

# ECE3065 Class Project: Terrain Diffraction Modeling for Microwave Radio

Due Date: 27 April 2006 (Thursday)

## 1 Introduction

You are a member of a small engineering consulting company that has been contacted by an upstart company, Wimaxorbust Inc., who wants to deploy a new generation of cellular wireless networks across the country at multiple frequency bands such as 1.9 GHz, 2.4 GHz, and 5.8 GHz. Wimaxorbust has recognized that the propagation models that the industry uses to design cellular networks need updating to design the most efficient possible frequency plan. To this end, it has invited your company and a handful of other firms to compete for a lucrative contract that will allow you to build their next-generation propagation modeling software.

A trial will be held in a rural part of the US where each company must produce accurate received signal strength maps of several real-live cellular base stations at 1920 MHz. After submission, these maps will be compared against real measured data from both indoor and outdoor locations. Wimaxorbust will provide you with some measurements and terrain maps for several base stations so that you can train and test your propagation engine. They will then give you the 4 “mystery base stations” for you to predict signal strength maps.

## 2 Background and Motivation

Early cellular networks were designed using very crude path loss exponent models, without taking terrain diffraction and other obstacles into consideration. When satellite-generated *digital elevation maps* became available, propagation engineers became a little more savvy and began to program diffraction-rendering codes that estimated loss based on terrain blockage. Though this practice continues today, it is hardly ubiquitous; furthermore, most of the diffraction models are attempts to apply physical diffraction theories to problems that are dissimilar to the canonical “wedges” and “screens” (can you guess why?)

Prediction of signal coverage during network planning is critical. Just a few extra dB of unnecessary uncertainty in the radio link budgets results in increased dropped calls, uncovered regions, and increased user frustration. When the business ramifications are considered across the nationwide cellular network over the course of many years of operation, that uncertainty translates into tens-of-millions of dollars in lost revenue.

There are further implications for developing better models in cellular networks. Accurate propagation models can, in some cases, allow a service provider to use signal strength measurements to back-solve the position of a wireless caller placing a 911 call. Furthermore, many other applications outside of cellular phones benefit from creative new propagation models; your ideas could be ported to the design of many other yet-unimagined radio networks. The stakes are high.

### 3 Data File

There is a project page on the class website that contains this document and a number of supplementary files that will assist you in your design and preparation. Also included is the data file `CellInfo.mat`, a Matlab file that contains information on 8 real 1920 MHz cell sectors that operate in a hilly or mountainous environment. We will label these sites A, B, C, and so forth. When the Matlab file is loaded, there will be 8 structure-variables loaded into the workspace named `Cell_Info_A`, `Cell_Info_B`, `Cell_Info_C`, and so forth; one variable for each of the eight sites.

Each structure variable contains a number of fields that specify some useful information about the transmitter. Here is a short summary of each of these fields:

- **meas**: A raster map of received powers in dBm, stored in a 2D matrix. Each raster point represents a  $30\text{m} \times 30\text{m}$  area where measured signal strength data has been taken. A value of 0 indicates that no received data has been measured at that point.
- **terrain**: A raster map of digital elevation values (in meters above sea level) taken from a satellite fly-over, stored in a 2D matrix. Each raster point represents a  $30\text{m} \times 30\text{m}$  area that corresponds to the same location as the points described in **meas**.
- **cellSite**: A structure that contains base station specifications. The seven variables below are fields of this structure.
- **azimuth**: The direction in azimuth that the antenna is pointing. Note: this azimuth angle is measured using the Geographic convention where north is  $0^\circ$ , east is  $90^\circ$ , south is  $180^\circ$ , and west is  $270^\circ$ .
- **eirp**: The effective isotropic radiated power of the antenna in units of dBm. This is transmitted power (dBm) plus peak antenna gain (dBi) in the link budget equation.
- **BS\_x** and **BS\_y**: The column and row coordinates in the raster map corresponding to the transmitter location.
- **freq**: radiation frequency in MHz.
- **cellSize**: size of each map pixel in meters. A value of 30 indicates that each measurement and terrain map pixel represents a  $30\text{m} \times 30\text{m}$  area.
- **height**: The height of the base station's antenna in meters above the ground (relative to the elevation at that point in space).

Each record is accessed by concatenating the record name to the structure variable name with a period `'.'` separating the two names. For example, `Cell_Info_E.cellSite.eirp` would access the effective radiated power recorded for cell site E.

