Ad hoc networks simulations with real 3D terrains

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Abstract — **Some of the most important application domains for ad hoc networks are battlefield communication, rescue missions and homeland security. All of these outdoor applications are places onto real, irregular terrains. Node placement over the terrain and radio signal fluctuation can degrade the quality of the radio links, which is why the terrain profile should be taken into consideration during simulation and estimation of the signal losses. In this paper we present a newly implemented Fresnel zones propagation model extension for the NS-2 network simulator for the purposes of simulating realistic network scenarios.**

Keywords — **3D terrain, ad hoc networks, Fresnel zones, propagation model, NS-2 network simulator.**

I. Introduction

Wireless channels experience high variability in channel quality due to multi-path propagation, fading, atmospheric effects, obstacles etc. While real world tests are crucial for understanding the performance of mobile network protocols, simulation provides an environment with specific advantages over real world studies. Very often ad-hoc network simulation undergoes simple assumptions. The model "Flat Earth" is very popular where the radio signals have circular range, travel in two dimensions and are omni directional. These axioms lead to simulation results which inappropriately show the behavior of ad-hoc networks. There are very big discrepancies between the simulating results and real-world environment if everything is based on stochastic simulations [2][3].

Several previous researches address the influence of obstacles and terrain information in ad-hoc network environment, abandoning the "Flat Earth" model. In [4] the simulation scenarios are based on urban network environment with polygonal obstacles, while in [5] a new method for modeling indoor radio propagation which takes into account all reflections and all diffractions is proposed. The incorporation of real terrain and location information in the routing protocol for wireless ad-hoc networks was demonstrated in [6].

For analyzing the performances of wireless networks several commercial simulators like OPNET Modeler [12] and QualNet [13] include the ability to place obstacles and real terrain information. The J-SIM [7] simulator also can use 3D terrain information but its main usage is for wireless sensors networks simulations.

The NS-2 [9] network simulator developers have foreseen the ability to expand the network simulation with 3D terrain support, but its implementation is still at its beginning. However, since NS-2 is one of the most accurate and popular network simulators for ad hoc networks [8] we decided to increase its capability with real 3D terrains. For this purposes we developed additional modules for 3D terrain support and propagation models that take into consideration the 3D terrain spatial data.

We implemented Fresnel zones module as an extension of the Freespace propagation model, using additional 3D terrain information via Geographic Information System (GIS) terrain data.

Using the developed modules, in this paper we present the obtained results for ad hoc network performance analysis in 3D environment in order to create more realistic simulations through the incorporation of real terrain. In this way we can analyze the behavior of the ad-hoc networks over their most important application domains: battlefield communication, rescue missions, homeland security, pollution sensing and traffic monitoring.

II. Implementation of Fresnel Zones Based Propagation Model in NS-2

Propagation models are fundamental tools for designing any wireless communication system. A propagation model basically predicts what will happen to the transmitted signal while in transit to the receiver. Traditionally, ‘propagation models’ is the term applied to those algorithms and methods used to predict the median signal level at the receiver.

The concept of a propagation model has been broadened to include models of the entire transfer function of the channel. These models are intended to represent all the modifications the transmitted signal undergoes in travelling from the transmitter to the receiver.

Modelling the radio channel is fundamental to predicting the performance of a wireless radio system. Radio channels of the statistical propagation models have

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mathematically modelled losses of obstacles, signal attenuation, atmospheric effects, signal reflection, diffraction etc.

Radio transmission in mobile communications is often over an irregular terrain whether it is a microwave link or mobile ad-hoc network. The spatial terrain parameters influence the performance, connectivity and capacity of the wireless network. Node placement over the terrain and radio signal fluctuation can degrade the quality of the radio links, which is why the terrain profile should be taken into consideration during simulation and estimation of the signal losses.

