RF Propagation (Lecture 6)

Lee Model

* Popular model
* Extension of the log-distance path loss approach
* Relatively simple, yet reasonably accurate
* Initially developed for propagation around quartzes
* Over last decades, extensive field collection campaigns demonstrated
  model validity up to 2 GHz.
* Developed in mid-seventies as a result of large measurement campaigns - Bell Labs, New Jersey

Model parameters are provided relative to reference conditions

* Reference conditions (as used by WIZARD)

- Transmit power $P_{t, [\text{dBm}]} = 50 \text{ dBm} \quad (100W)$
- Tx antenna height $l_{tx} = 150 \text{ feet}$
- Rx antenna height $l_{rx} = 10 \text{ ft}$
- Reference distance $d_r = 1 \text{ mile} \quad (or \quad 1 \text{ km})$

Equation of Lee model - 2 forms

1) RSL Form

$$ RSL_{[\text{dBm}]} = \text{RSL}_{ref, [\text{dBm}]} - 10 \log \left( \frac{d}{d_r} \right) - \text{log distance part} $$

- $\left( E_{PP_{[\text{dBm}]} - P_{t, [\text{dBm}]} \right) - \text{EPP complex part}$
- $+ C \log \left( \frac{l_{tx}}{l_{rx}} \right) - \text{effective antenna length}$
- $+ F \log \left( \frac{l_{tx}}{l_{rx}} \right) - \text{Rx height\mbox{-}combined}$
- $- K_{ED} + \text{clutter} + \text{Diffraction losses, clutter adjustment}$
Model parameter values

C = 15 - Effective antenna height multiplier
F = 10 - RX antenna height multiplier

RSllf - reference distance intercept (RSLL at reference distance)
M - slope in dB/dec
d - distance expressed in units (in km)

hTX - effective antenna height of the transmitter
hRX - effective antenna height of the receiver

X: The value is calculated using the slope model
X: The value is calculated using the absolute model

2) Path Loss Form

\[ PL(d) [\text{dB}] = PL_{0} [\text{dB}] + M \log(d/d_0) - 10 \log \text{distance} \]

\[ -C \log \left( \frac{h_{RX}}{h_{TX}} \right) \quad - \text{antenna height correction} \]

\[ -F \log \left( \frac{h_{TX}}{h_{RX}} \right) \]

\[ + KED + \text{clutter} \quad - KED & \text{clutter adjustments} \]

Slope and intercept values at 850 MHz

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Open area</td>
<td>-50.5</td>
<td>100</td>
<td>48.5</td>
</tr>
<tr>
<td>Suburban</td>
<td>-74</td>
<td>109</td>
<td>38.4</td>
</tr>
<tr>
<td>Urban</td>
<td>-63</td>
<td>118</td>
<td>40</td>
</tr>
<tr>
<td>Dense urban</td>
<td>-74</td>
<td>124</td>
<td>43.1</td>
</tr>
</tbody>
</table>
Example 1: Consider a transducer with the following parameters: ERP = 52 dBm, 
\( \text{ln}_{m} = 175 \text{ feet} \). Assume that the height of the RX is 10 feet. If the transducer is in the suburban environment, calculate RSL at the distance of 2.6 miles. Use standard reference conditions and \( f = 850 \text{ MHz} \).

\[
\text{RSL[dBm]} = \text{RSL}_{\text{ref}}[\text{dBm}] - 10 \log(d/\text{mi}) + 15 \log(\text{ln}_{m}/\text{ln}_{x}) + 10 \log(\text{ERP}[\text{dBm}]) - P_{\text{rx}}
\]

\[
= -50 \text{ dBm} - 38.4 \log(2.6/1) + 15 \log(175/150) + 10 \log(10/10) + (52 - 50)
\]

\[
\approx -70 \text{ dBm}
\]

Example 2: Consider a transducer in a suburban environment. The height of the transducer is 120 feet. Effective calculate required transducer ERP such that it is capable of providing RSL of -50 dBm at the distance of d = 6.4 miles. The height of the RX is 5 feet and \( f = 850 \text{ MHz} \).

\[
\text{RSL[dBm]} = \text{RSL}_{\text{ref}}[\text{dBm}] - 10 \log(d/\text{mi}) + 15 \log(\text{ln}_{m}/\text{ln}_{x}) + 10 \log(\text{ERP}[\text{dBm}]) - P_{\text{rx}}
\]

\[
-80 \text{ dBm} = -50 \text{ dBm} - 38.4 \log(6.4/1) + 15 \log(120/150) + 10 \log(6/10) + (\text{ERP} - 50)
\]

\[
\Rightarrow \text{ERP} \approx 53 \text{ dBm} \quad (P_{\text{rx}} \approx 200 \text{W})
\]
Frequency dependence of line model parameters.

Slope - usually assumed as constant over wide range of frequencies.

