Computer Propagation Analysis Tools

Introduction

By now you are probably getting the idea that predicting received signal strength is a really important task in the design of a wireless communication system. Empirical models like log-normal shadowing are simple to use and don't require too much input, but they only crudely represent the real world. Ideally we would be able to precisely describe the electromagnetic properties of our environment and then exactly calculate how radio waves will propagate in it. That's a pretty tall order. However, in some cases we can make a start by using topographic information.

In the US, the US Geological Survey (see www.usgs.gov) maintains Digital Elevation Model (DEM) data for the entire US. These give elevation as a function longitude and latitude. Using these data we can estimate diffraction effects due to the ground. Note that the USGS data is for the ground only, it does not include buildings and structures. In urban settings those are major components of the propagation environment. There are, however, private companies that develop and sell databases of urban structures. These data, as well as the USGS data, are primarily calculated from airplane and satellite images using stereoscopy and other methods.

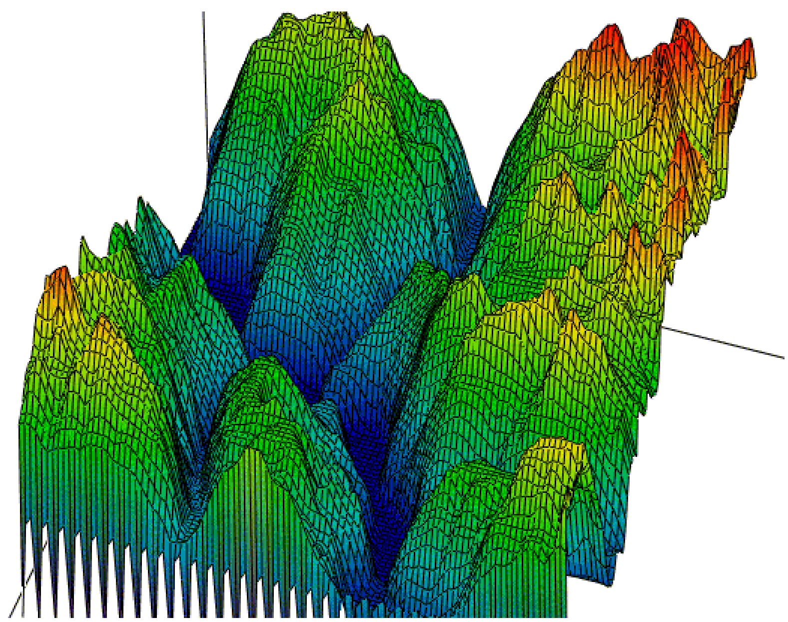

Figure 11.1: USGS topographic data for the Pullman area. The vertical scale is greatly exaggerated. Pullman is comprised by four "hills" – top left is Military Hill, right is College Hill, lower left is Sunnyside Hill, lower center is Pioneer Hill.

So, we will assume that we have topographic data for any region where we are interested in building a cellular system. Ultimately we want to be able to predict propagation over the three-dimensional ground. Since we've already treated diffraction in a two-dimensional environment, let's start with considering propagation in a 2D environment.

A Two-Dimensional Propagation Tool

Let's say we have a sampled two-dimensional topographic profile of the form $(r_i, z_i); i = 0, N$. Let the transmitter be at $i = 0$ and the receiver at $i = N$. (Because of reciprocity, we could switch them without changing the result.) The r values give the *range* (distance) from the transmitter and the z values the ground height at those ranges. Furthermore, let the transmitter and receiver heights above the ground be h_t and h_r. This is illustrated in Figure 11.2.

