EE6604
Personal & Mobile Communications

Week 8

Path Loss Models

Okumura-Hata Model

$$L_p = \begin{cases} A + B\log_{10}(d) & \textbf{for urban area} \\ A + B\log_{10}(d) - C & \textbf{for suburban area} \\ A + B\log_{10}(d) - D & \textbf{for open area} \end{cases}$$

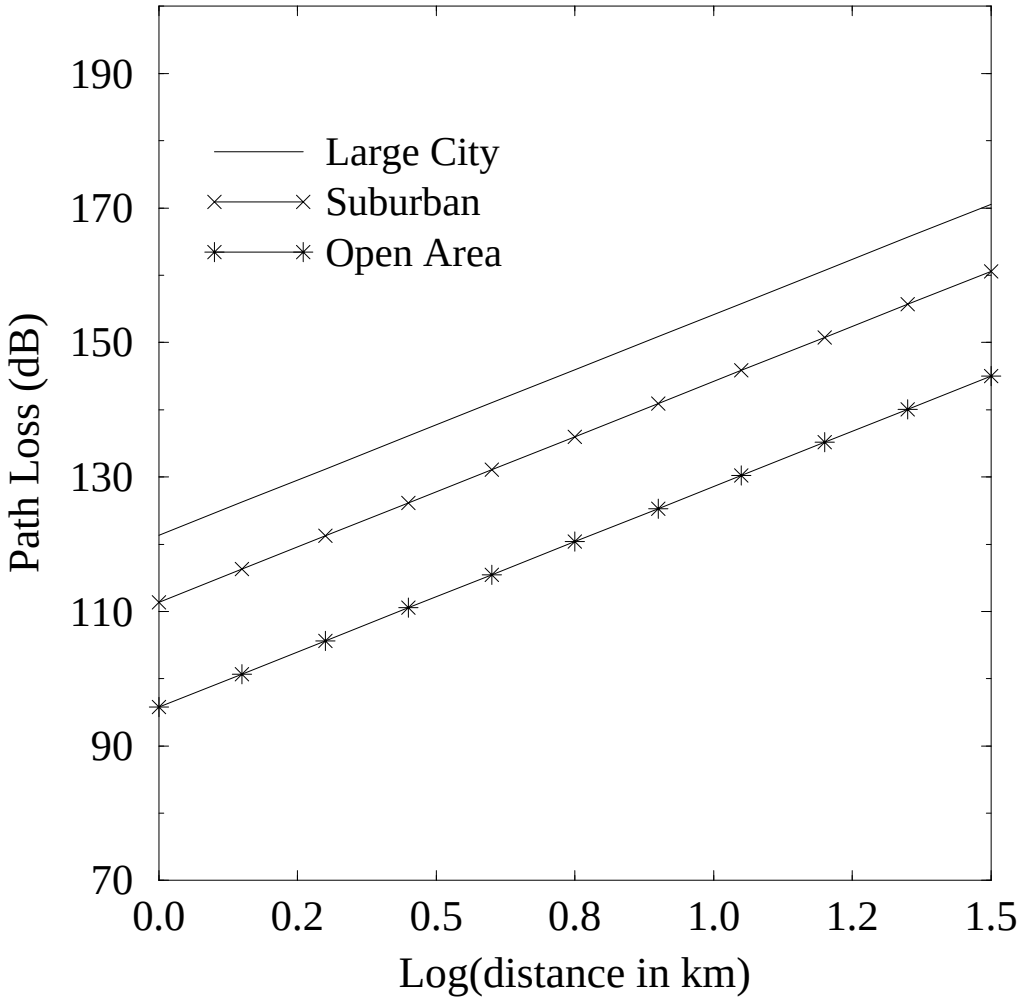
where

$$\begin{aligned} A &= 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - a(h_m) \\ B &= 44.9 - 6.55\log_{10}(h_b) \\ C &= 5.4 + 2\left[\log_{10}(f_c/28)\right]^2 \\ D &= 40.94 + 4.78\left[\log_{10}(f_c)\right]^2 - 19.33\log_{10}(f_c) \end{aligned}$$

