allow us to perform simulations in

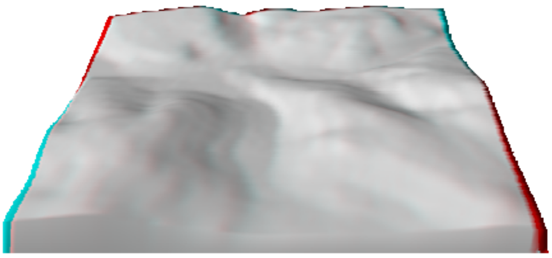

Fig. 1. Real terrain example 1 (1000 m x 1000 m)

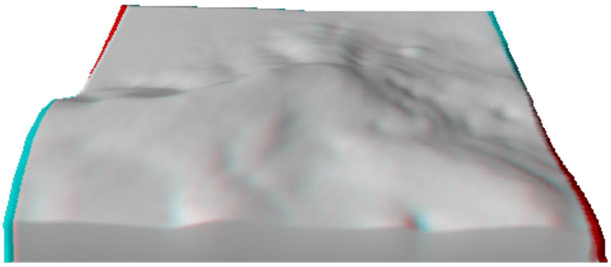

Fig. 2. Real terrain example 2 (1000 m x 1000 m)

parallel.

Thus, we decided to move the NS-2 code to our local branch of the SEEGRID infrastructure [2]. The grid infrastructure offers a great number of free computing elements that can be used for scientific purposes. In our case we wanted to use a homogenous part of the grid and we limited the execution of the simulation scripts only on our local branch that has 12 hyper threading processors that allow for 24 processes to be run at once. The use of homogenous computing elements was needed for the ability to measure the speedup of the simulations when running them in parallel. However, when the objective is to obtain results of the simulations only, then the complete seegrid environment comprised of heterogeneous computing elements can be used.

The computing elements in the grid are given the task that needs to be executed via a so-called job description language that defines the executable and it input and output parameters. The computing environment is run under different unix-like systems, depending on the local branch of the grid.

The possibility for using a so called parametric job definition has made the execution of the simulations very easy since everything that is needed is the simulator, one general tcl script with tuneable parameters, one text file with all parameter variations needed and a job wrapper that will set the execution environment. In order to use the grid infrastructure we only needed an executable NS-2 that can be obtained with static compilation which is supported by the make file of the NS-2.

Learning the job description language and some basic commands for managing in the grid environment has made our simulation time execution more than 20 times faster. At the same time the easy way of defining all of the simulations at once and letting the grid manager worry about scheduling allows for efficient time fulfilment while waiting for the information that the jobs are done.

The parallel execution of multiple simulation scripts is a way for receiving results much more rapidly and it is our strong belief that one should use this type of simulation execution as much as possible. Today's advances in technology especially in multicore graphics cards allow for a creation of a certain types of "miniature" grids inside the personal computer using the various available processing units. One of our future works is to try to develop a parallel execution environment using all of the resources available on a given PC.

B. Simulation Scenarios and Parameterization

In order to determine the efficiency of our parallel simulations we created several sets of scenarios. The scenarios were defined as typical scenarios for the purposes of evaluation of the ad hoc network performances. We measured the execution time of each parameterized simulation. Then we were able to compare the parallel versus sequential execution time as well as to pinpoint the simulation characteristics that mostly influence the length of the simulation duration.

The varied parameters include: different radio propagation model – two ray versus Durkin's; different terrain type, flat vs. real terrains; different node mobility, static nodes and nodes moving with speed of 1, 2 and 5 m/s; different traffic load varying from 0.1 to 7 Mbps.

For the simulations we used DEM files with dimensions of 1.000m x 1.000m with a 1:1:0.1 resolution and highest relative point of 200m. We have 100 nodes that are uniformly dispersed in the simulation area. The node transmission range is set to the standard 250m given by the use of the IEEE 802.11b standard wireless equipment. The antenna height is set to 1.5m and it has no relative offset against the wireless node. For route discovery and path set up we are utilizing the AODV protocol [13]. The offered network load is varied from 0.1 to 7 Mbps using UDP data packets with 1 KB size. The simulation time is set to 1.5 hours as to the average battery life of a notebook. During the mobile simulations, the nodes are moving according to the random direction model in the terrain boundaries. The average node speed is varied from 0 (static nodes) to 1, 2 or 5 m/s with deviation of 0.1 m/s.

