Statistical Path Loss Models

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Statistical Path Loss Models

Predicting path loss by computing specific combinations of direct paths, reflections and diffraction is not possible for real-world situations because it would take too much effort to accurately model the environment.

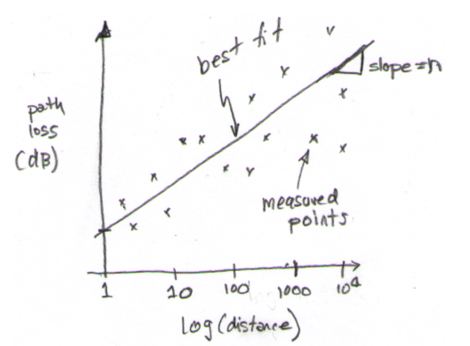
Instead, we have to use statistical models that predict path loss based on significant features of the propagation environment. Features that are useful for predicting path loss include the transmitter-receiver distance, antenna heights, the type of environment (open rural vs "urban canyon"), etc. The predictions generated by these models will have some uncertainty associated with them, perhaps on the order of ± 10dB.

Power Law Model

The simplest model is to assume that the path loss increases as a power n of the distance ($n = 2$ in the case of free space):

$$PL(d) \propto \frac{d}{d_0}^n$$

We can obtain the exponent for NLOS conditions by measuring the path loss in dB versus distance, plotting the path loss versus the log of distance and fitting a straight line:



The equation of the line is:

$$PL(dB) = PL(d_0) + 10n \log\left(\frac{d}{d_0}\right)$$

where d_0 is an arbitrary reference distance (often 1m) and $10n$ is the slope of the line. For free-space propagation n should be 2. But in NLOS environments n is larger, typically about 3 for outdoor cellular systems and 4 or higher for indoor propagation.

Exercise 1: What is the value of $PL(d_0)$ for a free-space ($n = 2$) propagation model at $f = 1800$ MHz if d_0 is 10m?

Okumura-Hata Model

We can improve the predictive property of the simple power-law path loss model by including additional parameters such as antenna heights, frequency and type of terrain.

The models of this type were derived by Okumura who made extensive measurements in Japan in the 1960's. He plotted best-fit loss versus distance curves for various combinations of parameters. Hata later derived equations that provided the same numerical results without having to look up values in graphs. A European committee, COST-231, extended the Hata model for frequencies above 1500 MHz.

The equations for the Hata and COST-231 models and the valid ranges for each of the parameters are given below.

Exercise 2: Compute the median path loss predicted by the Hata model for a large urban area at $f = 900$MHz, base station and mobile antenna heights of 30m and 1m respectively, and a distance of 2km.

There are various other models that attempt to improve the predictive power for specific systems by using different parameters. For example, the Walfish-Bertoni model is used for small cells with low base station heights and uses street widths and building heights as parameters.

These models are only valid over the parameter values represented in the original measurements. Extrapolating beyond these values may not produce accurate results.

Indoor Models

Statistical models for indoor propagation are more difficult to derive than models for outdoor because of the much wider range of building materials and widely varying configurations of interior spaces. For example, propagation in an open warehouse with metal walls and ceilings would be much different than propagation in a wood-frame house with drywall walls and vinyl siding.

One approach is to use a power-law model with the exponent depending on the type of construction. This can be augmented with a model that includes an attenuation factor for each wall, ceiling or floor that needs to be crossed. The usefulness of these models is limited because it is often easier to measure the path loss directly than to figure out the RF properties of the materials used in the building.

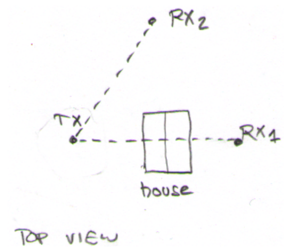
Propagation Models for Planning versus Deployment

Statistical models are useful for system-level planning purposes. They help answer questions such as how many base stations will be required to cover an area or the impact of mounting antennas at street level instead of on top of tall buildings.

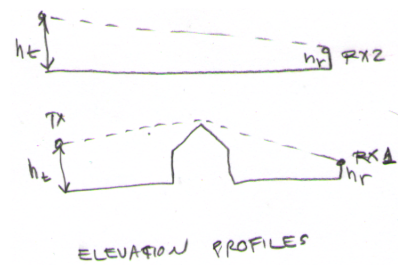
However, statistical path-loss models are not typically used for planning where to locate base stations. If we have topological information for an area such as terrain elevations, street widths and building heights then it's possible to estimate the elevation contour between any two locations. From these contours we can get more reliable estimates of the path loss than by using a statistical model.

