ITCE417: Mobile and Wireless Networking

LAB2: Mobile Radio Channel Propagation and Path Loss Calculation

1.1 Introduction

Radio-frequency propagation is fuzzy in multipath environments because of irregular terrain, RF barriers, and scattering phenomena. The performance of mobile communication systems is limited by the radio channel, and the transmission path between transmitter and receiver varies randomly from simple line of sight (LOS) to one obstructed severely by building and foliage [3]. Most cellular radio system operates in urban environment there is no direct wave at the receiver. Rather, an integrated wave resulting from diffraction, reflection, and scattering from various obstacles (buildings, moving objects, etc.).

Propagation models traditionally focus on the prediction of signal strength at the receiver, and distance (*d*) between transmitter and receiver plays the most critical role on the received signal strength. **Figure 1.1** illustrates a typical point-to-point mobile wireless communication system. A very common thing that could come in mind is what would be the distance *d* that can provide good received signal quality, and the relevant factors that influence largely to increase *d* the longest possible so as to increase cell coverage and consequently cost from investment. The simplistic answer is to increase transmit power. However, increasing transmit power causes additional interference such as intra-cell interference, inter-cell interference.

In this experiment, we focus on changes in the system parameters (other than transmit power) that result in increasing separation distance *d*, i.e. cell coverage. We will primarily carry out the impact of carrier frequency *f (MHz)* and distance *d (km) on* path loss. In addition, sensitivity analysis that provides critical parameters in the system with most impact on *d* is incorporated for the system design and planning purpose

We consider the very optimistic *Free-space* model, the very pessimistic *ITU-R* model, and the more realistic *Hata* model. All models are conceptually and analytically described, followed by respective simulation performance evaluation. We finish this experiment with a comparison of these path loss model simulation results in graph using the computational tool SCILAB.

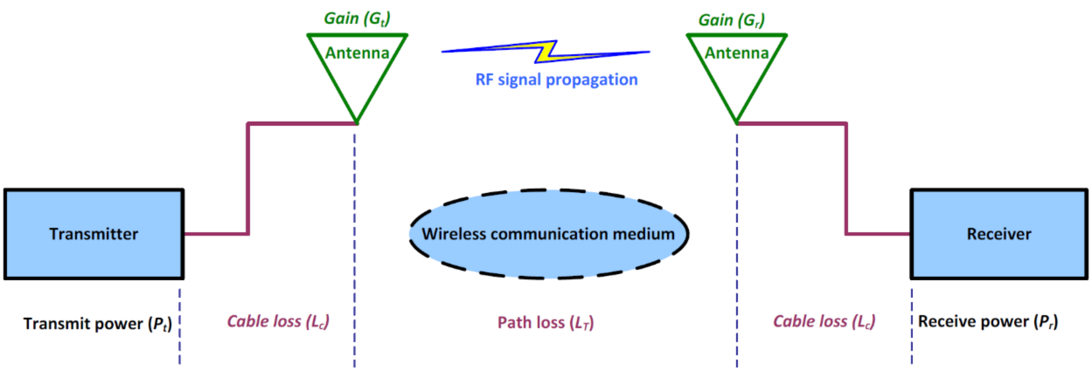

Figure 1.1: A typical mobile wireless communication system.

1.2 System Model

1.2.1 Free-space model

Free-space model is the simplest path loss model that takes only frequency (*f*) and distance (*d*) into account. In free-space (no obstacles and atmospheric effects) propagation, the received signal power is given by

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\Pi d}\right)^2 \quad (1.3)$$

where, P_r represents the received power,
P_t represents transmit power,
G_t and G_r represent gain of transmitter and receiver respectively, and
d is the distance between transmitter and receiver.

Equation 1.3 can be rewritten as follows for path loss.

$$L_{T-FS} = 32.45 + 20Log_{10}(d_{km}) + 20Log_{10}(f_{MHz}) \quad (1.4)$$

1.2.2 CCIR (ITU-R) model

This model takes terrain profile and its induced path loss into account in addition to the free space path loss and is given by

$$L_{ccir} = 69.55 + 26.16Log_{10}(f_{MHz}) - 13.82Log(h_b) - a(h_m) + [44.9 - 6.55Log_{10}(h_b)]Log_{10}(d_{km}) - B \quad (1.5)$$

where,
$a(h_m) = [1.1Log_{10}(f_{MHz}) - 0.7]h_m - [1.56Log_{10}(f_{MHz}) - 0.8]$
$B = (\%$ area covered by building$)$

So, the maximum distance in ITU-R model is given by

$$d_{ccir} = antiLog_{10}[P_t + G_T - P_r - 69.55 - 26.16Log_{10}(f_{MHz}) + 13.82Log(h_b) + a(h_m) + B] \Big/ [44.9 - 6.55Log_{10}(h_b)] \quad (1.6)$$

1.2.3 Hata Model

The Hata model is the empirical formulization of the graphical path loss information provided by Okumora [3]. It is based on ITU-R model and extensive measurements of urban as well as suburban radio propagation losses. This model provides a standard formula for path loss in **urban environment** and correction equations for other environments (suburban and rural as well) and is given by

$$L_{T-Hata}(urban) = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_{te} - a(h_{re}) + (44.9 - 6.55\log_{10} h_{te})\log_{10} d \quad (1.7)$$

where,
$L_{T\text{-}Hata}$: Hata path loss in dB,
f_c : carrier frequency in MHz (150-1500),
h_{te} (effective base station height), 30-200m,
h_{re} : mobile antenna height in m (1-10),
d : distance between transmitter and receiver in km, and
$a(h_{re})$: correction factor for effective mobile antenna height (function of the service area or city).

