Lecture 5

Empirical Propagation Models II

1 Introduction

The primary use of an empirical model such as log-normal shadowing, $P_r = P_0 - 10\,n \log\frac{r}{r_0} + X$, is to allow us to predict radio coverage when designing a wireless communication system. The question naturally arises as to what values of P_0 and n we should use. We could set up a prototype transmitter and make field strength measurements every time we design a system, but that's a lot of work. Instead various researchers have made extensive measurements in a variety of environments and then fit empirical models to the values of P_0 and n as a function of the basic system parameters, namely, the antenna heights and the radio frequency. Of the many empirical models that have been developed, one of the most widely used has been the Hata Model.

2 Hata Model

We define *path loss* (*PL*) using $P_R = P_T + G_T + G_R - PL$ where the powers are in dBm and the other values are in dB. Path loss differs from the system loss *L* we defined previously in that *PL* does not include the effects of antenna gain while *L* does. The relation is $L = PL - G_T - G_R$.

For propagation in urban environments, the Hata model predicts

$$\begin{aligned} PL = {} & 69.55 + 26.16 \log f(\mathrm{MHz}) - 13.83 \log h_b(\mathrm{m}) - a(h_m) \\ & + [44.9 - 6.55 \log h_b(\mathrm{m})] \log r(\mathrm{km}) \end{aligned} \tag{1}$$

where

$$a(h_m) = 3.2[\log 11.75\, h_m(\mathrm{m})]^2 - 4.97\,\mathrm{dB} \tag{2}$$

The model is applicable for the following parameters values

$$150 \le f \le 1500\,\mathrm{MHz}\ ;\ 30 \le h_b \le 200\,\mathrm{m}\ ;\ 1 \le h_m \le 10\,\mathrm{m}\ ;\ 1 \le r \le 20\,\mathrm{km} \tag{3}$$

Here h_b is the basestation antenna height and h_m is the mobile antenna height. T o see that the Hata model is an empirical form of the log-normal shadowing, note that once f, h_b, h_m are fixed, *PL* consists of a constant plus a term that varies as the log of distance. Writing

$$\begin{aligned} P_R &= P_0 - 10\,n \log\frac{r}{r_0} \\ &= P_T + G_T + G_R - PL \end{aligned} \tag{4}$$

with $r_0 = 1\,\mathrm{km}$, we have

$$\begin{aligned} P_0 &= P_T + G_T + G_R - 74.52 - 26.16 \log f + 13.83 \log h_b + 3.2[\log(11.75\, h_m)]^2 \\ n &= 4.49 - 0.655 \log h_b \end{aligned} \tag{5}$$

(note that $74.52=69.55+4.97$). As before, to account for the inability of a simple model to precisely account for propagation in a complex environment we would add a Gaussian random variable *X* with standard deviation σ .

We see that the Hata model treats the reference power as a function fo frequency and the heights of the basestation and mobile antennas while it considers the propagation exponent to be a function only of the basestation antenna height. In Fig. 1 we plot the three terms in the expression for P_0 that depend on frequency and antenna height.

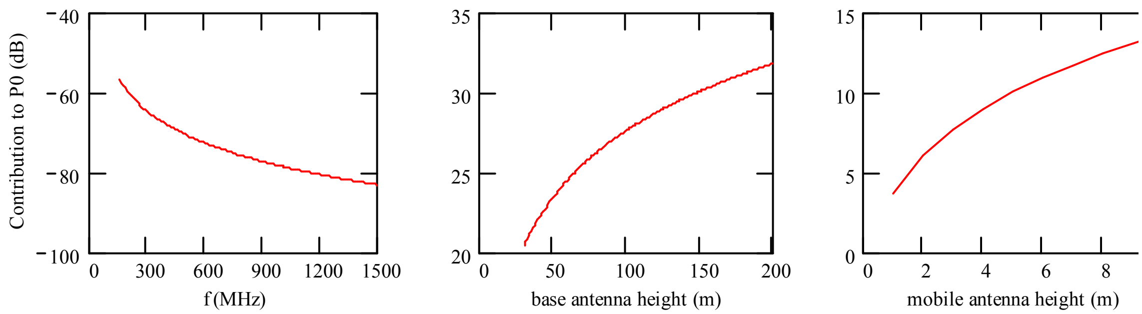

Fig. 1 Contribution of frequency and antenna-height terms to the received power at the reference distance of 1 km.

Notice that the model predicts a decrease in received power with an increase in frequency. In the free space propagation equation there is a term $-20\log\frac{4\pi r}{\lambda}$. Since $f=c/\lambda$ this predicts that power drops off as $-20\log f$. In the Hata model the dependence is $-26.16\log f$, a little more rapid drop off with frequency. The primary reason for this more rapid drop off is *diffraction* – as frequency increases fields are not as able to "bend" around obstacles. We will study diffraction in a later lesson.