Propagation planning tools for deployment purposes compute the elevation contour and the corresponding path loss for thousands of paths between a candidate transmitter location and locations within the coverage area. The resulting path loss distribution is used to estimate the fraction of the coverage area that would be adequately covered.

For example in the following location we know the location and height of a building:



For a given transmit location we can then compute the elevation profiles for different test points:



For each of these paths we can estimate the path loss using models similar to the knife-edge diffraction model. By computing the path loss for a large number of locations we can estimate what fraction of the area will have coverage. We can then test various candidate transmitter locations and choose the one(s) that gives the best coverage.

Site Surveys and Drive Testing

Propagation predictions always need to be verified. Terrain data is often incomplete and the path loss values generated by the propagation prediction tools are approximations.

Field measurements to validate propagation predictions are typically called "drive testing" for outdoor systems and "site surveys" for indoor systems.

Typically a number of candidate base station site locations will be chosen based on spatial call density estimates (for example, more calls in malls, fewer in parks), and databases of available base station locations.

The planners then use the deployment planning tools (and/or experience) to identify the candidate locations most likely to provide the required coverage.

Test transmitters and antennas are then set up at candidate sites and technicians then drive (or walk) around the coverage area and collect signal quality data along with location data (from GPS). The collected data is used to check the predicted results.

The following section is taken from the text by Rappaport.

4.10.4 Hata Model

The Hata model [Hat90] is an empirical formulation of the graphical path loss data provided by Okumura, and is valid from 150 MHz to 1500 MHz. Hata presented the urban area propagation loss as a standard formula and supplied correction Equations for application to other situations. The standard formula for median path loss in urban areas is given by

$$L_{50}(urban)(\text{dB}) = 69.55 + 26.16\log f_c - 13.82\log h_{te} - a(h_{re}) + (44.9 - 6.55\log h_{te})\log d \quad (4.82)$$

where f_c is the frequency (in MHz) from 150 MHz to 1500 MHz, h_{te} is the effective transmitter (base station) antenna height (in meters) ranging from 30 m to 200 m, h_{re} is the effective receiver (mobile) antenna height (in meters) ranging from 1 m to 10 m, d is the T–R separation distance (in km), and $a(h_{re})$ is the correction factor for effective mobile antenna height which is a function of the size of the coverage area. For a small to medium sized city, the mobile antenna correction factor is given by

$$a(h_{re}) = (1.1\log f_c - 0.7)h_{re} - (1.56\log f_c - 0.8) \text{ dB} \quad (4.83)$$

and for a large city, it is given by

$$a(h_{re}) = 8.29(\log 1.54h_{re})^2 - 1.1 \text{ dB} \quad \text{for } f_c \le 300 \text{ MHz} \quad (4.84.a)$$

$$a(h_{re}) = 3.2(\log 11.75h_{re})^2 - 4.97 \text{ dB} \quad \text{for } f_c \ge 300 \text{ MHz} \quad (4.84.b)$$

To obtain the path loss in a suburban area, the standard Hata formula in Equation (4.82) is modified as

$$L_{50}(\text{dB}) = L_{50}(urban) - 2[\log(f_c/28)]^2 - 5.4 \quad (4.85)$$

and for path loss in open rural areas, the formula is modified as

$$L_{50}(\text{dB}) = L_{50}(urban) - 4.78(\log f_c)^2 + 18.33\log f_c - 40.94 \quad (4.86)$$

Although Hata's model does not have any of the path-specific corrections which are available in Okumura's model, the above expressions have significant practical value. The predictions of the Hata model compare very closely with the original Okumura model, as long as d exceeds 1 km. This model is well suited for large cell mobile systems, but not personal communications systems (PCS) which have cells on the order of 1 km radius.

4.10.5 PCS Extension to Hata Model

The European Cooperative for Scientific and Technical research (EURO-COST) formed the COST-231 working committee to develop an extended version of the Hata model. COST-231 proposed the following formula to extend Hata's model to 2 GHz. The proposed model for path loss is [EUR91]

$$L_{50}(urban) = 46.3 + 33.9\log f_c - 13.82\log h_{te} - a(h_{re}) + (44.9 - 6.55\log h_{te})\log d + C_M \quad (4.87)$$

where $a(h_{re})$ is defined in Equations (4.83), (4.84.a), and (4.84.b) and

$$C_M = \begin{cases} 0 \text{ dB} & \text{for medium sized city and suburban areas} \\ 3 \text{ dB} & \text{for metropolitan centers} \end{cases} \quad (4.88)$$

The COST-231 extension of the Hata model is restricted to the following range of parameters:

f : 1500 MHz to 2000 MHz

h_{te} : 30 m to 200 m

h_{re} : 1 m to 10 m

d : 1 km to 20 km