City RF Propagation Models

Abstract:

Calculation of the path loss is usually called prediction. Exact prediction is possible only for simpler cases, such as the free space propagation or the flat-earth model, which is called deterministic methods. They based on the physical laws of wave propagation are also used; ray tracing is one such method. These methods are expected to produce more accurate and reliable predictions of the path loss than the empirical methods; however, they are significantly more expensive in computational effort and depend on the detailed and accurate description of all objects in the propagation space, such as buildings, roofs, windows, doors, and walls. For these reasons they are used predominantly for short propagation paths. Among the most commonly used methods in the design of radio equipment such as antennas and feeds is the finite-difference time-domain method. On the other hand, Statistical methods (also called stochastic or empirical) are based on measured and averaged losses along typical classes of radio links. Among the most commonly used such methods are COST-231, Okumura-Hata, W.C.Y.Lee, etc. The actual propagation of RF through an urban environment is dependent upon frequency, polarization, building geometry, material structure, orientation, height, and density. Statistical models are also known as radio wave propagation models and are typically used in the design of cellular networks and PLMN. For wireless communications in the VHF and UHF frequency band (the bands used walkie-talkies, police, taxis and cellular phones), one of the most commonly used methods is that of Okumura-Hata as refined by the COST-231 project. In addition to Hata and COST 231 are central to most commercial RF planning tools for mobile telephony. Other well-known models are those of Walfisch-Ikegami, W.C.Y. Lee, and Erceg. For FM radio and TV broadcasting the path loss is most commonly predicted using the ITU model.

1. Link budget Definition:

It is the accounting of all of the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in a telecommunication system. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains, feedline and miscellaneous losses. Randomly varying channel gains such as fading are taken into account by adding some margin depending on the anticipated severity of its effects. The amount of margin required can be reduced by the use of mitigating techniques such as antenna diversity or frequency hopping.

A simple link budget equation looks like this:

$$\text{Received Power (dBm)} = \text{Transmitted Power (dBm)} + \text{Gains (dB)} - \text{Losses (dB)}$$

Notice that decibels are logarithmic measurements, so adding decibels is equivalent to multiplying the actual numeric ratios.

1.1 Path Loss Exponent:

In the study of wireless communications, path loss can be represented by the path loss exponent, whose value is normally in the range of 2 to 4 (where 2 is for propagation in free space, 4 is for relatively lossy environments and for the case of full specular reflection from the earth surface -- the so-called flat-earth model). In some environments, such as buildings, stadiums and other indoor environments, the path loss exponent can reach values in the range of 4 to 6. On the other hand, a tunnel may act as a waveguide, resulting in a path loss exponent less than 2.

Path loss is usually expressed in dB. In its simplest form, the path loss can be calculated using the formula

$$L = 10\ n\ log_{10}(d) + C$$

where L is the path loss in decibels, n is the path loss exponent, d is the distance between the transmitter and the receiver, usually measured in meters, and C is a constant which accounts for system losses.

Environment	Path Loss Exponent n
Free Space	2
Urban area	2.7 to 3.5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6

Table 1: Path Loss Exponents for Different Environments.

1.2 Link budget for radio systems:

1.2.A For a line of sight radio system:

a link budget equation might look like this:

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX}$$

where:

P_{RX} = received power (dBm)

P_{TX} = transmitter output power (dBm)

G_{TX} = transmitter antenna gain (dBi)

L_{TX} = transmitter losses (coax, connectors...) (dB)

L_{FS} = free space loss or path loss (dB)

L_M = miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB)

G_{RX} = receiver antenna gain (dBi)

L_{RX} = receiver losses (coax, connectors...) (dB)

Communication links in free space have path losses that are the inverse square of the distance. The free space loss equation can be written in several equivalent ways depending on the units of measure. Here are some variations:

$$\text{FSL (dB)} = 20*\log[4*\pi*\text{distance/wavelength}]$$

(where distance and wavelength are in the same units)

$$\text{FSL (dB)} = 32.45 \text{ dB} + 20*\log[\text{frequency(MHz)}] + 20*\log[\text{distance(km)}]$$

$$\text{FSL (dB)} = -27.55 \text{ dB} + 20*\log[\text{frequency(MHz)}] + 20*\log[\text{distance(m)}]$$

$$\text{FSL (dB)} = 36.6 \text{ dB} + 20*\log[\text{frequency(MHz)}] + 20*\log[\text{distance(miles)}]$$

The inverse square law is independent of frequency, so one would expect path losses to also be constant with frequency. However, free space path loss is defined between isotropic antennas that have apertures that vary with the square of the wavelength. The apparent 6 dB increase of path loss with each octave (doubling) of frequency merely reflects this decrease in receive antenna aperture with increasing frequency. When a receive antenna of constant physical area receives a transmission from an isotropic antenna, the receive antenna gain increases 6 dB with each octave so the overall loss becomes independent of frequency. When antennas of constant physical area are used on both ends, the increase in total antenna gain is 12 dB per octave, so the net transmitter-to-receiver loss actually decreases 6 dB with each octave. This comes from the transmitting antenna being able to focus more of its power on the receive antenna.

