Application of GRASS in Mobile and Portable Communications

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Abstract

This paper discusses the application of GRASS in the area of mobile and portable radio communications. The growing interest in wireless personal communications has fueled efforts to produce systems with better performance and increased capacity. A brief view of mobile communications is presented along with the motivation for this research. The role of GRASS in radio propagation prediction is discussed. GRASS is used to analyze spatial information as well as display the results graphically. The work done in interfacing and applying GRASS toward the development of an integrated radio propagation prediction tool is presented. Finally, directions for future work are noted, including tessellation algorithms and enhanced attribute storage facilities. The adaptability of GRASS combined with the technical capabilities of propagation prediction software promise an effective software tool for mobile communication system design.

Introduction

Wireless mobile and portable communication has become an increasingly popular mode of communication in recent years. It gives the user the ability to stay in touch and be productive while on the move. Cellular and cordless phones, pagers, wireless modems and LANs and GPS (Global Positioning System) are some forms of mobile and portable communications. There has been rapid growth in the demand and capacity of such systems due to commercial and public interest, and this trend is expected to continue [1]. Currently there are 60 million cordless phones in service in the U.S., 6 million cellular phones and 4 million pagers. Mobile radio use has been ever increasing, and continues to expand at a rate of at least 20% per annum [2].

Due to the steadily increasing demand for portable communication services, the electromagnetic spectrum has become a prime resource and must be utilized to the fullest extent. Worldwide efforts are being made to design better systems that will accommodate more users and provide enhanced services at low cost [3]. A number of complex and
ambitious systems are being proposed, developed and deployed, for example personal communication services (PCS) that support ubiquitous voice and data communication facilities [4-5].

At the Mobile and Portable Radio Research Group at Virginia Tech, site-specific propagation prediction is a current research goal. The goal is to develop software design tools for mobile communication systems. Predicting the performance of a communication system is an important and critical step in the process of deploying a wireless system. Performance prediction software allows the designer to estimate how well the system will perform in the field. Alternative designs may be compared in this way without the cost of building and testing all of them, and the optimum one can be chosen. This can shorten the design cycle and let the developer better exploit the design parameters. Typical performance measures include area of effective coverage, number of simultaneous users, data capacity or quality of speech per user, etc.

Performance prediction is not an easy task, because the performance of a system depends on various external factors that are difficult to take into account. For example, buildings act as obstacles and reflectors for the radio waves, as do hills and mountains (see Fig.1) [6]. This gives rise to multiple direct and indirect propagation paths. The presence of multiple paths between the transmitter and the receiver cause "echoes" (see Fig.2). Each path has an associated path loss and delay, and isolating a particular signal is a difficult task. Besides, due to the changing nature of portable communications, the channel along which the signal travels varies unpredictably with time. This makes it difficult to estimate beforehand the properties of such channels. The site-specific information and channel properties must be analyzed for good performance prediction. GRASS fits into the picture because of its ability to handle site information such as terrain, land cover, buildings, etc.

The rest of the paper elaborates on the role of GRASS in propagation prediction. First the overall needs of the site-specific propagation prediction package are discussed, along with the role of GRASS in this context. Then the functions which GRASS can perform are discussed. The results obtained with GRASS are presented. Finally, future work is described, followed by conclusions.

Methods

A. Overall Needs
In this section, the overall scheme of the project is described, and the role of GRASS is presented. A diagram of the package being developed is depicted in Fig.3. It consists of a group of modules working together, each performing a specific function. First, there are propagation prediction programs that do the electromagnetic analyses such as diffraction and ray tracing study. These programs require site-specific data about the terrain and buildings. These site-specific data are handled by GRASS and AUTOCAD®, respectively. All of these programs interact by passing data back and forth.

The typical interfaces are shown in Fig.3. A ray tracing program [7-8] works on building
data and possibly terrain data to predict how radio waves will propagate in the given environment. The program interacts with AUTOCAD® to get this data, since both can handle block objects directly. A radio wave diffraction analysis program [9-10] will work with terrain as well as building data to predict electromagnetic fields at any location. The various analysis programs will generate contours of signal strength that will be displayed graphically by GRASS. Also, there is interaction between AUTOCAD® and GRASS. Building data as well as terrain attributes like surface roughness need to be exchanged between the two packages. Terrain information should be transferred into AUTOCAD® for use by ray tracing packages. These interfaces are denoted by arrows in the figure. Note that the user interface is not shown, nor is an optimization package that will locate optimum transmitter and receiver locations.

B. Functions of GRASS

GRASS performs three major functions as part of the package - data storage, data generation and display, and data analysis.

GRASS stores the terrain information that is used in site-specific propagation prediction. The surface of the terrain is stored as a GRASS raster map. This is later used to detect obstacles between a given transmitter-receiver pair. The buildings require separate storage, and are handled by AUTOCAD®. GRASS also permits quick and automated access to the terrain data with its built-in functions.

Data generation and display are also done by GRASS. GRASS will be used to generate contour maps of path loss over a surface, thus helping locate positions for the transmitters and receivers for better performance. This makes use of the data generation capabilities of GRASS, allowing the results to be displayed effectively in GRASS.

Terrain data analysis is done within GRASS to help in propagation prediction. New GRASS programs determine if a line-of-sight communication path exists between a transmitter and receiver. This program can be extended further to estimate the path loss as radio waves propagate over the terrain surface.

