Measurement-Based Propagation Models

Outdoor Propagation Models

- Radio transmission in a mobile communications system often takes place over irregular terrain (landscape).

- The terrain profile of a particular area needs to be taken into account for estimating the path loss. The terrain profile may vary from a simple curved earth profile to a highly mountainous profile.

- The presence of trees, buildings, and other obstacles also must be taken into account. A number of propagation models are available to predict path loss over irregular terrain.

- While all these models aim to predict signal strength at a particular receiving point or in a specific local area (called a sector), the methods vary widely in their approach, complexity, and accuracy.

- Most of these models are based on a systematic interpretation of measurement data obtained in the service area. **Some of the commonly used outdoor propagation models are now discussed**.

Here are number of standard models for computing the mean received signal level. These are well-treated in the literature.

Models are typically developed to approximate system behavior over a given area. Models are developed for different types of areas using extensive measured data. Curve-fitting techniques are used to fit equations to the experimental data. Models are usually developed for the following classifications of areas:

- urban area (built up area such as city centers)
- suburban area (one and two story homes with open spaces)
- open areas (pastures, farms, etc.)

Other models are often included. Examples are

- geographical data bases (USGS data base for the US)
- atmospheric models for scattering

Parameters of interest often include the following:

- transmission frequency
- antenna heights
- surface reflectivity
- path length
- ground dielectric and conductivity constants
- polarization
- terrain effects (ground cover, etc.)

Many different models are possible and most have both strong and weak points to recommend their use.

Okumura Model

The Okumura model is widely used. It is simple to apply and often gives reasonable results. Based a set of curves obtained by curve fitting to measurement results. Typical parameters:

- Frequency range: 150MHz to 2 or 3 GHz
- Distances: 1 km to 100 km
- Base station antenna heights: 30 m to 1000 m

$$\boxed{L_{50} = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}, \quad \text{dB}}$$

where

$$L_F = \text{free space path loss} = -10\log_{10}\left[\left(\frac{\lambda}{4\pi d}\right)^2\right]$$

$A_{mu}(f,d)$ = medium attenuation relative to free space (in graph)

G_{AREA} = terrain correction (in graphs)

$G(h_{re})$ = receiving antenna factor

$G(h_{te})$ = transmitting antenna factor

L_{50} is the 50th percentile (i.e., median) value of propagation path loss,

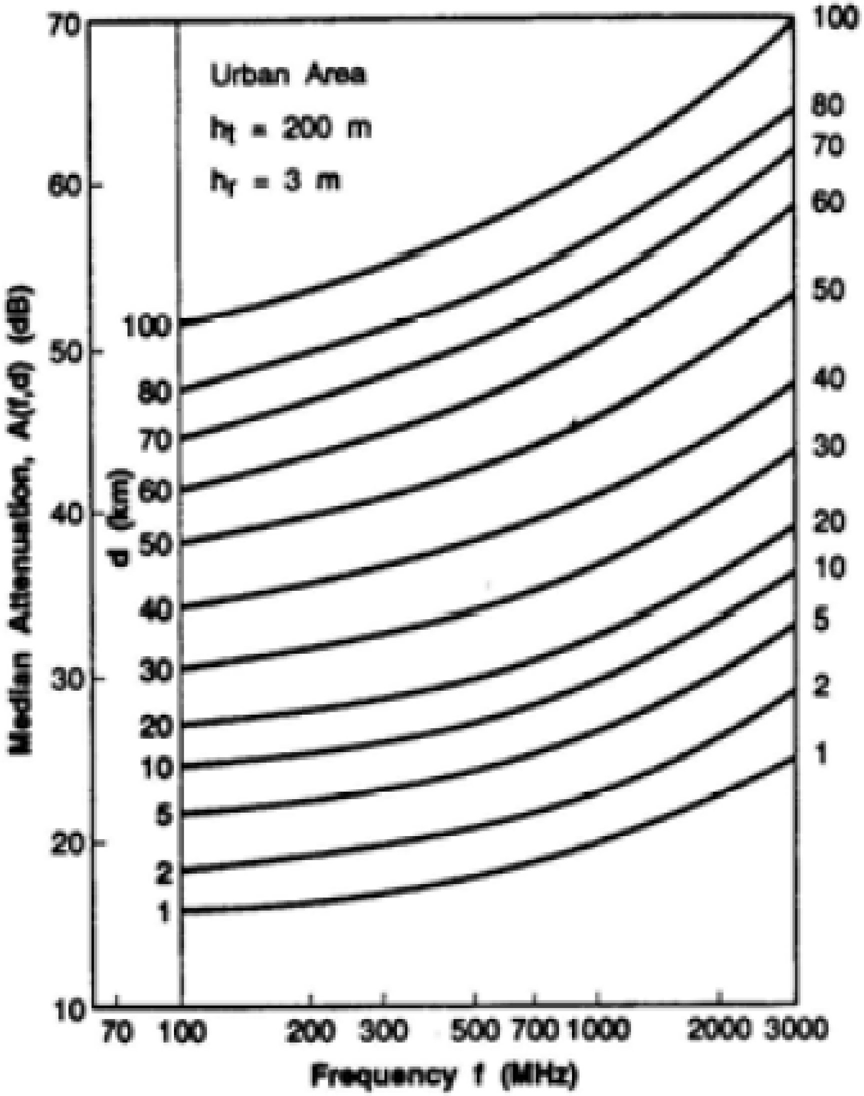

Figure 4.23 Median attenuation relative to free space ($A_{mu}(f,d)$), over a quasi-smooth terrain [from [Oku68] © IEEE].