- **Okumura and Hata's model is in terms of**
  - **carrier frequency** $150 \le f_c \le 1000$ **(MHz)**
  - **BS antenna height** $30 \le h_b \le 200$ **(m)**
  - **MS antenna height** $1 \le h_m \le 10$ **(m)**
  - **distance** $1 \le d \le 20$ **(km) between the BS and MS.**
- **The model is known to be accurate to within 1 dB for distances ranging from 1 to 20 km.**

- **The parameter $a(h_m)$ is a "correction factor"**

$$a(h_m) = \begin{cases} (1.1\log_{10}(f_c) - 0.7)\, h_m - (1.56\log_{10}(f_c) - 0.8) \\ \qquad\qquad\qquad\qquad \textbf{for medium or small city} \\ \begin{cases} 8.28\,(\log_{10}(1.54 h_m))^2 - 1.1 & \textbf{for } f_c \leq 200 \textbf{ MHz} \\ 3.2\,(\log_{10}(11.75 h_m))^2 - 4.97 & \textbf{for } f_c \geq 400 \textbf{ MHz} \end{cases} \\ \qquad\qquad\qquad\qquad \textbf{for large city} \end{cases}$$



Path loss predicted by the Okumura-Hata model. Large city, $f_c = 900$ *MHz,* $h_b = 70$ *m,* $h_m = 1.5$ *m.*

CCIR Model

- **To account for varying degrees of urbanization, the CCIR (Comité International des Radio-Communication, now ITU-R) developed an empirical model for the path loss as:**

$$L_{p\ (\mathrm{dB})} = A + B\log_{10}(d) - E$$

where A and B are defined in the Okumura-Hata model with $a(h_m)$ being the medium or small city value.

- **The parameter E accounts for the degree of urbanization and is given by**

$$E = 30 - 25\log_{10}(\%\text{ of area covered by buildings})$$

where $E = 0$ when the area is covered by approximately 16% buildings.

Lee's Area-to-area Model

- **Lee's area-to-area model is used to predict a path loss over flat terrain. If the actual terrain is not flat, e.g., hilly, there will be large prediction errors.**
- **Two parameters are required for Lee's area-to-area model; the power at a 1 mile (1.6 km) point of interception, $\mu_{\Omega_p}(d_o)$, and the path-loss exponent, β.**
- **The received signal power at distance d can be expressed as**

$$\mu_{\Omega_p}(d) = \mu_{\Omega_p}(d_o)\left(\frac{d}{d_o}\right)^{-\beta}\left(\frac{f}{f_o}\right)^{-n}\alpha_0$$

or in decibel units

$$\mu_{\Omega_p\ (\mathrm{dBm})}(d) = \mu_{\Omega_p\ (\mathrm{dBm})}(d_o) - 10\beta\log_{10}\left(\frac{d}{d_o}\right) - 10n\log_{10}\left(\frac{f}{f_o}\right) + 10\log_{10}\alpha_0 \quad ,$$

where d is in units of kilometers and $d_o = 1.6$ km.

- **The parameter α_0 is a correction factor used to account for different BS and MS antenna heights, transmit powers, and antenna gains.**

Lee's Area-to-area Model

- **The following set of *nominal* conditions are assumed in Lee's area-to-area model:**
  - **frequency $f_o = 900$ MHz**
  - **BS antenna height = 30.48 m**
  - **BS transmit power = 10 watts**
  - **BS antenna gain = 6 dB above dipole gain**
  - **MS antenna height = 3 m**
  - **MS antenna gain = 0 dB above dipole gain**
- **If the actual conditions are different from those listed above, then we compute the following parameters:**

$$\alpha_1 = \left(\frac{\textbf{BS antenna height (m)}}{30.48 \text{ m}}\right)^2$$

$$\alpha_2 = \left(\frac{\textbf{MS antenna height (m)}}{\textbf{3 m}}\right)^{\kappa}$$

$$\alpha_3 = \frac{\textbf{transmitter power}}{10 \textbf{ watts}}$$

$$\alpha_4 = \frac{\textbf{BS antenna gain with respect to } \lambda_c/2 \textbf{ dipole}}{4}$$

$$\alpha_5 = \textbf{different antenna-gain correction factor at the MS}$$

Lee's Area-to-area Model

- **The parameters β and $\mu_{\Omega_p}(d_o)$ have been found from empirical measurements, and are listed in the Table below.**