On Fig. 1 and Fig. 2 the terrain shapes of two real terrains that represent the terrain profile close to Eldorado, USA are shown using the DEM file visualizing software 3Dem [14]. For comparison and verification purposes we use the results obtained for a perfectly flat terrain. In this way we can determine the terrain features impact on the network performances

Using the seegrid user interface we defined each simulation using the parametric job description. All different types of scenarios are defined in the parameters

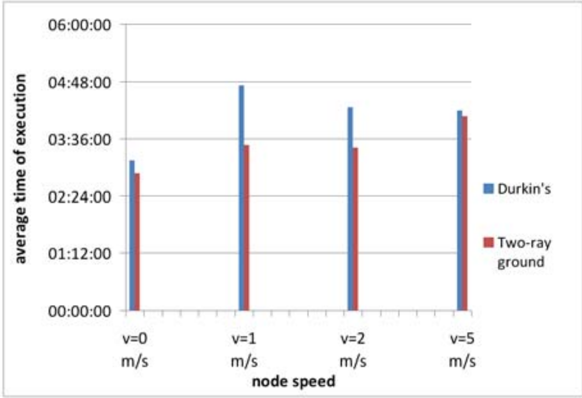

Fig.3. Comparison of the average time of execution for the Two-ray and Durkin's radio propagation models for different node speeds and flat terrain

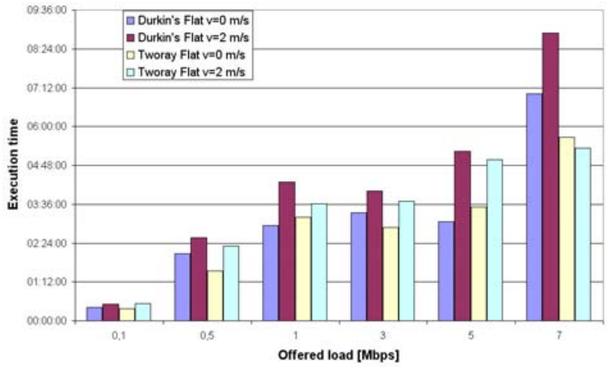

Fig.4. Comparison of the average time of execution for the Two-ray and Durkin's radio propagation models for different offered load in the network

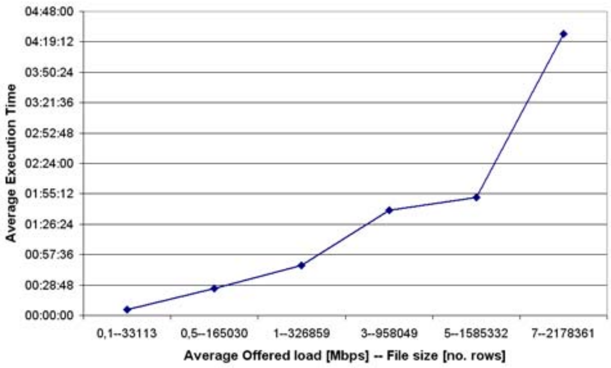

Fig.5. Average time of execution of the MANET 3D simulations depending on the network load (output file size)

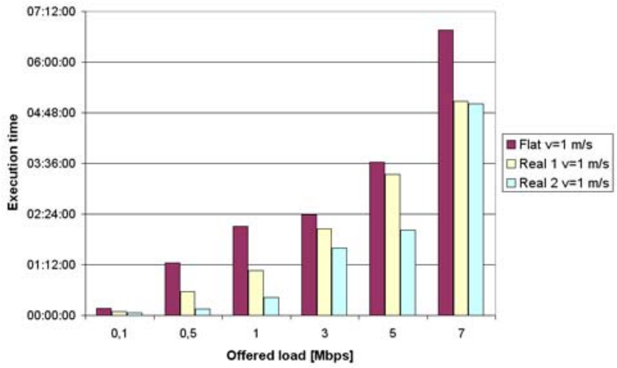

Fig.6. Average time of execution of the MANET 3D simulations depending on the network load (output file size) for different terrain shapes

files, and each parameterized scenario is run independently on one computing elements. We observe the timestamps when the job is starting with execution and before the moment when the results are sent back to the network proxy manager.