Intercept

\[
 \text{DSL}_{\text{inter}}(f_2) = \text{DSL}_{\text{inter}}(f_1) + 20 \times \log \left[ \frac{f_1}{f_2} \right] (\ast)
\]

Default intercepts \((\nu = 2)\)

<table>
<thead>
<tr>
<th>Environment</th>
<th>(f = 150\text{ Hz})</th>
<th>(450\text{ Hz})</th>
<th>(850\text{ Hz})</th>
<th>(900\text{ Hz})</th>
<th>(1000\text{ Hz})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Space</td>
<td>-50.1</td>
<td>-39.6</td>
<td>-42.2</td>
<td>-45.7</td>
<td>-51.7</td>
</tr>
<tr>
<td>Open urban</td>
<td>-62.0</td>
<td>-52.0</td>
<td>-55.0</td>
<td>-58.5</td>
<td>-63.5</td>
</tr>
<tr>
<td>Suburban</td>
<td>-41.0</td>
<td>-52.0</td>
<td>-59.0</td>
<td>-64.5</td>
<td>-69.5</td>
</tr>
<tr>
<td>Urban</td>
<td>-46.0</td>
<td>-58.0</td>
<td>-63.0</td>
<td>-68.5</td>
<td>-74.5</td>
</tr>
<tr>
<td>Dense urban</td>
<td>-51.0</td>
<td>-67.0</td>
<td>-74.0</td>
<td>-74.5</td>
<td>-80.5</td>
</tr>
</tbody>
</table>

Note: default value for \(\nu\) in \((\ast)\) is 2.

Based on many measurements, use (2,3)

Example 2: Consider the transmittal in Example 1. How would the DSL value change if the frequency of operation is changed from 850 Hz to 1400 Hz. Assume \(\nu = 2\).

\[
\text{DSL}(f_2) = \text{DSL}(f_1) + 20 \times \log \left[ \frac{f_1}{f_2} \right] =
\]

\[
= -70\text{ dB}_w + 20 \times \log \left[ \frac{850}{1400} \right] =
\]

\[
= -77\text{ dB}_w
\]

Note: As the frequency increases, path loss increases and the DSL becomes lower.
Lee model uses slope method for the harswiler effective height

RSL predicted by the model

Note: When known upslopes = gain
when known downslopes = loss
Consider the situation given in the figure. \( f = 850 \text{ MHz} \)

Calculate RSL at the mobile.

\[
\text{Example: } E_{\text{PR}} = 53.1 \text{ dBw} \\
L_{\text{g}} = 100 \text{ ft} \\
\theta = 5^\circ \\
d_1 = 2 \text{ km} \\
d_2 = 1 \text{ km} \\
\theta = 5^\circ \\
\alpha = 10 \text{ ft} \\
\beta_1 = \alpha \tan \theta = 2 \text{ km} \cdot \tan \left( \frac{5^\circ}{100} \right) = 174.97 \text{ m} = 574.07 \text{ ft} \\
\theta = \beta_1 \\
\text{RSL} = \text{RSL}_{\text{ref}} - \alpha \log_2 \left( \frac{d}{d_{\text{ref}}} \right) + \\
( \cdot 10 \log \left( \frac{d}{d_{\text{ref}}} \right) + \text{Flux}\left( \frac{d}{d_{\text{ref}}} \right) + \text{EPP} - 50 = \\
= -59 - 36.4 \log \left( \frac{3}{100} \right) + \\
+15 \cdot \log \left( \frac{574.07 + 100}{150} \right) + 10 \log \left( 10/10 \right) + 53 - 50 \\
= -56.6 \text{ dBw} \\
\text{Due to upshifting of the femtocell the signal is received at a higher level.}
Okumura model

- One of the first broadly accepted models
- Developed in 60's as a result of large scale measurement campaign in Japan cities. Valid from 200 MHz to 1920 MHz.
- In broad use even today through one of its numerous modifications.

Model equation

Median path loss attenuation is given by

$$ l_{50} = l_{fs} + A_{wu} + H_{tu} + H_{ru} \quad \text{in dB} $$

- $l_{50}$ - median path loss between TX & RX - expressed in dB
- $l_{fs}$ - free space path loss in dB
- $A_{wu}$ - median attenuation - additional losses due to propagation in urban environment
- $H_{tu}$ - number of height correction factor
- $H_{ru}$ - receiver height correction factor

Note: Default environment for Okumura model is Urban environment.

$l_{fs}$ is calculated analytically

$$ l_{fs} = 32.44 + 20 \log f + 20 \log (d_{fms}) + 20 \log (d_{fms}) $$

- $f$ - Frequency in MHz
- $d$ - distance between TX & RX expressed in km

Factors $A_{wu}$, $H_{tu}$ & $H_{ru}$ are obtained from a set of curves published by Okumura.