Terrain	$\mu_{\Omega_p}(d_o)$ **(dBm)**	β
Free Space	**-45**	**2**
Open Area	**-49**	**4.35**
North American Suburban	**-61.7**	**3.84**
North American Urban (Philadelphia)	**-70**	**3.68**
North American Urban (Newark)	**-64**	**4.31**
Japanese Urban (Tokyo)	**-84**	**3.05**

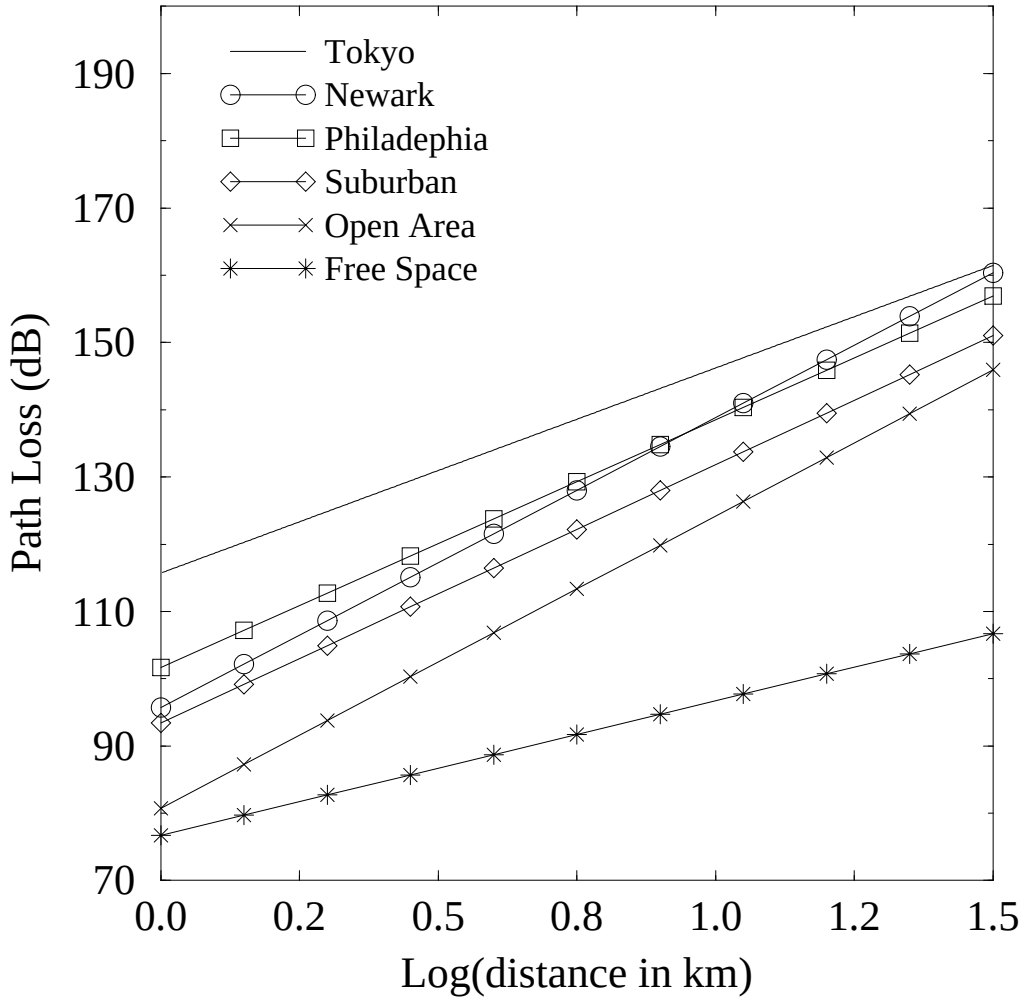
- **For $f_c < 450$ MHz in a suburban or open area, $n = 2$ is recommended. In an urban area with $f_c > 450$MHz, $n = 3$ is recommended.**
- **The value of κ in is also determined from empirical data as**

