1st Project in Advanced Topics in Antennas, Propagation of EMF fields, and Wireless Networks

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1. Introduction

The electromagnetic wave loses a proportion of its power density (attenuation) as it gets propagates from the transmitter to the receiver. Propagation models are often utilized to predict the mean power of the signal for a given distance between transmitter and receiver, which depends on:

- Environment (urban or rural areas)
- Distance
- Frequency
- Atmosphere conditions
- Indoor / Outdoor

➢ There are two general categories of propagation models:

Empirical Models (statistical): depend on empirical practices for measuring data, are simpler but not as accurate(e.g., Hata Model, Okumura Model, Cost 231 Model)

Physical Models (deterministic): these are a lot more accurate models (e.g., Ray tracing Model, Ikegami Model)[2]

➢ There are several types of propagation losses:

- *Path loss*: depends on the distance between transmitter and receiver

$$\mathrm{PL(d)} = \mathrm{PL}(d_0) + 10\mathrm{nlog}\frac{d}{d_0}$$

Important factor: ***path loss exponent (n)*** which depends on the type of environment in which the propagation takes place
- free space: n =2
- urban area: 2.7 ≤ n ≤ 3.5
- urban area with obstacles: 3 ≤ n ≤ 5
- inside buildings: 4 ≤ n ≤ 6

- *Shadowing*: caused by the traversal of the radio wave through and obstacle
Depends on:
- wavelength of the signal
- obstacle
- path distance inside the obstacle

$$Loss(dB) = 10\log\frac{(signal\ power\ before\ obstacle)}{(signal\ power\ after\ obstacle)}$$

- *Multipath*: because of the radio signal reaching the receiving antenna by two or more different paths (fading incidents). Every copy of the signal travels a different distance for reaching the receiver, thus different signal copies reach the receiving antenna with different phase. Hence, the different copies of the signal may be added or subtracted.

The overall propagation loss is estimated by considering the aforementioned three types of losses.

$$L_{total} = L_{path} + L_{shadowing} + L_{multipath} = 10\log_{10}(\frac{received\ signal\ power}{transmitted\ signal\ power})$$

2. Outdoor Propagation Models

1. Free Space Propagation Model

Line of Sight (***far field***)

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 d^2 L}$$ -> **received power density**

$$(\frac{P_t(d)}{P_r})_{dB} = -10\log(\frac{G_T G_R \lambda^2}{(4\pi)^2 d^2 L})$$ -> ***path loss***

Where:
P_R : receiver power
G_R : receiver antenna gain
P_T : transmitter power
G_T transmitter antenna gain
$\lambda = c/f_0$: carrier wave length
c: speed of light ($3\text{x}10^8$ m/s)
f_0 : carrier frequency
d: distance between receiver and transmitter
L: loss exponent (transmitter or receiver) [4]

Path Loss: the difference between transmitted and received power

Free Space Path Loss in dB:

$$FSPL = 20\log_{10}(d) + \log_{10}(f) - 145.55$$

d: distance in km
f: carrier frequency in Megahertz

2. Two-ray ground-reflection model

• One LOS path, one reflected path.

• At small distances, power falls off proportional to d^2 (free space loss on both paths).

• Above some critical distance dc, received power given by:

$$P_r \approx P_t \left[\frac{\sqrt{G} h_t h_r}{d^2}\right]^2$$

where G approximates the combined transmit and receiver gains of both multipath components.

• Above dc, power falls off proportional to d^4 and is independent of signal wavelength (frequency)

• Model not generally accurate for cities or indoors. [5]

2-Ray Path Loss

$$PL_{2-ray} = 40\log_{10}(d) - 10\log_{10}(G{h_{tr}}^2 {h_{tt}}^2)$$

d: distance in km
f: carrier frequency in Megahertz
h_{tt}: receiver antenna height in meters
$G(h_{tr})$: transmitter antenna height in dB

3. Μοντέλο Okumura – Hata

➢ Okumara's model is an empirical model for signal prediction in urban areas. [4]

Applicable for:
- *frequencies* -> 150 MHZ - 1920 MHZ (extended up to 3000MHZ)
- *base station antenna height* -> 30m – 100m
- *mobile station antenna height* -> 1m – 3m
- *distances* -> 1km - 100 km

Okumura Path Loss

$$PL_{ok}(50)(dB) = L_{FSPL} + A_{mu} - Gh_{tr} - Gh_{tt} - G_{area}$$

La: propagation loss of free space
A_{mu} is the median attenuation relative to free space
$G(h_{tr})$: base station antenna height gain factor in dB
$G(h_{tt})$: mobile antenna height gain factor in dB
G_{area}: gain due to the type of environment

$$where\ G(h_{tt}) = 10\log_{10}\frac{h_{tt}}{200}, \qquad for\ h_{tt} < 3m$$

$$G(h_{tt}) = 20\log_{10}\frac{h_{tt}}{200}, \qquad for\ 3m < h_{tt} < 10m$$

$$G(h_{tr}) = 20\log_{10}\frac{h_{tr}}{3}$$

- The Hata model is the empirical mathematical relationship to describe the graphical path loss data provided by Okumura's model. [2]
  Applicable for:
  - carrier frequency(fc): 150 MHZ - 1500 Megahertz
  - effective base station antenna height(h_{tr}): 30m - 200m
  - effective mobile antenna height(h_{tt}): 1m - 10m