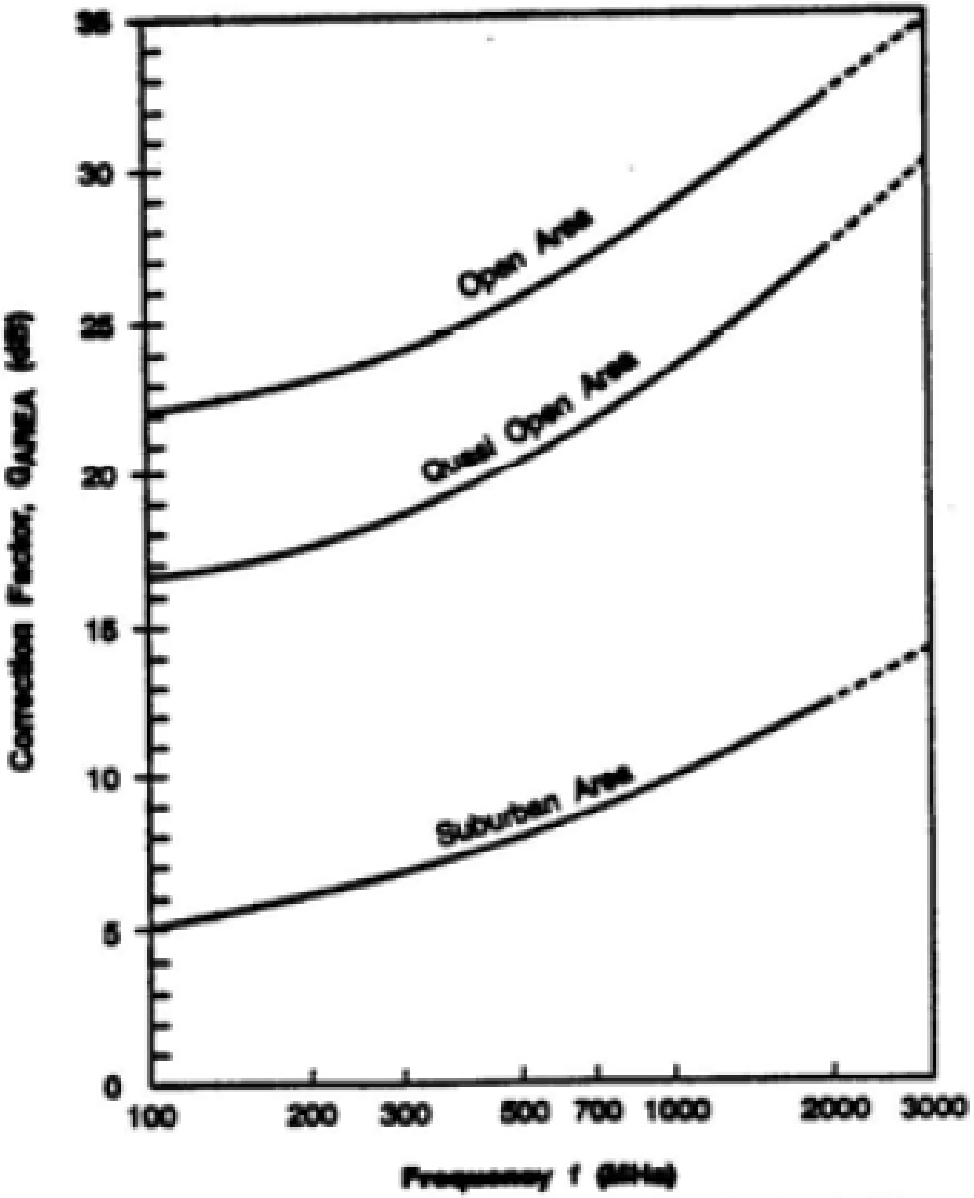

Figure 4.24 Correction factor, G_{AREA}, for different types of terrain [from [Oku68] © IEEE].