Reception is reliable when RxP > receiver sensitivity

1.2.B Link budgets for non-line of sight radio:

Indoor deployments for example will refraction, reflection, multipath... etc.

1.3 Link budgets for other media:

Guided media such as coaxial and twisted pair electrical cable, radio frequency waveguide and optical fiber have losses that are exponential with distance. The path loss will be in terms of dB per unit distance. This means that there is always a crossover distance beyond which the loss in a guided medium will exceed that of a line-of-sight path of the same length. Long distance fiber-optic communication became practical only with the development of ultratransparent glass fibers. A typical path loss for single mode fiber is 0.2 dB/km, far lower than any other guided medium.

2. Radio Propagation Model:

It is a mathematical formulation for the characterization of radio wave propagation as a function of parameters like frequency, transmitter-receiver separation, dielectric constant of the propagation medium and heights of the transmitter and receiver. Created with the goal of formalizing the way radio waves are propagated from one place to another, a model typically predicts the path loss along a link or the effective coverage area of a transmitter.

Types of Radio Propagation Models

2.1 Deterministic models:

They are based on electric field calculations. Parameters such as transmitter height, receiver height, transmitter and receiver separation, propagation constant and terrain information of the environment are used as inputs in the calculations. These models require extensive calculations and hence involve large processing power and time. They also require a very large amount of terrain data. However, the results are accurate and very close to the actual propagation environment. Exact prediction is possible only for simpler cases, such as the free space propagation or the flat-earth model.

2.2 Empirical models:

They are based on large collections of data collected for the specific scenario. For any model, the collection of data has to be sufficiently large to provide enough likeliness (or enough scope) to all kind of situations that can happen in that specific scenario. Like all empirical models, radio propagation models do not point out the exact behavior of a link, rather, they predict the most likely behavior the link may exhibit under the specified conditions. We will go deep about City Models in this papers.

3. City models:

It is also called Modeling of Built-Up Areas. The actual propagation of RF through an urban environment is dependent upon frequency, polarization, building geometry, material structure, orientation, height, and density. This section treats propagation between elevated base stations and mobiles that are at street level in urban and suburban areas. The median value depends heavily upon the size and density of the buildings, so classification of urban terrain is important. The models discussed are the Young, Okumura, Hata, and Lee models.

3.1 Young Model:

It is a radio propagation model that was build on the data collected on New York City. It typically models the behavior of cellular communication systems in large cities. In addition to this model is ideal for modeling the behavior of cellular communications in large cities with tall structures. Young model was built on the data of 1952 in New York City.

3..1.A Coverage:

- Frequency: 150 MHz to 3700 MHz

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3.1.B Mathematical formulation:

The mathematical formulation for Young model

$$L = G_B \, G_M \left(\frac{h_B \, h_M}{d^2} \right)^2 \beta$$

Where,

L = path loss. Unit: decibel (dB)

G_B = gain of base transmitter. Unit: decibel (dB)

G_M = gain of mobile transmitter. Unit: decibel (dB)

h_B = height of base station antenna. Unit: meter (m)

h_M = height of mobile station antenna. Unit: meter (m)

d = link distance. Unit: kilometer (km)

β = clutter factor

Notice that, β is not the same β that used in the Egli model. From Young's measurements, β is approximately 25 dB for New York City at 150 MHz.

The Young model covers frequencies of 150-3700 MHz. The curve presented in Figure.1 displays an inverse fourth-power law behavior, similar to the Egli model.