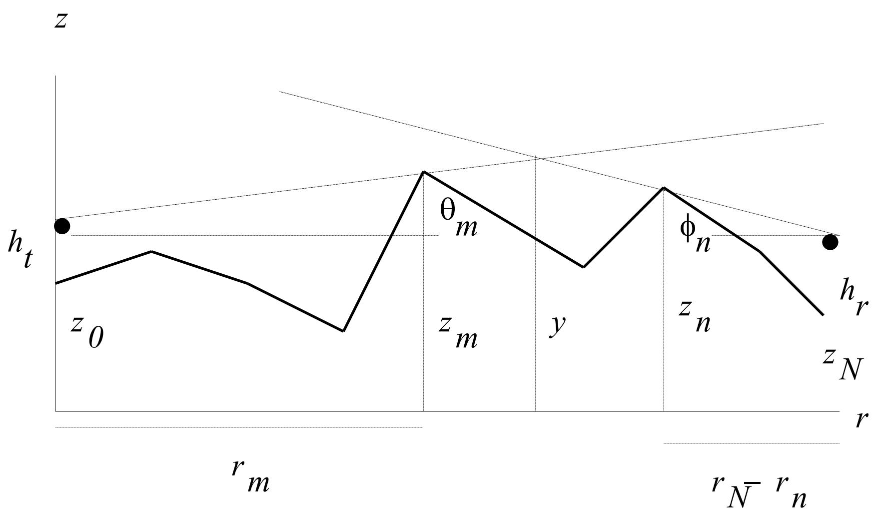

Figure 11.2: Geometry of a two-dimensional diffraction problem.

We will model the ground by linearly interpolating between the sample points. We want to know whether or not there is a line-of-sight (LOS) path between TX and RX. If the LOS is blocked then we want to estimate the diffraction gain. One approach is as follows. Imagine that we had a surveyor's sight at both TX and RX. We could look at each data point and record its viewing angle above (or below) level. These are the angles θ and ϕ in Figure 11.2. That point with the largest angle defines the horizon. If the line between TX and RX falls above the horizon, then there is a clear LOS path, otherwise there is not and we will need to consider diffraction. If there is a clear LOS path, then we will use a log-normal shadowing model of the form

$$P_r = P_0 - 10n \log \frac{r}{r_0} \tag{11.1}$$

to estimate received signal strength. We could use, say, the Hata model to estimate P_0 and n.

We can calculate the angles θ_k and ϕ_k using trigonometry

$$\theta_k \approx \tan\theta_k = \frac{z_k - (z_0 + h_t)}{r_k}$$
$$\phi_k \approx \tan\phi_k = \frac{z_k - (z_N + h_r)}{r_N - r_k} \tag{11.2}$$

Let's assume that the LOS is blocked, as shown in Figure 11.2. If the horizon angles from TX and RX are θ_m and ϕ_n, respectively, then (10.14) gives

$$u \approx \sqrt{\frac{2r_N}{\lambda}(\theta_m - \psi)(\phi_n + \psi)}$$
$$\psi \approx \tan\psi = \frac{(z_N + h_r) - (z_0 + h_t)}{r_N} \tag{11.3}$$

We can then calculate the diffraction gain G_d from (10.11) and modify the received signal strength of (11.1) accordingly.

A Three-Dimensional Propagation Tool

Here we'll consider a very simple propagation-modeling tool written for EE432 that uses USGS topographic data together with log-normal shadowing and diffraction models. Consider Figure 11.3. We have some elevation data $z(x,y)$ where x,y denotes position on the ground. If the transmitter and receiver locations are (x_t, y_t) and (x_r, y_r) then the line connecting TX and RX defines a two-dimensional topography $z(r)$ of the kind illustrated in Figure 11.2. We have

$$x(r) = x_t + (x_r - x_t)\frac{r}{r_{tr}}$$
$$y(r) = y_t + (y_r - y_t)\frac{r}{r_{tr}} \tag{11.4}$$
$$z(r) = z(x(r), y(r))$$
$$r_{tr} = \sqrt{(x_r - x_t)^2 + (y_r - y_t)^2}$$

We can then apply the type of analysis described above. By doing this for all possible RX points (x,y) we can build a map of predicted signal strength vs. location.