$$\kappa = \begin{cases} 2 \text{ for a MS antenna height } > 10 \text{ m} \\ 3 \text{ for a MS antenna height } < 3 \text{ m} \end{cases} .$$

Lee's Area-to-area Model

- **The path loss $L_{p\ (\mathrm{dB})}$ is the difference between the transmitted and received field strengths, $L_{p\ (\mathrm{dB})} = \mu_{\Omega_{p\ (\mathrm{dBm})}}(d) - \mu_{\Omega_{t\ (\mathrm{dBm})}}$.**
- **To compare directly with the Okumura-Hata model, we assume an isotropic BS antenna with 0 dB gain, so that $\alpha_4 = -6$ dB.**
- **Then by using the same parameters as before, $h_b = 70$ m, $h_m = 1.5$m, $f_c = 900$ MHz, a nominal BS transmitter power of 40 dBm (10 watts), and the parameters in the Table for $\mu_{\Omega_{p\ (\mathrm{dBm})}}(d_o)$ and β, the following path losses are obtained:**

$$L_{p\ (\mathrm{dB})} = \begin{cases} 85.74 + 20.0 \log_{10} d & \textbf{Free Space} \\ 84.94 + 43.5 \log_{10} d & \textbf{Open Area} \\ 98.68 + 38.4 \log_{10} d & \textbf{Suburban} \\ 107.31 + 36.8 \log_{10} d & \textbf{Philadelphia} \\ 100.02 + 43.1 \log_{10} d & \textbf{Newark} \\ 122.59 + 30.5 \log_{10} d & \textbf{Tokyo} \end{cases}$$



Path loss obtained by using Lee's method; $h_b = 70\ m$, $h_m = 1.5\ m$, $f_c = 900\ Mhz$, *and an isotropic BS antenna.*

COST231-Hata Model

- **COST231 models are for propagation in the PCS band.**
- **Path losses experienced at 1845 MHz are about 10 dB larger than those experienced at 955 MHz.**
- **The COST-231 Hata model for NLOS propagation is**

$$L_p = A + B\log_{10}(d) + C$$

where

$$\begin{aligned} A &= 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_b) - a(h_m) \\ B &= 44.9 - 6.55\log_{10}(h_b) \\ C &= \begin{cases} 0 & \textbf{medium city and suburban areas} \\ & \quad \textbf{with moderate tree density} \\ 3 & \textbf{for metropolitan centers} \end{cases} \end{aligned}$$

COST231-Walfish-Ikegami LOS Model

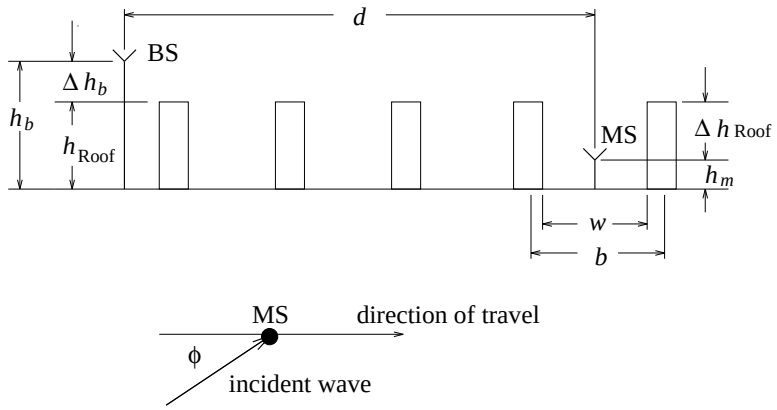
- **For LOS propagation in a street canyon, the path loss is**

$$L_p = 42.6 + 26\log_{10}(d) + 20\log_{10}(f_c), \quad d \geq 20\ m$$

  where the first constant is chosen so that L_p is equal to the free-space path loss at a distance of 20 m.

