

3.10.3 Okumura Model (1968)

Okumura's model is one of the most widely used models for signal prediction in urban areas. This model is applicable for frequencies in the range 150 MHz to 1920 MHz (although it is typically extrapolated up to 3000 MHz) and distances of 1 km to 100 km. It can be used for base station antenna heights ranging from 30 m to 1000 m.

Okumura developed a set of curves giving the median attenuation relative to free space (A_{mu}), in an urban area over a quasi-smooth terrain with a base station effective antenna height (h_{te}) of 200 m and a mobile antenna height (h_{re}) of 3 m. These curves were developed from extensive measurements using vertical omni-directional antennas at both the base and mobile, and are plotted as a function of frequency in the range 100 MHz to 1920 MHz and as a function of distance from the base station in the range 1 km to 100 km. To determine path loss using Okumura's model, the free space path loss between the points of interest is first determined, and then the value of $A_{mu}(f, d)$ (as read from the curves) is added to it along with correction factors to account for the type of terrain. The model can be expressed as

$$L_{50}(\text{dB}) = L_F + A_{mu}(f, d) - G(h_{te}) - G(h_{re}) - G_{AREA} \quad (3.80)$$

where L_{50} is the 50th percentile (i.e., median) value of propagation path loss, L_F is the free space propagation loss, A_{mu} is the median attenuation relative to free space, $G(h_{te})$ is the base station antenna height gain factor, $G(h_{re})$ is the mobile antenna height gain factor, and G_{AREA} is the gain due to the type of environment. Note that the antenna height gains are strictly a function of height and have nothing to do with antenna patterns.

Plots of $A_{mu}(f, d)$ and G_{AREA} for a wide range of frequencies are shown in Figure 3.23 and Figure 3.24. Furthermore, Okumura found that $G(h_{te})$ varies at a rate of 20 dB/decade and $G(h_{re})$ varies at a rate of 10 dB/decade for heights less than 3 m.

$$G(h_{te}) = 20 \log \left(\frac{h_{te}}{200} \right) \quad 1000 \text{ m} > h_{te} > 30 \text{ m} \quad (3.81.a)$$

$$G(h_{re}) = 10 \log \left(\frac{h_{re}}{3} \right) \quad h_{re} \leq 3 \text{ m} \quad (3.81.b)$$

$$G(h_{re}) = 20 \log \left(\frac{h_{re}}{3} \right) \quad 10 \text{ m} > h_{re} > 3 \text{ m} \quad (3.81.c)$$

Other corrections may also be applied to Okumura's model. Some of the important terrain related parameters are the terrain undulation height (Δh), isolated ridge height, average slope of the terrain and the mixed land-sea parameter. Once the terrain related parameters are calculated, the necessary correction

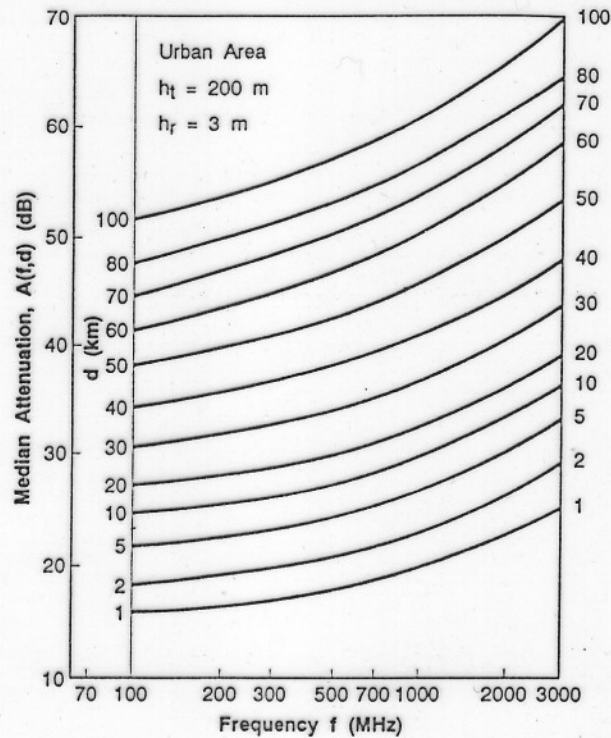


Figure 3.23

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

factors can be added or subtracted as required. All these correction factors are also available as Okumura curves [Oku68].

Okumura's model is wholly based on measured data and does not provide any analytical explanation. For many situations, extrapolations of the derived curves can be made to obtain values outside the measurement range, although the validity of such extrapolations depends on the circumstances and the smoothness of the curve in question.

Okumura's model is considered to be among the simplest and best in terms of accuracy in path loss prediction for mature cellular and land mobile radio systems in cluttered environments. It is very practical and has become a standard for system planning in modern land mobile radio systems in Japan. The major disadvantage with the model is its slow response to rapid changes in terrain, therefore the model is fairly good in urban and suburban areas, but not as good in rural areas. Common standard deviations between predicted and measured path loss values are around 10 dB to 14 dB.