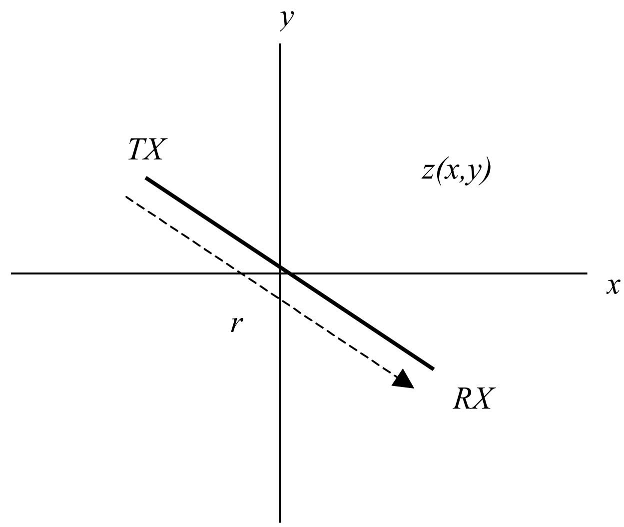

Figure 11.3: The path between TX and RX defines a two-dimensional profile of the kind illustrated in Figure 11.2.

Spherical Trigonometry

$$\mathbf{r} = (x, y, z) = r(\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta)$$

$$\begin{aligned}\frac{\mathbf{r}_1\cdot\mathbf{r}_2}{r^2} &= \sin\theta_1\sin\theta_2\left(\cos\phi_1\cos\phi_2+\sin\phi_1\sin\phi_2\right)+\cos\theta_1\cos\theta_2 \\ &= \sin\theta_1\sin\theta_2\cos\left(\phi_2-\phi_1\right)+\cos\theta_1\cos\theta_2\end{aligned}$$

$$\begin{aligned}d &= r\psi \\ &= r\cos^{-1}\left[\sin\theta_1\sin\theta_2\cos\left(\phi_2-\phi_1\right)+\cos\theta_1\cos\theta_2\right]\end{aligned}$$

A *nautical mile* is defined to be the distance along the surface of the earth corresponding to an angle of 1 minute of arc.

Experiment

As part of a Senior Project at WSU, a group of students placed a 915MHz transmitter on top of the EME building. They used the propagation tool described above to predict signal strength in the Pullman area and then performed an extensive drive test, using a GPS receiver and a field strength meter, to measure the actual signal. Their results are shown in Figure 11.4. The drive test data covered a fairly large area – about 12 by 12 miles.

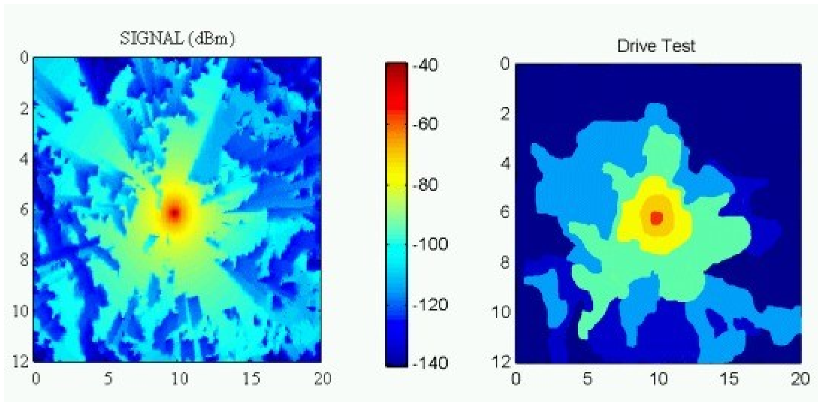

Figure 11.4: Example use of the propagation tool in the Pullman area. A 915MHz transmitter was place on top of the EME building. Predicted signal strength is shown at left. Drive-test measurements are shown at right. Number on axes indicate minutes of longitude/latitude. Figures are approximately 12 nautical miles on a side.