- **The model parameters are the distance d (km) and carrier frequency f_c (MHz).**

COST231-Walfish-Ikegami NLOS Model



Definition of parameters used in the COST231-Walfish-Ikegami model.

- **For NLOS propagation, the path loss is composed of three terms, viz.,**

$$L_p = \begin{cases} L_o + L_{\text{rts}} + L_{\text{msd}} & \textbf{for } L_{\text{rts}} + L_{\text{msd}} \geq 0 \\ L_o & \textbf{for } L_{\text{rts}} + L_{\text{msd}} < 0 \end{cases}$$

  - **The free-space loss is**

$$L_o = 32.4 + 20\log_{10}(d) + 20\log_{10}(f_c)$$

  - **The roof-top-to-street diffraction and scatter loss is**

$$L_{\text{rts}} = -16.9 - 10\log_{10}(w) + 10\log_{10}(f_c) + 20\log_{10}\Delta h_m + L_{\text{ori}}$$

where

$$\begin{aligned} L_{\text{ori}} &= \begin{cases} -10 + 0.354(\phi)\ , & 0 \leq \phi \leq 35^{\text{o}} \\ 2.5 + 0.075(\phi - 35)\ , & 35 \leq \phi \leq 55^{\text{o}} \\ 4.0 - 0.114(\phi - 55)\ , & 55 \leq \phi \leq 90^{\text{o}} \end{cases} \\ \Delta h_m &= h_{\text{Roof}} - h_m \end{aligned}$$

- **The multi-screen diffraction loss is**

$$L_{\text{msd}} = L_{\text{bsh}} + k_a + k_d \log_{10}(d) + k_f \log_{10}(f_c) - 9\log_{10}(b)$$

where

$$L_{\text{bsh}} = \begin{cases} -18\log_{10}(1+\Delta h_b) & h_b > h_{\text{Roof}} \\ 0 & h_b \le h_{\text{Roof}} \end{cases}$$

$$k_a = \begin{cases} 54\ , & h_b > h_{\text{Roof}} \\ 54 - 0.8\Delta h_b\ , & d \ge 0.5\textbf{km and } h_b \le h_{\text{Roof}} \\ 54 - 0.8\Delta h_b d/0.5\ , & d < 0.5\textbf{km and } h_b \le h_{\text{Roof}} \end{cases}$$

$$k_d = \begin{cases} 18\ , & h_b > h_{\text{Roof}} \\ 18 - 15\Delta h_b/h_{\text{Roof}}\ , & h_b \le h_{\text{Roof}} \end{cases}$$

$$k_f = -4 + \begin{cases} 0.7(f_c/925 - 1)\ , & \textbf{medium city and suburban} \\ 1.5(f_c/925 - 1)\ , & \textbf{metropolitan area} \end{cases}$$

and

$$\Delta h_b = h_b - h_{\text{Roof}}\ .$$

- **k_a is the increase in path loss for BS antennas below the roof tops of adjacent buildings.**
- **k_d and k_f control the dependency of the multi-screen diffraction loss on the distance and frequency, respectively.**
- **The model is valid for the following ranges of parameters,** $800 \leq f_c \leq 2000$ **(MHz),** $4 \leq h_b \leq 50$ **(m),** $1 \leq h_m \leq 3$ **(m), and** $0.02 \leq d \leq 5$ **(km).**
- **The following default values are recommended,** $b = 20 \ldots 50$ **(m),** $w = b/2$**,** $\phi = 90^{\mathrm{o}}$**, and** $h_{\mathrm{Roof}} = 3 \times$ **number of floors** $+ \mathrm{roof}$ **(m), where** $\mathrm{roof} = 3$ **(m) pitched and 0 (m) flat.**