IV. RESULTS

The results obtained from our simulation scenarios show some interesting conclusions concerning the time duration of a network simulation.

Our first investigation was to conclude how our Durkin's extension influences the execution time of the simulation in the worst case scenario. The worst case scenario for this radio propagation model is when it is used with a perfectly flat terrain, since in this case there is no diffraction and the inspection of the LOS condition together with the clear Fresnel zone are done for the complete T-R line without any effect.

On Fig. 3 the comparison of the average time of execution is shown when using the traditional Two-ray ground model and the Durkin's model for different node speeds. It can be seen that when the nodes are mobile they affect the execution time of the simulation but not in a drastic manner. Also it can easily be concluded that the introduction of the Durkin's propagation model does not introduce a great amount of additional time for simulating the network. The average excess time needed when using the Durkin's model (in it worst case scenario) is 10% over the time needed for the two ray ground simulations to end.

Unlike the previous example where it can be seen that the node speed does not greatly impact the execution time of the simulations, Fig. 4 shows the execution time for the simulations depending on the offered load in the network for perfectly flat terrain when using the two ray ground and Durkin's radio propagation model. The figure shows two characteristic behaviors: the increased offered load greatly influences the length of the simulation time and, as the offered load increases, the node speed begins to influence the execution time more noticeably. The second observation is more evident for the Durkin's model. One can also notice that the difference in time of execution between the two ray and the Durkin's model increases with the offered load. This is due to the fact that when the offered load increases dramatically, the number of times that we need to access the topographical databases increases tremendously and this causes lengthier simulations.

While changing the terrain type, node speed and offered load in the network, we came to the conclusion that the output trace file has the biggest impact on the performances (in terms of execution time) of the network simulator. This behavior is closely related to the fact that the access to the output file is one of the slowest parts of the executing simulation. When considering the fact that the file size is closely related to the offered load in the network since the content of the trace file are the events of sending, receiving and dropping of a packet. On Fig. 5 we present the average execution time of the simulations that run with the Durkin's radio propagation model as a function of the offered load and the average file size that is expected to be encountered for the specified offered load in the network. However, this is not always what is encountered in many simulations since there are many other factors that influence whether a packet is going to be received or dropped. When talking about dropped packets, we must stress that in situations when it is difficult to obtain a route to a destination, the number of dropped packets in the trace file rises rapidly. In this case the execution time of the particular scenario becomes very long.

Fig. 6 presents the influence of the terrain shape on the performances of the network simulator with the Durkin's propagation model. The shape of the terrain has a great influence on the execution time of the simulation scenario especially because of the optimizations in our code that cut down the number of iterations when we encounter 'worst cases' of diffraction. The average simulation time for real terrain DEM1 is 74% of the simulation time of flat terrain. For DEM2 real terrain, the simulation time is only 57% of the flat terrain simulation time.

V. Conclusion

In this paper the performances of the network simulation NS-2 extended with the Durkin's radio propagation model where investigated. The performances of the simulator were observed when simulating wireless ad hoc mobile networks in 3D environment defined using a DEM standard file. Because of the overwhelming duration of the simulations, the extended network simulator is ported to the Seegrid environment in order to benefit the possibilities for parallel execution of a number of parameterized simulation scripts.

The performance of the extended simulator was compared to the original version that uses the traditional two ray ground propagation model. When observing the two models under equal scenarios, we conclude that our optimized extension of the Durkin's model needs around 10% more execution time than the estimated value for the two ray ground model, which we feel is a relatively small amount compared to the gained benefits of the more realistic simulation.

The results show that the main impact on the duration of the execution time of the simulator scripts can be found in the offered load in the network. Also, when using terrains, the terrain shape greatly influenced the execution time of the script.

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