The Hata model also predicts that power will increase with an increase in either the basestation or mobile antenna height. This makes sense since the higher either antenna is, the less likely it is that the direct path from base station to mobile will be obstructed.

Fig. 2 shows how the model predicts the propagation exponent *n* depends on the height of the basestation antenna. As the basestation antenna gets higher *n* decreases. A smaller value of *n* means the field strength does not decay as rapidly. This part of the model is simply saying that as we raise the basestation antenna up higher it is able to more effectively project RF power out to large distances. This makes sense as the higher the basestation antenna is the fewer obstacles we would expect to interfere with the radio path.

Example 1: Let's see what the Hata model predicts for the following situation: 1 Watt of transmitted power, basestation antenna gain of 3 dB, mobile antenna gain of 0dB, mobile antenna height of 2 m, basestation height of 40 m, and frequency of 880 MHz.

From (5) we have

$$\begin{aligned} P_0 &= 30+3+0-74.52-26.16\log 880+13.83\log 40+3.2[\log(11.75\cdot 2)]^2 \\ &= -90\,\text{dBm} \end{aligned}$$

and

$$n = 4.49 - 0.655 \log 40$$
$$= 3.4$$

The log-normal shadowing model is therefore

$$P_R = -90 - 34 \log \frac{r}{1\,\text{km}} + X$$

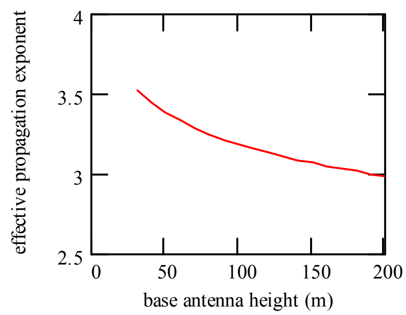

Fig. 2 Effective propagation exponent as a function of basestation antenna height.

There are other empirical propagation models available and more being developed every year. The so-called COST231-Hata model is an extension of the Hata model up to 2 GHz. It looks more or less like the Hata model with different numerical values.

3 Indoor Models

We tend to think of cellular phone systems as "outdoor" systems. Models such as the Hata model are designed to predict propagation in an outdoor environment. However, the use of indoor wireless systems, including phones and mobile computers, is a major sector of the wireless market. Therefore indoor propagation models are important tools for the RF engineer.

One approach is our trusty log-normal shadowing model. As an example, Fig. 3 shows a log-normal model for 915-MHz propagation in the EME building at WSU-Pullman. A transmitter was placed in a laboratory on the second floor and field-strength measurements were taken at several locations on the four floors of the building. Linear regression was performed using the three-dimensional TX-RX distances. This gave a propagation exponent of about 6.3, a value quite a bit higher than the ~3 or so that tends characterizes outdoor propagation. Typically propagation exponents will be on the high side in indoor environments, as long-distance paths tend to require penetration through more walls, floors and other obstacles.

In most buildings, the floors are much thicker and contain more metal than the interior walls. Consequently there tends to be a significantly greater loss when a wave travels through a floor than when it travels through an interior wall. It makes sense then to separate out paths that travel through floors from those that don't. This leads to the idea of a floor attenuation factor (FAF) model. In this case we can use the two-dimensional TX-RX distance, that is, we measure TX-RX separation as if all floors were collapsed onto the ground. Then for paths that cross floors we reduce the received power by a floor attenuation factor. That is

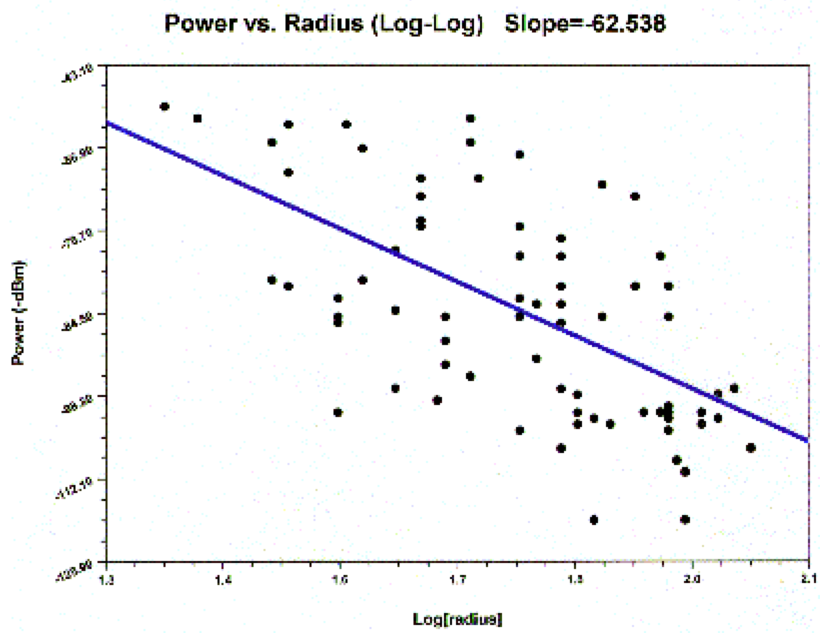

Fig. 3 915 MHz propagation in the EME build including data from all floors. The horizontal axis is the log of the three-dimensional distance between transmitter and receiver.