Results

A. Work Done

Work has been done on developing the different interfaces with GRASS (as in Fig.3), as well as expanding the analysis capabilities in GRASS. The interface between GRASS and AUTOCAD® has been partially developed, as has the interface from GRASS to the diffraction program.

Buildings should be treated similarly to terrain while doing a line-of-sight analysis. For this, we need to get the building information into GRASS from AUTOCAD®, which is the standard storehouse of building data. GRASS by itself has a limited ability to import AUTOCAD® files in the DXF format. The existing GRASS program can import points and lines from a DXF file. But the outlines (area edges) and heights of the buildings can not be
imported, and they are required in the analysis. So the import program was extended to recognize area edges and building heights stored as text in the DXF files. This gave rise to a new program called v.in.dxfnew, based on the program v.in.dxf in GRASS. This program gets a DXF file as an input and produces a vector file with the building boundaries in it. An associated program, v.cadlabelnew, was developed similarly from v.cadlabel. It is simply an extension to the original program that takes into consideration area edges in addition to lines.

After importing the buildings into GRASS, they must be integrated with the terrain so that both are treated simultaneously. This is done by the new program r.drape in GRASS. This program takes in a building raster file produced by v.to.rast on the building file, and overlays it on a specified terrain surface. The input parameters are the buildings map, the terrain map and the vertical offset for the buildings. As a result, we get a new raster map made up of the whole surface with the buildings on the terrain. The GRASS program r.mapcalc is used in the process. If the new map is denoted by "result", the buildings map denoted by "buildings", the terrain map denoted by "terrain" and the offset for the buildings map given by "offset", the following expression in r.mapcalc produces the required output:

\[ \text{result} = \max(\text{terrain}, (\text{buildings} + \text{offset})) \]

A sample map generated by these programs is shown in Fig.4.

A new program (d.knifedet) for doing the line-of-sight (LOS) analysis has been written for GRASS. The existing GRASS los program can not be used for this purpose, because a line-of-sight as required for radio communication is not simply a straight line in 3 dimensions connecting the transmitter and the receiver. For a direct path, an unobstructed tube of space must be available between the transmitter and the receiver [11]. Thus there must be some clearance around the straight path. The required clearance is denoted by the Fresnel zone, which is an elliptical region centered on the straight line joining the transmitter and the receiver, as shown in Fig.5. If there is any object within the Fresnel zone, it gives rise to a reflected or diffracted ray that interferes with the line-of-sight ray. This can cause severe degradation in communication. Current microwave links take this into consideration. These obstacles must be detected for a detailed electromagnetic analysis.

The d.knifedet program is an interactive program based on the GRASS program d.profile. It obtains the transmitter and receiver locations interactively, and then does the radio LOS analysis. Its inputs include the transmitter frequency, the heights of the transmitter and receiver above ground level, initial transmitter location and number of initial sampling points. A typical display is shown in Fig.6. Notice the detected obstacles denoted by vertical lines in the profile windows. Any obstacles in the communication path are modeled as knife-edges, i.e. as thin, sharp vertical objects over which the radio waves diffract. The relative positions and heights of these knife-edges are important in the diffraction analysis. The d.knifedet program extracts this information and passes it on to the above-mentioned analysis program. Then it writes the locations of the obstacles into a site file. After this, it does an interpolation on these points to generate a new raster file. This file roughly shows the areas in the region that are highly shadowed by obstacles, and areas that are less shadowed (see Fig.7). The result is an estimate of better receiver locations based on the
degree of shadowing from the transmitter.

B. Future Work
From the point of view of the site specific propagation prediction package, work needs to be done on more interfaces between packages. The interface between GRASS and the propagation programs should include extrapolation programs that can generate contours of path loss and received power over regions. The display capabilities of GRASS should be exploited fully. Work is also to be done with the user interface to the package. XGEN, an X-Windows-based interface generator tool [12], could be used to develop new interfaces.

The object-oriented ray tracing programs interface with AUTOCAD®. They need terrain information in special formats. The terrain data from GRASS should be exported to AUTOCAD®. A tessellation algorithm [13-14] must be implemented to represent the raster-based terrain information by a set of planes. An appropriate algorithm should be chosen, after considering the accuracy and efficiency requirements.

Some important factors in propagation prediction are the material composition of buildings, the dielectric properties, terrain surface roughness and absorption, etc. These represent multiple attributes for the raster files. GRASS can currently store only a single attribute per pixel. This limitation must be circumvented, and the different attribute values must be stored simultaneously. These attributes should also be exchanged with AUTOCAD®, because the building information originates in AUTOCAD®. Building heights are an example of building attributes. Several workarounds have already been adopted by the GRASS user community. Work is being done elsewhere on interfacing GRASS with databases, that should prove helpful [15].

Conclusions

GRASS is being used as part of a software tool for mobile communication system design. For this, it must be extended to suit the analysis requirements of this application, as well as interfaced with various other programs. Work has been done on interfacing GRASS with AUTOCAD®. An obstacle detection program for radio propagation has also been written for GRASS. Future work includes implementing a tessellation algorithm for data transfer to AUTOCAD®, handling multiple attributes and improving the user interface.

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Figure 1 - Portable communication environments
Figure 2 - Multipaths in propagation, including direct line-of-sight, diffracted and reflected rays.
Figure 3 - Site specific propagation prediction programs and interfaces
Figure 4 - Buildings and terrain in GRASS
Figure 5 - Fresnel zone and obstacles
Figure 6 - Knife edge detection program
Figure 7 - Aerial view of regions with obstructions in the path to the transmitter. Transmitter is located on mountain top overlooking the buildings.