Our implementation of a new propagation model is based on the geometry of the Fresnel zones [1] where the radio channel includes the geographical parameters of the terrain using DEM (Digital Elevation Model) [10] files as a digital representation of it.

A. *Fresnel zones*

Diffraction occurs when there is a partial blocking of a portion of the wave front by an object of some kind. The concept of diffraction loss as a function of the path difference around an obstruction is explained by Fresnel zones. The Fresnel zones are ellipsoids around the transmit-receive propagation path and the vertical section are concentric circles which represent the location of the origins of secondary waves with total path length increased by $\lambda/2$ for successive circles [1], where λ is the wave length of the radio signal.

The Fresnel radius r_n at a distance d_1 from the transmitter and d_2 from the receiver can be approximated by:

$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \tag{1}$$

This approximation is valid for $d_1, d_2 >> r_n$.

Conceptually, the first Fresnel zone can be thought of as the region where the significant power is transmitted. A general criterion for link system design is to set the path clearance so that a radius equal to 60% of the first Fresnel zone is unobstructed.

B. *Digital Elevation Model* (*DEM*)

There are two methods for storing terrain data in GIS, raster and vector type of data. The raster data type consists of rows and columns of cells where in each cell a single value is stored (discrete reality), while vector data type uses geometries such as points, lines or polygons, also called areas to represent objects. The vector data type is more processing intensive, while the raster data type is with reduced accuracy, because there are many lost details with the digitalization.

US Geospatial Standards DEM is a geospatial file format for storing a raster-based digital elevation model. DEM files contain information about topographic elevations for selected area. DEM's are actually an array of heights (integer values) for certain number of points in the terrain on regular spatial intervals (latitude and longitude). The value of the cells can be the exact measured elevation, interpolated elevation or average height through the entire cell. DEM files can be used to determine the morphology of the ground, slopes and other aspects of the terrain.

DEM format is an ASCII flat file organized in three parts (records) A, B and C.

A record appears only once at the beginning and it contains information which define DEM characteristic including name, borders, units, minimal and maximal levels, projection parameters and number of B records.

The B record is called terrain profile, it contains the elevation data and it is has multiple appearances. The B record is like a vertical section of the terrain. B records (profiles) are columns of longitude with variable raster elevation length which start on specific location. Each line of the record contains header with summary of the characteristic of the profile. Each elevation is an integer. DEM file is read from west to east, but profile elevations are from south to north.

The C record can appear at the end of the file, but it is not mandatory. It contains the root-mean squared error (RMSE) quality control data, using ten six-character integer fields. It also contains statistical data about the accuracy of the DEM file.

C. *NS-2 implementation details*

The terrain information with the node location and their trajectory gives realistic view of the network topology and connectivity. If a node has data to send, it can check whether there is line of sight among the neighbor nodes assuming that the trajectories of the other nodes are known.

All additional modules were developed for the NS-2 network simulator version 2.30.

The new model - Fresnel propagation model is based on FreeSpace propagation model and it belongs in the group of propagation environment models.

The first part of the model is importing the topographic data from a DEM file and reconstruction of the terrain profile along the path which connects the data exchanging nodes. There is a possibility to import a digital terrain map into NS-2 simulator through DemFile class. In order to input the DEM files for the terrain data we had to make several modifications in the class methods so they comply with the DEM standard.

