

# ECE4370 Class Project: Indoor/Outdoor Antennas and Propagation Modeling on Georgia Tech Campus

## 1 Introduction

You are a member of a small engineering consulting company that has been contacted by the wireless provider Atlantastic Communications, an upstart wireless carrier that is looking to provide a data-centric network to its customers. AC has recognized that the propagation models that it uses to design cellular networks needs to be tweaked in the Atlanta area, with updating to reflect new environments and new user habits. 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 on the campus of Georgia Tech where each company must produce accurate received signal strength maps of several real-live base stations. After submission, these maps will be compared against real measured data from both indoor and outdoor locations.

AC will provide you with some measurements 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. Any extracurricular resource that your company desires to acquire and consult is fair game. This includes satellite photographs, GIS terrain maps, manufacturer’s antenna patterns, Tiger data for streets and highways, etc. Be creative.

## 2 Background and Motivation

Early cellular networks were designed for in-vehicle callers using very crude outdoor propagation models. This is a practice that continues to this day, even though typical cell use has changed dramatically. For example, most cell phone calls now originate *indoors* in areas with much denser cellular coverage. Prediction of signal coverage in these regions is critical. Just a few extra dB of unnecessary uncertainty in the indoor/outdoor 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.

## 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 850 MHz cell sectors that operate on or near the campus of Georgia Tech. 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:

- **cellID**: This is a unique numerical identifier for the cell; not important for modeling.
- **lon** and **lat**: The longitude and latitude coordinates of the base station transmit antenna.
- **antenna**: Part-number string specifying the antenna type used by the carrier to transmit at the base station.
- **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  $270^\circ$ .
- **tilt**: Mechanical downtilt angle in degrees for the base station antenna.
- **bspwrB**: Transmit power setting into the antenna. (no units)
- **erp**: The effective radiated power of the antenna in units of dBm. This is transmitted power (dBm) plus peak antenna gain (dBi) in the link budget equation.
- **freq**: Carrier frequency of the transmitter in MHz.
- **Lon\_UL** and **Lat\_UL**: The longitude and latitude of the upper-left corner of the raster map.
- **Lon\_LR** and **Lat\_LR**: The longitude and latitude of the lower-right corner of the raster map.
- **BS\_x** and **BS\_y**: The column and row coordinates in the raster map corresponding to the transmitter location.
- **ReceivedPowerMap**: A raster map of received powers in dBm, stored in a 2D matrix. Each raster point represents a  $10\text{m} \times 10\text{m}$  area where measured signal strength data has been taken. A value of 0 indicates that no received data has been taken at that point.

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.erp` 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 **ReceivedPowerMap** (A-D) that will allow you to test your modeling algorithm. Half of these structures will contain an empty, all-zero **ReceivedPowerMap** (E-H) that will be used in the blind evaluation phase of the project.

Manipulating data in **ReceivedPowerMap** 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 `ReceivedPowerMap(171,121)`. Since each raster point in the matrix is 10m-by-10m, this point would be 1700 meters north and 1200 meters east of the lower-left corner of **ReceivedPowerMap**.

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

```
imagesc(Cell_Info_A.ReceivedPower);    % 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 `ReceivedPowerMap` 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 4-15 instantaneous power measurements. Some of these measurements were taken while driving around on the road, some of these measurements were taken while walking around the campus, and some of these measurements were taken indoors. You will not be able to discern from `ReceivedPowerMap` whether the location was indoors or outdoors, but a clever student may be able to discern this information from a satellite photograph.

## 4 Deliverables

You must prepare a short technical report detailing the results of your study. The report should be in PDF format and prediction maps in Matlab should be submitted electronically to the instructor by the project deadline. 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 and how you arrived at specific forms and values.
- 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. These maps will be tested against real measurement data and a mean/standard deviation will be 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:

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

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 group with the best RPS will have a ceiling score of 100, the project group with the second best RPS will have a score of 99, the project group with the third best RPS will have a score of 98, and so on.

**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

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.**