From this data – and any other data that you collect – you must construct 2D maps of received signal strength. Half of these structures will contain some measurement data in **meas** (A-D) that will allow you to test your modeling algorithm. Half of these structures will contain an empty, all-zero **meas** (E-H) that will be used in the blind evaluation phase of the project.

Manipulating data in **meas** is important for a successful project. Because Matlab uses a (row,column)-format to index 2D matrices, you must always keep in mind that a matrix map must be referenced *backwards* with *xy*-coordinates. For example, if the lower-left corner of the map is given the *xy*-coordinate (1,1) and we desire to access the received signal strength at *xy*-coordinate (121,171), we would use the command `meas(171,121)`. Since each raster point in the matrix is 30m-by-30m, this point would be 5100 meters north and 3600 meters east of the lower-left corner of **meas**.

To plot a received power map in Matlab, the following procedure is recommended:

```

imagesc(Cell_Info_A.meas);           % Plots a 2D image from a matrix
axis equal;                          % sets aspect ratio equal
axis xy;                              % vertical flip so (1,1) is at lower-left
colorbar;                             % puts a colorbar legend on right of graph

```

These commands will make a colorful map of received signal strength in dBm with  $x$  and  $y$  in units of tens-of-meters. Do not forget to label the axes and add titles for any plots included in your write-up.

The measurements in `meas` were taken with a scanner unit and averaged to remove the effects of small-scale fading. Thus, the value in each raster point in this matrix is actually a linear average of 3-10 instantaneous power measurements. These measurements were taken by an industry engineer who was driving around on the road with an antenna on the top of a car. Measurements that resulted in a value at or below the noise floor of the receiver were discarded.

## 4 Deliverables

You must prepare a short technical report detailing the results of your study. The report should be in html-format with all files submitted in-class on a CD or through e-mail<sup>1</sup>. The report must include:

- A very concise discussion of the problem you are solving and its benefit to society.
- A technical discussion of your propagation model, describing how you used terrain to increase your model's accuracy.
- A concise written and numerical comparison of your empirical diffraction model to physical forms of diffraction modeling (Sommerfeld's screen solution or the GTD wedge solution, as examples).
- Documentation of the 4 known coverage maps (A-D) and your model's mean/standard deviation errors in dB.
- A short discussion about the practicality and economics of using your model on a nation-wide cellular network.

Be sure to reference any external sources that you consult during the course of this project.

In addition to the report, you must use your model to construct RF maps for sites E, F, G, and H. ZIP this file and e-mail it to *both* the teaching assistant (cody.lamb AT ece.gatech.edu) and your instructor (durgin AT ece.gatech.edu). *Be sure to name the file in the form: 'Lastname-Firstname.mat'*. These maps will be tested against real measurement data and a mean/standard deviation calculated. This submitted data must contain these sites in the format specified in the previous section. Irregularities in the submitted file format will result in *severe* grade reductions.

## 5 Grading

Each submitted project will be assigned a *Raw Performance Score* based on a formula involving the mean  $\mu$  and standard-deviation  $\sigma$  errors calculated from maps E-H:

$$\text{RPS} = \frac{1}{50}\mu^{1.5} + \sigma$$

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<sup>1</sup>e-mail submissions must be ZIPped and are recommended for files less than 5 MB

With this formula,  $\sigma$  error contributes far more than  $\mu$ , unless the mean error becomes particularly egregious. All class projects will be ranked in order according to their RPS. Each project is then assigned a ceiling score which is 100 minus a half-point for each ranked place behind the project with the best RPS. Thus, the project with the best RPS will have a ceiling score of 100, the project with the second best RPS will have a score of 99.5, the project with the third best RPS will have a score of 99, and so on. There are 40 people registered for this section of ECE3065, so the worst ceiling score will be 81%.

**Note: Signal strength maps submitted with an incorrect format will instantly be given a bottom-of-class ranking.**

Once the ceiling score has been established, your report will be graded on the following criteria:

- Completeness
- **Technical Writing**
- Technical Correctness
- Professional Content
- Research (cite all references)
- Conciseness

Deductions from these categories will be subtracted from the ceiling score. I will offer +5% bonus points to superlative reports in the following categories (one per category):

- Best Technical Writing
- Best Researched Ideas
- Most Original Propagation Model
- Most Artistic
- Creative Use of Web Presentation

All projects must be submitted before 12pm noon on the 27th of April, 2006. Late projects will not be accepted. I will enshrine (with the author's permission, of course) exceptional reports on the web for all time.

**Note: I am assuming up front that I have received your implicit permission to post projects on the web. Please let me know if you do *not* want your project posted on the web when you turn in the final files.**