Hata Path Loss

- For **urban** area:

$$PL_{HA}(\mathrm{dB}) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10} h_{tr} - \mathrm{a}(h_{tt}) + (44.9 - 6.55\log_{10} h_{tr}) * \log_{10} d$$

a(h_{tt}): correction factor for effective mobile antenna height in km

- *For small or medium-sized city*

$$a_{htt} = 0.8 + (1.1\log_{10} f - 0.7)h_{tt} - 1.56\log_{10} f$$

- *For large cities*

$$a_{htt} = 8.29(\log_{10}(1.54h_{tt}))^2 - 1.1, \quad if\ 150 \le f \le 200$$
$$a_{htt} = 3.2(\log_{10}(11.75h_{tt}))^2 - 4.97, \quad if\ 200 < f \le 1500$$

- For **suburban** area:

$$PL_{HA}(\mathrm{db}) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10} h_{tr} - \mathrm{a}(h_{tt}) + (44.9 - 6.55\log_{10} h_{tr}) * \log_{10} d - 5.4 + 2[\log_{10}(\frac{f}{28})]^2$$

where $a_{htt} = 0.8 + (1.1\log_{10} f - 0.7)h_{tt} - 1.56\log_{10} f$ (same as for the small city)

- For **open** area:

$$PL_{HA}(\mathrm{db}) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_{tr}) - \mathrm{a}(h_{tt}) + (44.9 - 6.55\log_{10}(h_{tr})) * \log_{10}(d) - 40.99 - 4.78\,[\log_{10}(f)]^2 + 18.33\log_{10}(f)$$

where $a_{htt} = 0.8 + (1.1\log_{10} f - 0.7)h_{tt} - 1.56\log_{10} f$ (same as for the small city)

f: carrier frequency in Megahertz
h_{tr}: base station antenna height in m
d: transmitter-receiver distance in km

This model gives the better result in urban and suburban area but in the rural areas its efficiency decreases. This model is not suitable for personal communication systems.

4. ECC 33 Model

The ECC model is electronics communication system developed for fixed wireless access systems. [1]

ECC 33 Path Loss

$$PL_{ECC}(dB) = A_{sf} + A_{mb} - G_d - G_s$$

$$\boldsymbol{where}$$

$A_{sf} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f)$, free space attenuation

$A_{mb} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56(\log_{10}(f))^2$, basic medium path loss

$G_d = \log_{10}(\frac{h_{tr}}{200})[13.958 + 5.8(\log_{10}(d))^2]$, base station antenna height gain factor

$G_s = [42.57 + 13.7(\log_{10}(f)][\log_{10}(h_{tt}) - 0.585]$, receiver antenna height gain factor

$$\boldsymbol{whereas\ for\ big\ cities}$$

$$G_s = 0.759h_{tt} - 1.862$$

f: is the frequency in Megahertz,
d: is the distance between transmitter and receiver in km,
h_{tr} is the BS antenna height in meters
h_{tt} is the CPE antenna height in meters.

5. Cost- 231 Hata Model

The COST-231 Hata model extended Hata's model for use in the 1.5-2MHZ frequency range. This model is used in base station antenna is above the roof tops and is widely used in radio transmission in mobile telephony. [1]

COST-231 Path Loss

$$PL_{231}(dB) = 46.3 + 33.9\log_{10}(f) - 13.28\log_{10}(h_{tr}) - a(h_{tt}) + 44.9 - 6.55\log_{10}(h_{tr}) + \log_{10}(d) + Cc$$

Cc =0, for medium city and suburban areas
Cc=3, for metropolitan areas
f: carrier frequency -> 1.5-2MHZ
h_{tr}: base station antenna height -> 30-200m
h_{tt}: mobile station antenna height -> 1-10m
d: transmission distance -> 1-20km

$a(h_{tt}) = 3.2\,(\log_{10}(11.75h_{tt}))^2 - 4.97$, for urban areas

$a(h_{tt}) = (1.1\log_{10}(f) - 0.7)h_{tt} - (1.56\log_{10}(f) - 0.8)$, for suburban and rural areas

6. Ericsson Model [1]

Ericsson Path Loss

$$PL = a_0 + a_1\log_{10}(d) + a_2\log_{10}(h_{tr}) + a_3\,(\log_{10}(h_{tr}))\,(\log_{10}(d)) - 3.2(\log_{10}(11.75h_{tr}))^2 + g(f)$$

where

$$g(f) = 44.49(\log_{10}(f) - 4.78\log_{10}(f))^2$$

d: distance between base station antenna and users in km
f: frequency in Gigahertz
h_{tr}: base station antenna height