For small to medium sized city,

$$a(h_{re}) = (1.1\log_{10} f_c - 0.7)h_{re} - (1.56\log_{10} f_c - 0.8)dB$$

And for a large city,

$$a(h_{re}) = \{8.29(\log_{10} 1.54h_{re})^2 - 1.1\}dB \cdots (f_c \le 300MHz)$$
$$a(h_{re}) = [3.2\{\log_{10}(11.75h_{re})\}^2 - 4.97]dB \cdots (f_c > 300MHz)$$

For **suburban area**, the path loss is give by

$$L_{T-Hata} = L_{T-Hata}(urban) - 2[\log_{10}(f_c/28)]^2 - 5.4 \text{ dB} \quad (1.8)$$

For **open areas (rural),** the formula is modified as

$$L_{T-Hata} = L_{T-Hata}(urban) - 4.78(\log_{10} f_c)^2 + 18.33\log_{10} f_c - 40.98 \text{ dB} \quad (1.9)$$

Hence, the maximum distance in Hata model is given by

$$d_{Hata} = antiLog_{10}[P_t + G_T - P_r - 69.55 - 26.16\log_{10} f_c + 13.82\log_{10} h_{te} + a(h_{re})] \Big/ (44.9 - 6.55\log_{10} h_{te})$$

For higher carrier frequencies [2] of 1500 – 2000 MHz, the following modification of Hata model for urban area has been proposed.

$$L_{T-Hata}(urban) = 46.3 + 33.9\log_{10} f(MHz) - 13.82\log_{10} h_{te} - a(h_{re}) + (44.9 - 6.55\log_{10} h_{te})\log_{10} d + C \quad (1.10)$$

Additional correction factor, C = 0 dB for medium-sized cities and = 3 dB for metropolitan centers. These modified equations have been successfully used for cellular mobile network design at 1800 MHz band. However, it should be noted that (modified) Hata model is only valid for macrocell (d > 1 km) design. Note that in the aforementioned models, h_b and h_{te}, h_m and h_{re}, as well as $f\ (MHz)$ and fc are used interchangeably.

1.3 Simulation Experimental Procedure

1.3.1 Set values to simulation variables for path loss models as follows.

Free-space model

Carrier frequency, f *(MHz)* = 900 and 1800,
Transmit power P_t = 39 dBm,
Cable loss L_c= 4 dB (total),
Antenna gain G_t =28 dBi (total).

CCIR model

h_b=35 m,
h_m=1 m,
B=25% area is covered by buildings,
Carrier frequency, f *(MHz)* = 900 and 1800,
Transmit power P_t = 39 dBm,
Cable loss L_c= 4 dB (total),
Antenna gain G_t =28 dBi (total).

Hata model

h_b=35 m,
h_m=1 m,
Carrier frequency, f *(MHz)* = 900 and 1800,
Transmit power P_t = 39 dBm,
Cable loss L_c= 4 dB (total),
Antenna gain G_t =28 dBi (total),

for f *(MHz)* = 1800;
C = 0 dB for medium-sized cities,
= 3 dB for metropolitan area.

1.3.2 Simulation Algorithm

Path loss versus distance (cell coverage)

Step 1 define variables;
Step 2 set values for d_{max} , *f(MHz)*, P_t , L_c , G_t , h_b, h_m, $a(h_m)$, B;
Step 3 define path loss expressions for Free-space, CCIR, and Hata model (with various cases: urban, suburban, and rural);
Step 4 repeat step 2 up to $d=d_{max}$;
Step 5 plot *distance* versus *path losses* for all models and cases or display any result.

1.4 Discussion

Question 01

Plot the path loss as a function of distance for all considered models.

Question 02

Plot the received signal power *Pr* as a function of distance for all considered models. Assume transmit power *Pt = 39 dBm*, total antenna gain *Gt = 28 dBi (14 dBi* for each antenna: *Tx* and *Rx*), total cable loss *Lc = 4 dB (2 dB* at each side*; Tx and Rx).* Hint: use **Equation 1.1**.

Question 03

Write a discussion about the achieved results.

1.6 References

[1] **W. Debus**, "RF Path Loss & Transmission Distance Calculations", Technical Memorandum, Axonn LLC, August 4, 2006.

[2] **K. M. Ahmed**, "Cellular Mobile Systems" Lecture notes: AT77.07, Asian Institute of Technology, Thailand, January 2010.

[3] **R. K. Saha**, "A Report On Path Loss Models Used In Mobile Communications and a Comparative Analysis of these Models for Urban Case using Suitable Parameters**"** Report on AT77.07: Cellular Mobile Systems, Asian Institute of Technology, Thailand, January 2010.