Okumura Model

Antenna height correction factors:

$$G(h_{te}) = 20\log_{10}(h_{te}/200), \qquad 30\text{ m} < h_{te} < 1000\text{ m}$$

$$G(h_{re}) = 10\log_{10}(h_{re}/3), \qquad h_{re} < 3\text{m}$$

$$G(h_{re}) = 20\log_{10}(h_{re}/3), \qquad 3\text{ m} < h_{re} < 10\text{ m}$$

Example 3.10

Find the median path loss using Okumura's model for $d = 50$ km, $h_{te} = 100$ m, $h_{re} = 10$ m in a suburban environment. If the base station transmitter radiates an EIRP of 1 kW at a carrier frequency of 900 MHz, find the power at the receiver (assume a unity gain receiving antenna).

Solution to Example 3.10

The free space path loss L_F can be calculated using equation (3.6) as

$$L_F = 10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] = 10\log\left[\frac{(3\times 10^8/900\times 10^6)^2}{(4\pi)^2\times(50\times 10^3)^2}\right] = 125.5 \text{ dB}.$$

From the Okumura curves

$$A_{mu}(900 \text{ MHz}(50 \text{ km})) = 43 \text{ dB}$$

and

$$G_{AREA} = 9 \text{ dB}.$$

Using equation (3.81.a) and (3.81.c) we have

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) = 20\log\left(\frac{100}{200}\right) = -6 \text{ dB}.$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) = 20\log\left(\frac{10}{3}\right) = 10.46 \text{ dB}.$$

Using equation (3.80) the total mean path loss is

$$\begin{aligned} L_{50}(\text{dB}) &= L_F + A_{mu}(f, d) - G(h_{te}) - G(h_{re}) - G_{AREA} \\ &= 125.5 \text{ dB} + 43 \text{ dB} - (-6) \text{ dB} - 10.46 \text{ dB} - 9 \text{ dB} \\ &= 155.04 \text{ dB}. \end{aligned}$$

Therefore, the median received power is

$$\begin{aligned} P_r(d) &= EIRP(\text{dBm}) - L_{50}(\text{dB}) + G_r(\text{dB}) \\ &= 60 \text{ dBm} - 155.04 \text{ dB} + 0 \text{ dB} = -95.04 \text{ dBm}. \end{aligned}$$

Hata Model

An easy to use model that is quite popular is the Hata/Okumura model defined using by following assumptions:

Base station height: between 30 and 200 meters
Carrier frequency: between 150 and 1,500 MHz
Mobile station antenna height: between 1 and 10 meters
Distance from BS to MS: between 1 and 20 meters

For these assumptions, the model on the following page applies. Note that the model is used to calculate path loss. The path is converted to a dB scale and subtracted from the transmitted power expressed in dB.

Hata Model

The path loss (in dB) for urban areas is given in the Hata model as

$$L_{50}(urban) = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_{te} - a(h_{re})$$
$$+ (44.9 - 6.55\log_{10} h_{te})\log_{10} d$$

For various environments we apply a correction factor for the mobile antenna height. For a small to medium size city

$$a(h_{re}) = (1.1\log_{10} f_c - 0{,}7)h_{re} - (1.56\log_{10} f_c - 0.8)$$

For a large city the correction factors take the form

$$a(h_{re}) = 8.29(\log_{10} 1.54 h_{re})^2 - 1.1, \qquad f_c < 300 \text{ MHz}$$
$$a(h_{re}) = 3.2(\log_{10} 11.75 h_{re})^2 - 4.97, \qquad f_c > 300 \text{ MHz}$$

Hata Model .

For a suburban area the original expression is modified as

$$L_{50}(suburban) = L_{50}(urban) - 2\left[\log(f_c/28)\right]^2 - 5.4$$

Finally for open rural areas we have

$$L_{50}(suburban) = L_{50}(urban) - 4.78\left[\log(f_c)\right]^2 + 18.33\log_{10}(f_c) - 40.94$$

Note that the Hata model is a formula and does not have the path specific graphical corrections available in the Okumura model.

Model Accuracy

As previously illustrated, a random variable may be added to account for random fluctuations due to shadowing.

Keep in mind that these models are not very precise and provide only very rough approximations. The approximations are useful however.

Empirical Path Loss: Okamura, Hata, COST231

- Empirical models include effects of path loss, shadowing and multipath.
  - Multipath effects are averaged over several wavelengths: local mean attenuation (LMA)
  - Empirical path loss for a given environment is the average of LMA at a distance d over all measurements
- **Okamura**: based upon Tokyo measurements. 1-100 lm, 150-1500MHz, base station heights (30-100m), median attenuation over free-space-loss, 10-14dB standard deviation.

$$P_L(d)\ \text{dB} = L(f_c, d) + A_{mu}(f_c, d) - G(h_t) - G(h_r) - G_{AREA}$$

- **Hata**: closed form version of Okamura

$$P_{L,urban}(d)\ \text{dB} = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + (44.9 - 6.55\log_{10}(h_t))\log_{10}(d). \quad (2.31)$$

- **COST 231:** Extensions to 2 GHz

$$P_{L,urban}(d)\text{dB} = 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + (44.9 - 6.55\log_{10}(h_t))\log_{10}(d) + C_M, \quad (2.34)$$

Source: A. Goldsmith book