Environment	a_0	a_1	a_2	a_3
Cities	36.2	30.2	12	0.1
Suburban	43.20	68.93	12	0.1
Villages	45.95	100.6	12	0.1

1. Indoor Propagation Models

The free space path loss model is not directly applicable to indoor propagation, but it is computed because it is needed to compute the path loss at a close-in reference distance

1. Log-Distance Path Loss

The log-distance path loss model assumes that path loss varies exponentially with distance. The path loss in dB is given by the equation [6]:

Log-Distance Path Loss

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma$$

n: path loss exponent,
d: is the distance between transmitter and receiver in meters
d_0: is the close-in reference distance in meters.
$PL(d_0)$: free space path loss.

The value d_0 should be selected such that it is in the far-field of the transmitting antenna, but still small relative to any practical distance used in the mobile communication system. The value of the path loss exponent n varies depending upon the environment.

Calculation of path loss exponent (n):

Building Type	**Frequency of Transmission**	**n**
Vacuum, Infinite Space		2.0
Retail Store	914 MHz	2.2
Grocery Store	914 MHz	1.8

Office with hard partition	1.5 GHz	3.0
Office with soft partition	900 MHz	2.4
Office with soft partition	1.9 GHz	2.6
Textile or chemical	1.3 GHz	2.0
Textile or chemical	4 GHz	2.1
Office	60 GHz	2.2
Commercial	60 GHz	1.7

X_σ is a normal (or Gaussian) random variable with zero mean, reflecting the attenuation in decibels caused by flat fading.

- In case of no-fading this variable is 0 and the equation becomes as in (1):

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\log(\frac{d}{d_0}) \quad (1)$$

- In case of only shadow fading or slow fading, X_σ has Gaussian distribution, whereas in case of only fast fading due to multipath propagation X_σ has Rayleigh or Ricean distribution, and thus the equation has the form of (2):

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma \quad (2)$$

2. ITU model for indoor attenuation

This model is applicable to only the indoor environments. Typically, such appliances use the lower microwave bands around 2.4 GHz. However, the model applies to a much wider range. [3]

ITU Path Loss

$$L_{ITU} = 20\log_{10}(f) + N\log_{10}(d) + P_f(n) - 28$$

f: carrier frequency in Megahertz
d: distance between transmitter in receiver in meters
N: distance power loss coefficient
n: number of floors between transmitter and receiver
$P_f(n)$: floor loss penetration factor

Calculation of distance power loss coefficient (N): [7]

Frequency Band	Residential Area	Office Area	Commercial Area
900 MHz	N/A	33	20
1.2 – 1.3 GHz	N/A	32	22
1.8 – 2.0 GHz	28	30	22
4 GHz	N/A	28	22
5.2 GHz	30 (apartment), 28 (house)	31	N/A
5.8 GHz	N/A	24	N/A
6.0 GHz	N/A	22	17

Calculation of floor penetration factor ($P_f(n)$): [7]

Frequency Band	Number of floors	Residential Area	Office Area	Commercial Area
900 MHz	1	N/A	9	N/A
900 MHz	2	N/A	19	N/A
900 MHz	3	N/A	24	N/A
1.8 – 2.0 GHz	n	4n	15+4(n-1)	6+3(n-1)
5.2 GHz	1	N/A	16	N/A
5.8 GHz	1	N/A	22 (1 floor), 28 (2 floors)	N/A

References

[1] Bengawan Alfaresi, Taufik Barlian, Feby Ardianto, and Muhammad Hurairah. 2020. Path Loss Propagation Evaluation and Modelling based ECC-Model in Lowland Area on 1800 MHz Frequency. *J. Robot. Control* 1, 5 (2020). DOI:https://doi.org/10.18196/jrc.1534

[2] V. Armoogum, K.M.S. Soyjaudah, N. Mohamudally, and T. Fogarty. 2010. Propagation Models and their Applications in Digital Television Broadcast Network Design and Implementation. *Intech* 32, (2010), 165–184. Retrieved from https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics

[3] Itu-R. 2012. Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz P Series Radiowave propagation. P Series R, (2012).

[4] Suraj Ram Kumar, Premchandra, Bhushan Patil. 2015. Selection of Radio Propagation Model for Long Term Evolution (LTE) Network. *Int. J. Eng. Res. Gen. Sci.* 3, 1 (2015), 373–379.

[5] Thomas Schwengler. 2019. Radio Propagation Modeling. Retrieved June 16, 2021 from http://morse.colorado.edu/~tlen5510/text/classwebch3.html

[6] Log-distance path loss model. Retrieved June 16, 2021 from https://en.wikipedia.org/wiki/Log-distance_path_loss_model

[7] ITU terrain model. Retrieved June 10, 2021 from https://en.wikipedia.org/wiki/ITU_terrain_model