Personal Communication Systems (Lecture 7)

Macroscopic propagation modeling

- Used to predict median path loss attenuation in terminal environment
- There are many macroscopic models available. They can be divided into two main categories.

1) Statistical Propagation Models
   - derived through statistical analysis of path loss measurements

a) Deterministic/Semi-deterministic models
   - Ray tracing

Statistical propagation models

1) Log distance path loss model

\[ PL_d = PL_{d0} + 10 \log \left( \frac{d}{d_0} \right) \]

Parameters \( PL_{d0} \) and \( 10 \) are Environment-dependent and usually determined through statistical analysis of path loss data measurements in a given environment.

* Note: straight line is the simplest way of fitting measurement points.
2) Empirical propagation models:

\[ PL(d) = F(d, h_{tx}, h_{rx}, f, clutter, obstacles, \ldots) \]

The idea is to use more complex equations to fit the measurement data in a better way. The data fitting process must not be too site specific, i.e., the fitting needs to be done so that the model is applicable to a wide range of propagation environments.

Example 1: Hata-Okumura model

Valid for: \( f \in (150 \text{ MHz} - 1500 \text{ MHz}) \) : Frequency range
\( h_{tx} \in (30 \text{ m} - 200 \text{ m}) \) : Effective base station height
\( h_{rx} \in (10 \text{ m} - 100 \text{ m}) \) : Effective mobile station height
\( d_0 = 1 \text{ km} \) : Reference distance

Equation: (For Urban area):

\[ PL(d) = 69.55 + 26.16 \log f - 13.82 \log h_{tx} + (44.9 - 6.55 \log h_{rx}) \log \frac{d_0}{d_0 - d_{tx}} \]

Three set of terms:

Term 1: \[ T_1 = 69.55 + 26.16 \log f - 13.82 \log h_{tx} \]

Note: effective horizon height obtained as the height at the radiation centreline above average terrain.
In original Okumura's work, $D_{mn} = 5 \text{ km}$ & $D_{max} = 15 \text{ km}$

For a given transmitte brightness & given direction beam $T_i$ becomes constant and should be compared with $P_{(0,0.1)}$ term of the log distance model.

![Diagram of path profile and signal strength](image)

- **Term 1:** $T_i = (44.9 - 6.55 \log d_e)$

This term specifies the increase in the path loss as a function of the log($d_e$). Therefore, it should be compared with the slope of the log distance model.

- **Hub - Okumura model has path loss slope that changes as a function of transmitter effective height**

- **Term 2:** $T_i = A(h_e) - \text{constant for mobile reception}$

\[ A(h_e) = (1.1 \log f - 0.7)\nu_m - (1.56 \log f - 0.8)\nu_s \] for small city

\[ A(h_e) = 8.21 (\log f) + 1.1 \] for $f_s \leq 300 \text{ MHz}$ & large city

\[ A(h_e) = 3.2 (\log f) - 4.97 \] for $f_s > 300 \text{ MHz}$
Basic Hata-Okumura model is given for urban environment. For other environments, Hata-Okumura modifies various constants.

For suburban environment

\[ P_l(d) = P_{\text{urban}}(d) - 2 \left[ \log \left( \frac{d}{d_0} \right) \right]^2 - 5.4 \]

For open rural environments

\[ P_l(d) = P_{\text{urban}}(d) - 478 \left[ \log \left( \frac{d}{d_0} \right) \right]^2 + 18.32 \log d + 10.98 \]

Even in the original work, Hata envisioned various constants for different properties of the propagation environment. Some of these are as follows:

* Sloping of the terrain
* Obstruction
* Street orientation
* Clutter
* Average height of buildings
* Etc.

This approach was followed by other authors as well. Therefore, typical propagation models use:

1) Basic correction - valid at the time and in most environments
2) Various constants for specific properties of the environment

Example: Consider a cell site with following properties:

- ERP = 50 dBm
- \( f_c = 900 \text{ MHz} \)
- \( h_m = 30 \text{ m} \)
- \text{ in urban environment of a small city}
Calculate RSL received by a mobile at a distance of 9 km.

\[ \text{RSL (dBm)} = \text{ERP (dBm)} - \text{PL (dBi)} \]

\[ \text{PL (dBi)} = 69.55 + 26.16 \log (d) - 13.82 \log (\lambda) + 44.9 - 6.65 \log (\lambda) \log (d) \]

\[ a(\lambda) = (1.1 \log P_e - 0.7) \log \lambda - (1.56 \log P_e - 0.8) \]

\[ = (1 \log 300 - 0.7) \log \lambda - (1.56 \log 300 - 0.8) = 0.015 \text{ dB} \approx 0 \]

\[ \text{PL (dBi)} = 69.55 + 26.16 \log (300) - 13.82 \log (300) + (44.9 - 6.65 \log (300)) \log (\lambda) \log (d) \]

\[ = 126 + 35.22 \log (\lambda) = 143.28 \text{ dB} \]

Therefore: \( \text{RSL (dBm)} = 50 \text{ dBm} - 143.28 \text{ dB} = -93.28 \text{ dBm} \)

**PCS extension of Hall Model**

* European regulatory/FCC recommends COST 231 extended Hall model to 2000 MHz.*

The set of equations is given as:

\[ \text{PL (dBi urban) = 46.3 + 38.9 log (d) - 13.82 log (\lambda) - a(\lambda) + 44.9 - 6.65 log (\lambda) \log (d) \log (\lambda)} \]

\[ a(\lambda) = 0 - \text{medium size city and suburban areas} \]

\[ -13.08 - \text{for metropolitan centers} \]

\[ \text{dBm} \]
Other schemes are done in the same manner as in the original
two-antenna model.

Example: Consider a system deployed in 1900 MHz band. The
following numerical data are known:

\[ E_{LP} = 50 \text{ dBm} \quad \text{radiated power of the base station} \]
\[ L_{Bn} = 20 \text{ m} \quad \text{length of the cable} \]
\[ L_{Wn} = 65 \text{ m} \quad \text{height of the antenna} \]

Required road reliability = 90% \quad \text{6 = 8 dB}

Required RSL = -90 dBm

Calculate required cell radius of a cell in urban environment using
Hata-Okumura propagation model.

1) Fade margin calculation

\[ L_{2} = 44.9 - 6.55 \log L_{Bn} = 44.9 - 6.55 \log (30) = 35.22 \]
\[ H = 3.52 \]

Thus \[ \frac{H}{n} = 8.0 / 3.52 = 2.27 \]

Using FH table: \( z = 0.6957 \)

Thus \[ \Delta = 0.6957 \times 8 = 5.56 \text{ dB} \]

\[ RSL_{P} = RSL + \Delta = -84.42 \text{ dBm} \]
1. Nominal cell radius

\[ PL[dB] = ERP dBm - RL dBi = \]
\[ = -134.43 \, dB \]

\[ PL[dB] = 46.3 + 33.9 \log f - 13.2 \log \text{h} \text{ue} + (4.4 - 6.15 \log \text{h} \text{ue}) \log \left( \frac{d}{3} \right) - 9(\text{he}) \]

In Kus's case

\[ 134.43 = 46.3 + 33.9 \log (130) - 13.2 \log (100) + 3.22 \log (d/\text{km}) \]

\[ \Rightarrow d/\text{km} \approx 0.0124 \, \text{km}. \]

Other commonly used propagation models:

1. Lee model
2. Longley-Rice model
3. Cle veree angle model
4. In the text book = Dr. Dunkin's model
5. Walfish-Brown model

Numerous propagation models either derived separately or as enhancements of the other listed models.