$$P_R = P_0 - 10\,n \log \frac{r_{2D}}{r_0} - FAF_m + X \tag{6}$$

where r_{2D} is the two-dimensional TX-RX distance and FAF_m is the attenuation factor for going through *m* floors. Fig. 4 shows this sort of model for 463-MHz propagation in the EME building. Received field strength behaves more or less the same within each floor but is approximately 10-dB weaker every time we go down another floor. That is, this group of students found that $FAF_m \approx 10\,m\,\text{dB}$.

Another approach is to use the attenuation-factor idea for walls also. We can model propagation as essentially the free-space case with attenuation each time the path crosses a wall or a floor. We could then write

$$P_R = P_0 - 20 \log \frac{r}{r_0} - n_W\,WAF - n_F\,FAF \tag{7}$$

where n_W, n_F are the number of walls and floors the TX-RX path crosses, and WAF, FAF are the attenuation factors for a single wall or floor.

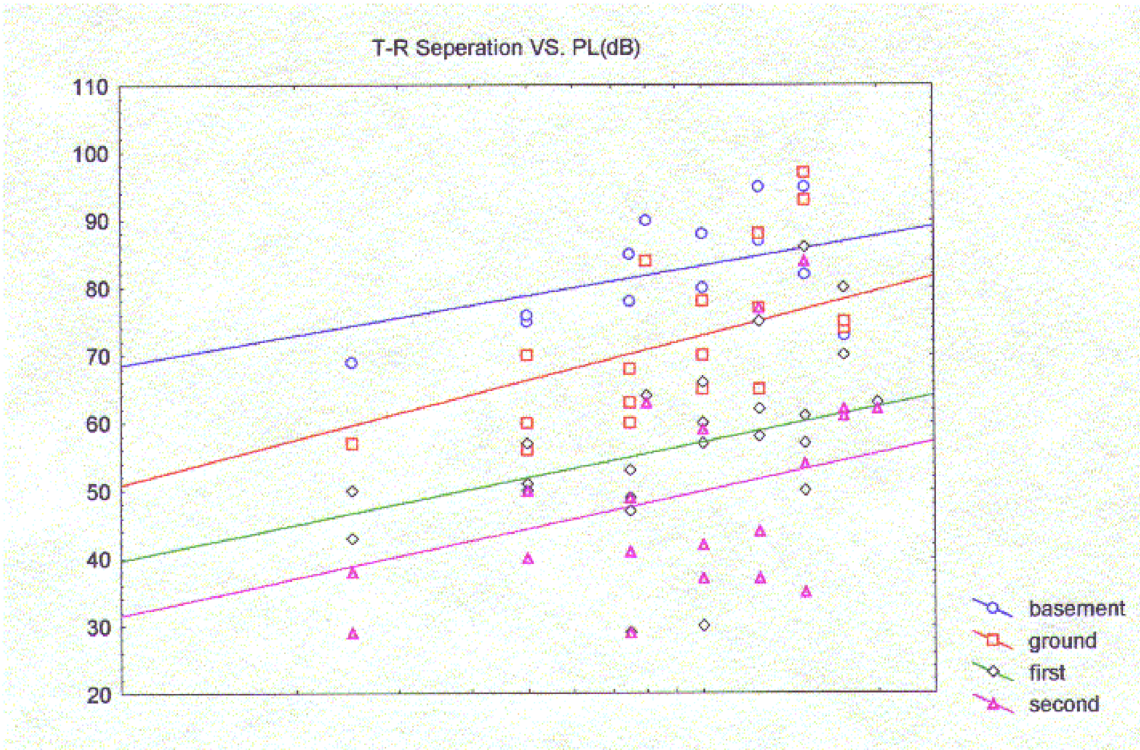

Fig. 4 463 MHz propagation in the EME building separated by floor. The transmitter was on the second floor. For each floor crossed by the radio path an attenuation of about 10 dB is experienced. The horizontal axis is the log of the two-dimensional distance between transmitter and receiver, that is, the distance between the ground projections of the antennas.

4 References

1. Garg, V. K. and J. E. Wilkes, *Wireless and Personal Communications Systems*, Prentice Hall, 1996, ISBN 0-13-234626-5.
2. Saunders, S. R., *Antennas and Propagation for Wireless Communication Systems*, Wiley,1999, ISBN 0-471-98609-7.