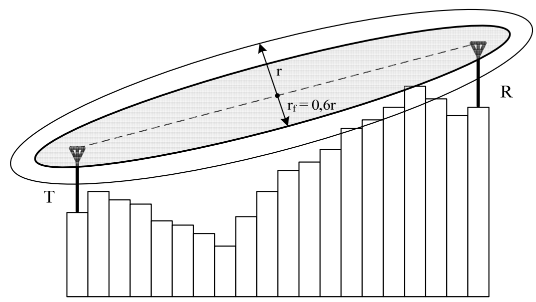

Fig. 1. Ground profile obtained from DEM data used for Fresnel zone calculation

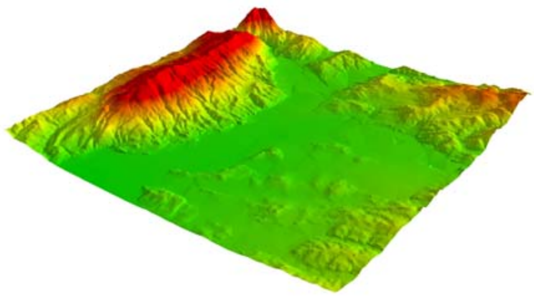

Fig. 2. Example real terrain: Valley

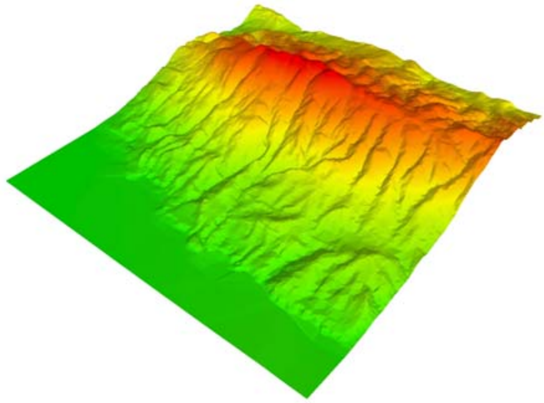

Fig. 3. Example real terrain: Mountain

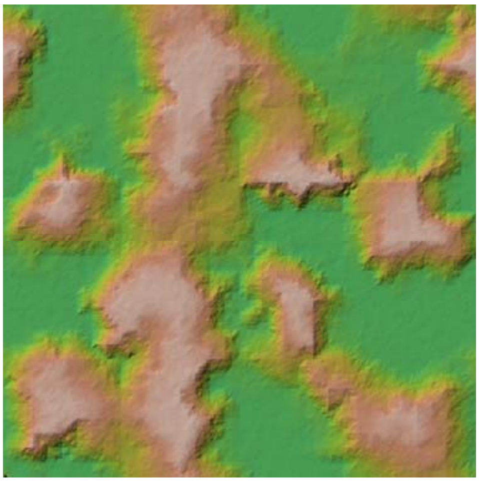

Fig. 4. Example generated terrain: Hilly terrain

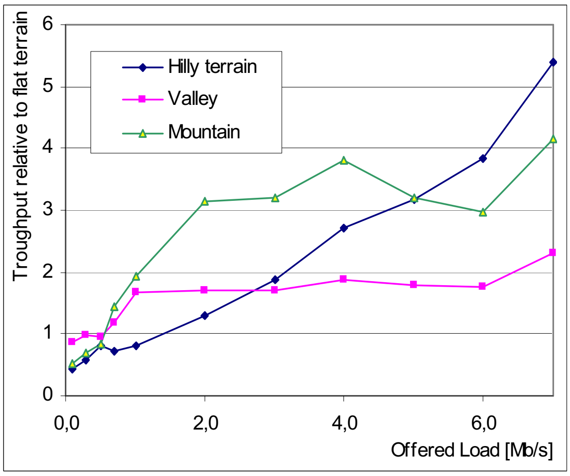

Fig. 5. Relative throughput for the example terrains using the Fresnel zone propagation model

The second part of the model is determination of the first Fresnel zone. To determine the LOS (Line of sight) parameter we need the node location in 3D space. The antenna height, the carrier frequency of the radio signals and node position in XY plane are input parameters to the propagation model. The overall node elevation is sum of terrain elevation and antenna height. Unlike the usual 2D considerations in NS-2, with this propagation model the distance between the nodes depends on all three coordinates. The algorithm calculates the straight line between the two nodes. Using the quantized map of terrain heights the propagation model reconstructs the ground profile along this straight line that joins the transmitter and receiver (Fig. 1).

