EE6604
Personal & Mobile Communications

Week 8
Path Loss Models
Okumura-Hata Model

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

where

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

- Okumura and Hata’s model is in terms of
  - carrier frequency \( 150 \leq f_c \leq 1000 \) (MHz)
  - BS antenna height \( 30 \leq h_b \leq 200 \) (m)
  - MS antenna height \( 1 \leq h_m \leq 10 \) (m)
  - distance \( 1 \leq d \leq 20 \) (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”

$$a(h_m) = \begin{cases} 
(1.1 \log_{10}(f_c) - 0.7) h_m - (1.56 \log_{10}(f_c) - 0.8) \\
8.28 (\log_{10}(1.54 h_m))^2 - 1.1 \quad \text{for } f_c \leq 200 \text{ MHz} \\
3.2 (\log_{10}(11.75 h_m))^2 - 4.97 \quad \text{for } f_c \geq 400 \text{ MHz} 
\end{cases}$$

for medium or small city

for large city
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:

\[ L_p \text{ (dB)} = A + B \log_{10}(d) - E \]

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, $\beta$.

• 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

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

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

• The parameter $\alpha_0$ 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:
  \[
  \alpha_1 = \left(\frac{\text{BS antenna height (m)}}{30.48 \text{ m}}\right)^2 \\
  \alpha_2 = \left(\frac{\text{MS antenna height (m)}}{3 \text{ m}}\right)^\kappa \\
  \alpha_3 = \frac{\text{transmitter power}}{10 \text{ watts}} \\
  \alpha_4 = \frac{\text{BS antenna gain with respect to } \lambda_c/2 \text{ dipole}}{4} \\
  \alpha_5 = \text{different antenna-gain correction factor at the MS}
  \]
Lee’s Area-to-area Model

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

<table>
<thead>
<tr>
<th>Terrain</th>
<th>$\mu_{\Omega_p}(d_o)$ (dBm)</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Space</td>
<td>-45</td>
<td>2</td>
</tr>
<tr>
<td>Open Area</td>
<td>-49</td>
<td>4.35</td>
</tr>
<tr>
<td>North American Suburban</td>
<td>-61.7</td>
<td>3.84</td>
</tr>
<tr>
<td>North American Urban (Philadelphia)</td>
<td>-70</td>
<td>3.68</td>
</tr>
<tr>
<td>North American Urban (Newark)</td>
<td>-64</td>
<td>4.31</td>
</tr>
<tr>
<td>Japanese Urban (Tokyo)</td>
<td>-84</td>
<td>3.05</td>
</tr>
</tbody>
</table>

- 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 $\kappa$ 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 $L_p \text{ (dB)}$ is the difference between the transmitted and received field strengths, $L_p \text{ (dB)} = \mu_{\Omega_p \text{ (dBm)}}(d) - \mu_{\Omega_t \text{ (dBm)}}$.

- 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 $\mu_{\Omega_p \text{ (dBm)}}(d_o)$ and $\beta$, the following path losses are obtained:

$$L_p \text{ (dB)} = \begin{cases} 85.74 + 20.0 \log_{10} d & \text{Free Space} \\ 84.94 + 43.5 \log_{10} d & \text{Open Area} \\ 98.68 + 38.4 \log_{10} d & \text{Suburban} \\ 107.31 + 36.8 \log_{10} d & \text{Philadelphia} \\ 100.02 + 43.1 \log_{10} d & \text{Newark} \\ 122.59 + 30.5 \log_{10} d & \text{Tokyo} \end{cases}$$
Path loss obtained by using Lee’s method; $h_b = 70\, \text{m}$, $h_m = 1.5\, \text{m}$, $f_c = 900\, \text{MHz}$, 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

\[
A = 46.3 + 33.9 \log_{10}(f_c) - 13.82 \log_{10}(h_b) - a(h_m)
\]

\[
B = 44.9 - 6.55 \log_{10}(h_b)
\]

\[
C = \begin{cases} 
0 & \text{medium city and suburban areas} \\
1 & \text{with moderate tree density} \\
3 & \text{for metropolitan centers}
\end{cases}
\]
COST231-Walfish-Ikegami LOS Model

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

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

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.,

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

- 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

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

where

\[ L_{ori} = \begin{cases} 
-10 + 0.354(\phi) , & 0 \leq \phi \leq 35^\circ \\
2.5 + 0.075(\phi - 35) , & 35 \leq \phi \leq 55^\circ \\
4.0 - 0.114(\phi - 55) , & 55 \leq \phi \leq 90^\circ 
\end{cases} \]

\[ \Delta h_m = h_{\text{Roof}} - h_m \]
The multi-screen diffraction loss is

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

where

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

\[
k_a = \begin{cases} 
54 , & h_b > h_{Roof} \\
54 - 0.8\Delta h_b , & d \geq 0.5\text{km and } h_b \leq h_{Roof} \\
54 - 0.8\Delta h_b d/0.5 , & d < 0.5\text{km and } h_b \leq h_{Roof} 
\end{cases}
\]

\[
k_d = \begin{cases} 
18 , & h_b > h_{Roof} \\
18 - 15\Delta h_b / h_{Roof} , & h_b \leq h_{Roof} 
\end{cases}
\]

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

and

\[
\Delta h_b = h_b - h_{Roof} .
\]
• $k_a$ 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, $b = 20\ldots50$ (m), $w = b/2$, $\phi = 90^\circ$, and $h_{\text{Roof}} = 3 \times \text{number of floors} + \text{roof}$ (m), where $\text{roof} = 3$ (m) pitched and 0 (m) flat.