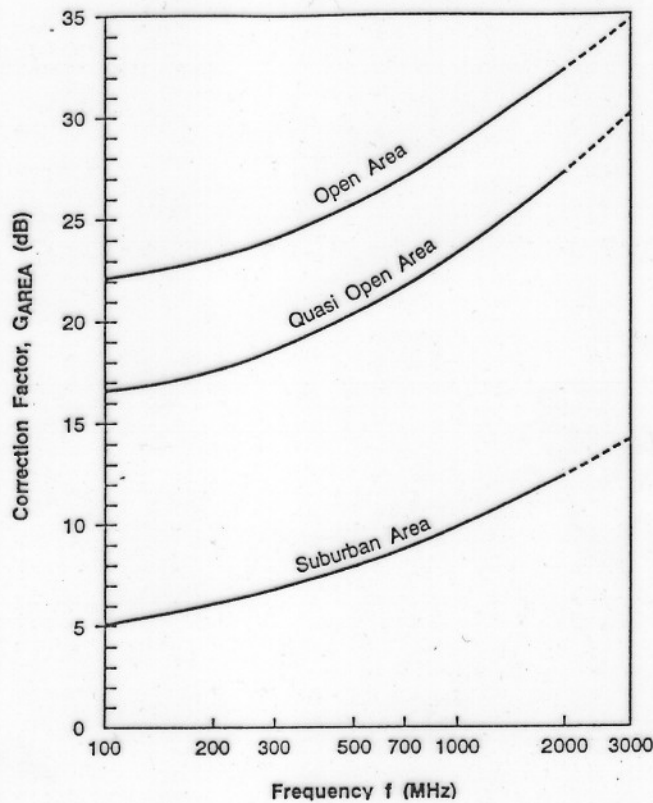


Figure 3.24
Correction factor, G_{AREA} , for different types of terrain [From [Oku68] © IEEE].

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 ^{median} 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

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

3.10.4 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

$$\begin{aligned} L_{50}(\text{urban})(\text{dB}) &= 69.55 + 26.16 \log f_c - 13.82 \log h_{te} - a(h_{re}) \\ &\quad + (44.9 - 6.55 \log h_{te}) \log d \end{aligned} \quad (3.82)$$

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

$$a(h_{re}) = (1.1 \log f_c - 0.7) h_{re} - (1.56 \log f_c - 0.8) \text{ dB} \quad (3.83)$$

and for a large city, it is given by

$$a(h_{re}) = 8.29 (\log 1.54 h_{re})^2 - 1.1 \text{ dB} \quad \text{for } f_c \leq 300 \text{ MHz} \quad (3.84.a)$$

$$a(h_{re}) = 3.2 (\log 11.75 h_{re})^2 - 4.97 \text{ dB} \quad \text{for } f_c \geq 300 \text{ MHz} \quad (3.84.b)$$

To obtain the path loss in a suburban area the standard Hata formula in equation (3.82) is modified as

$$L_{50}(\text{dB}) = L_{50}(\text{urban}) - 2[\log(f_c/28)]^2 - 5.4 \quad (3.85)$$

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

$$L_{50}(\text{dB}) = L_{50}(\text{urban}) - 4.78(\log f_c)^2 + 18.33 \log f_c - 40.94 \quad (3.86)$$

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.

3.10.5 PCS Extension to Hata Model

The European Co-operative 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]

$$L_{50}(\text{urban}) = 46.3 + 33.9 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log d + C_M \quad (3.87)$$

where $a(h_{re})$ is defined in equations (3.83), (3.84.a), and (3.84.b) and

$$C_M = \begin{cases} 0 \text{ dB} & \text{for medium sized city and suburban areas} \\ 3 \text{ dB} & \text{for metropolitan centers} \end{cases} \quad (3.88)$$

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

$$\begin{aligned} f &: 1500 \text{ MHz to } 2000 \text{ MHz} \\ h_{te} &: 30 \text{ m to } 200 \text{ m} \\ h_{re} &: 1 \text{ m to } 10 \text{ m} \\ d &: 1 \text{ km to } 20 \text{ km} \end{aligned}$$

3.10.6 Walfisch and Bertoni Model

A model developed by Walfisch and Bertoni [Wal88] considers the impact of rooftops and building height by using diffraction to predict average signal strength at street level. The model considers the path loss, S , to be a product of three factors.

$$S = P_0 Q^2 P_1 \quad (3.89)$$

where P_0 represents free space path loss between isotropic antennas given by

$$P_0 = \left(\frac{\lambda}{4\pi R} \right)^2 \quad (3.90)$$

The factor Q^2 gives the reduction in the rooftop signal due to the row of buildings which immediately shadow the receiver at street level. The P_1 term is