Now the problem is reduced to a one dimensional point-to-point link calculation. The algorithm checks to see whether first Fresnel zone clearance is achieved. This is done by comparing the terrain elevation and the height of the straight line connecting the nodes at every discrete point.

As explained earlier, if the first Fresnel zone of the radio path is unobstructed the expected signal loss calculation is according to the free space propagation model. If the difference is smaller than the 60% of the radius of the first Fresnel zone we determine that there is a breach in the zone. At the moment of loss of line of sight the procedure immediately exits with false value.

We also modified the CSMA/CA channel in NS-2 so that it can determine the presence of line of sight. This means that the detection and the transmission area of the nodes are not an ideal circle but they depend on the ground configuration. The difference between the situations with or without terrain is that the nodes which were blocked (ex. hidden and exposed terminal problem) to access the channel from sending nodes, are now isolated and they can transmit. In this way the resources of the channel are more utilized.

At the wireless channel level, the detection area in the current design of the NS-2 wireless channel is a square as seen from the perspective of the transmitting node. Therefore the nodes which are in the range of the square are not able to access the channel. When using our Fresnel propagation model in the areas of flat terrain the detection area is very near to its original omni-directional spherical shape.

III. SIMULATIONS

The primary objective of our simulations is to understand the impact of the terrain presence in a simulation environment. To this end, we evaluate the aspects of traffic throughput of the Fresnel propagation model compared with the FreeSpace propagation model. In the simulation we are utilizing AODV protocol for route discovery and path set up. We are using two real terrains representing a valley (Fig. 2) and a mountain (Fig. 3) and one generated hilly terrain (Fig. 4) from Terragen [11].

A. *Simulation Environment*

The simulation area is 1000m x 1000m, and the transmission range is 250m. In ad-hoc network environment the default NS-2 values were inappropriate using the Fresnel propagation model and terrain elevations. We can see with Equation (1) that even at distances of 100 meters on a flat terrain the ground penetrates into the first Fresnel zone. Thus, we changed some of the default parameter values: the carrier frequency of the simulations is taken to be 2.472 GHz (channel 13 of IEEE 802.11b) and the antenna height is set to 2 meters. The proposed values for the frequencies and antenna height equalize the conditions for the simulations with the Fresnel propagation model compared with the statistical propagation models.

The ad hoc nodes are moving according to the Random Direction mobility model with average speed of 1 m/s. The offered network load is varied from 0.1 to 7 Mbps using data packet with 1 KB size.

The first set of simulations uses FreeSpace propagation model, while the other three use Fresnel propagation model and the three terrains accordingly.

On Fig. 5 the relative throughput for the example terrains compared to flat terrain when using the Fresnel zone propagation model is shown. It can be concluded that for lower network load the network total throughput for real terrains is smaller because there are obstacles between nodes that would otherwise be able to communicate.

For higher offered loads, the total throughput is increased for every example terrain. When analyzing the valley terrain we have steady increased performances because of possibilities for simultaneous parallel communication. In the case of the mountain terrain, the network is split into two separate parts which increases the utilization through the possibility of decreasing the occupation of the CSMA/CA wireless channel. The hilly terrain shows lower performances for lower offered load because the hills are making the communication between distant nodes unable. As the network load rises, this terrain shows greater improvement in performances as the number of simultaneous communications grows.

IV. CONCLUSION

In this paper we present simulations of ad hoc networks on real 3D terrains. The simulations were made using an implementation of a Fresnel zones propagation model in the NS-2 network simulator. The problem of this new implementation is that depending on the terrain configuration it requires a lot of processor power and computational time. The simulation run takes different computation time especially for plain terrains. This is expected because for plain terrains the line of sight is almost always true, but the algorithm always tries to computes its value. But, on the other hand this opens an opportunity for research on development of new, more realistic radio models, mobility models, real environments for the most important ad-hoc applications and determining the real behavior of old and new routing protocols.

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