ECE3065 Class Project: CSI Wave Propagation

Due Date: 23 April 2009 (Thursday)

1 Introduction

After taking Spring 2009 Electromagnetic Applications and graduating, a few of your classmates get together and start an engineering consulting firm. Since you are all 7th-level wavemasters, one of the services your group offers is propagation modeling. The Georgia district attorney's office approaches you with an interesting problem: they are looking for a firm to help with investigations and analysis of crime-scene cellular data. Such a firm would receive high-profile cases ... if they can prove they have the technical smarts to pull off the case. Unfortunately for your group, there are several competing firms who would love to win this contract and the subsequent cases.

To down-select the firms capable of providing their services, the Georgia DA proposes a competitive trial between firms in two phases. In the Phase I trial, your firm will be asked to make cellular propagation predictions in a suburban area. A trial will be held in somewhere in the US where each competing firm must produce accurate received signal strength maps of several real-live cellular base stations. After blind submission, these maps will be compared against real measured data from both indoor and outdoor locations. The Georgia DA office will provide you with some measurements and some geographical information services (GIS) 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.

In the Phase II trial, you will be asked to help the DA office with a high-profile murder case where cell-phone data is a key component in the trial against the alleged murderers. Your scientific analysis of the cell phone records will be crucial to the trial; the best, most-thorough analysis of the Phase II data will result in your firm being awarded the contract. The final deliverable will be a web-based report documenting your efforts in Phase I and II portions of the trial.

2 Phase I: Map Trials

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 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 30m × 30m 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 30m × 30m 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°, east is 90°, south is 180°, and west is 270°.
- `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 30m × 30m 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.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 `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 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.

3 Phase II: Case Data

The Georgia DA has a particularly high-profile case involving a political assassination in a nearby Atlanta county. In November, a new police captain won the county election for sheriff on a pledge to clean up the corrupt sheriff's office. One month later, the sheriff-elect was gunned down in front of his home after returning from a political function by a gang of men. Police take 2 primary suspects into custody who they believe were hired by the incumbent sheriff to assassinate his victorious challenger. Both, of course, deny their involvement, but a police investigator subpoenas the cell-phone records from AT&T Wireless for both suspects' phones as they call each other through the night. By law, cellular companies keep 90-day records of customer call times, durations, and serving base stations (largely for billing purposes) which may be subpoenaed in crime cases. The sequence, duration, and serving cell information tell quite a different story than suspects, which is that they were working at Burger King the entire evening.

The goal of this phase of the trial is to reconstruct the likely events of the crime based on cell phone call records and coverage analysis. What is the likelihood that these calls were placed at the crime scene rather than at the suspects' workplace? Online you will find a PDF copy of the publicly available county police report. Here are a few helpful pieces of information to get you started:

- The victim's house is at 1666 Glasgow Dr. in Decatur.
- The address of the Burger King is 2830 Panola Rd., Lithonia, GA.
- Base station 214 is located at lat/lon (33.736974°,−84.233980°) with three distinct sectors: alpha centered at 330° from North, beta centered at 210° from North, gamma/charlie centered at 90° from North.
- Base station 222 is located at lat/lon (33.702885°,−84.265695°) with three distinct sectors: alpha centered at 330° from North, beta centered at 210° from North, gamma/charlie centered at 90° from North.
- Base station 223 is located at lat/lon (33.706848°,−84.216900°) with three distinct sectors: alpha centered at 330° from North, beta centered at 210° from North, gamma/charlie centered at 90° from North.
- Base station 224 is located at lat/lon (33.700814°,−84.181666°) with three distinct sectors: alpha centered at 330° from North, beta centered at 210° from North, gamma/charlie centered at 90° from North.
- Base station 041 is located at lat/lon (33.715416°,−84.231319°) with three distinct sectors: alpha centered at 330° from North, beta centered at 210° from North, gamma/charlie centered at 90° from North.
- Base station 071 is located at lat/lon (33.738598°,−84.216471°) with three distinct sectors: alpha centered at 330° from North, beta centered at 210° from North, gamma/charlie centered at 90° from North.
- Base station 013 is located at lat/lon (33.700350°,−84.261274°) with three distinct sectors: alpha centered at 330° from North, beta centered at 210° from North, gamma/charlie centered at 90° from North.

You will need to either do some field research or make some reasonable estimates of cellular base station technical details, since wireless companies are extremely guarded about their frequency plan information.

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[1]. The report must include:

- A concise discussion of the problem you are solving.
- A technical discussion of your propagation model, describing how you used terrain to increase your model's accuracy.
- Documentation of the 4 known coverage maps (A-D) and your model's mean/standard deviation errors in dB.
- A carefully-reasoned analysis of the Phase II data, with probability estimates of the defendants being at the scene of the crime versus their alibi location.

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 your instructor (durgin AT gatech.edu). *Be sure to name the file in the form: 'GroupName.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 μ and standard-deviation σ errors calculated from maps E-H:

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

With this formula, σ error contributes far more than μ, 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 2-points 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 98, the project with the third best RPS will have a score of 96, and so on. There are 8 groups for this semester's section of ECE3065, so the worst ceiling score will be 86%.

Note: Signal strength maps submitted with an incorrect format will instantly be given a bottom-of-class #8 ranking.

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

- Completeness
- **Technical Writing**
- Technical Correctness
- Professional Content

[1] e-mail submissions must be ZIPped and are recommended for files less than 20 MB

- Research (cite all references)
- Reasoning behind Phase II Analysis and Reconstruction
- Conciseness

Deductions from these categories will be subtracted from the ceiling score. I will offer +3% bonus points to superlative reports in the following categories (one per category):

- Best Technical Writing
- Best Researched Ideas
- Most Original Propagation Model
- Creative Use of Web Presentation
- Best Phase II Analysis and Reconstruction

All projects must be submitted before 12pm noon on the 23th of April, 2009. Late projects will not be accepted. I will enshrine the reports on the class web page 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 group's project posted on the web when you turn in the final files.