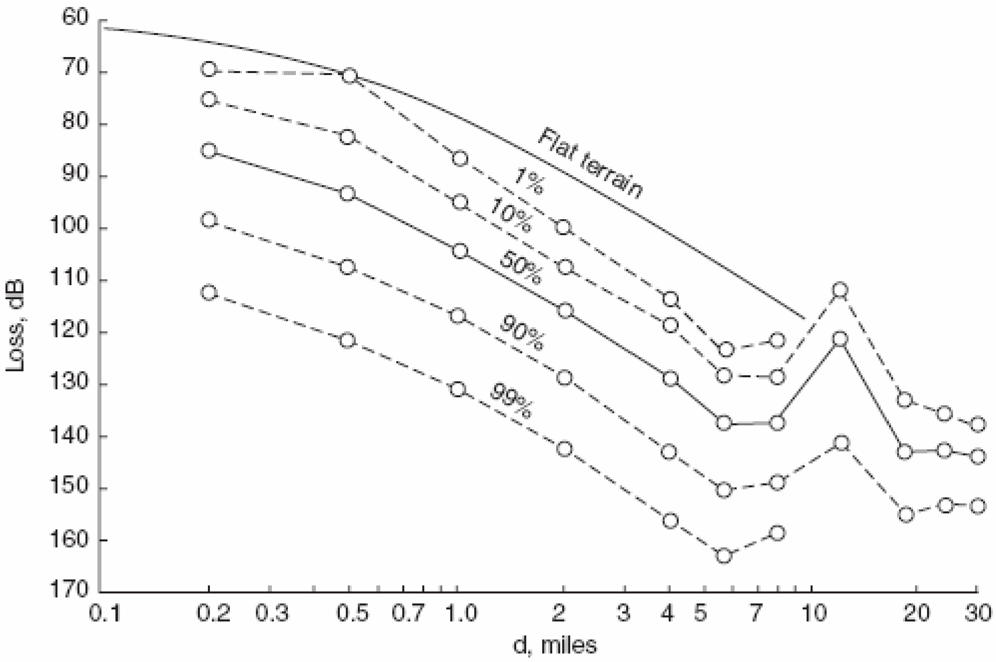


Fig.1 Results of Young's measurement of path loss versus distance in miles in Manhattan and the Bronx at 150 MHz.

3.2 Okumura Model:

It is a Radio propagation model that was built using the data collected in the city of Tokyo, Japan. The model is ideal for using in cities with many urban structures but not many tall blocking structures. The model served as a base for Hata models. For the Okumura model, the prediction area is divided into terrain categories: open area, suburban area, and urban area. The Okumura model uses the urban area as a baseline and then applies correction factors for conversion to other classifications.

3.2.A Coverage:

- Frequency = 200 MHz to 1920 MHz

3.2.B Mathematical formulation:

The Okumura model is formally expressed as:

$$L = L_{FSL} + A_{MU} - H_{MG} - H_{BG}$$

where,

L = The median path loss. Unit: Decibel (dB)

L_{FSL} = The Free Space Loss. Unit: Decibel(dB)

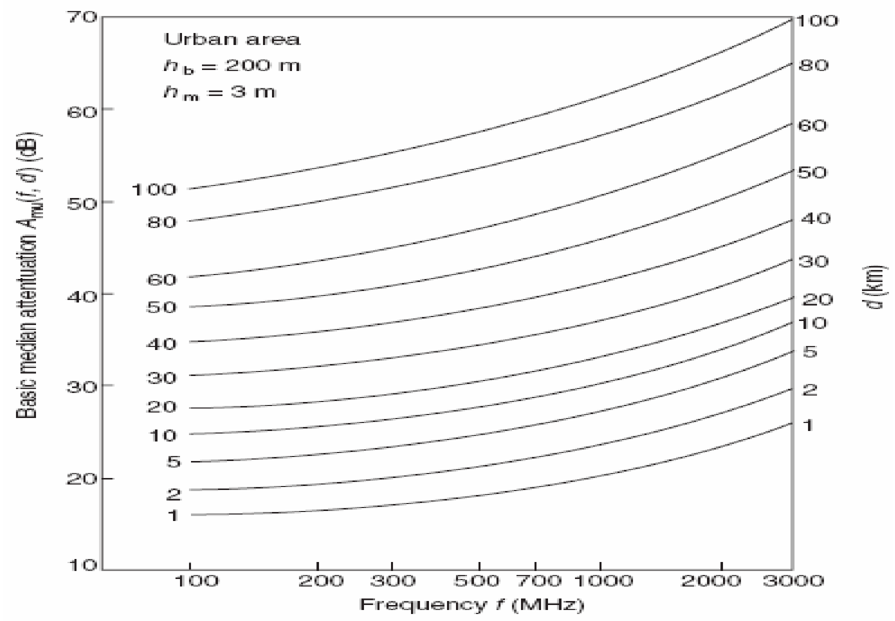
A_M = Median attenuation. Unit: Decibel(dB)

H_{MG} = Mobile station antenna height gain factor.

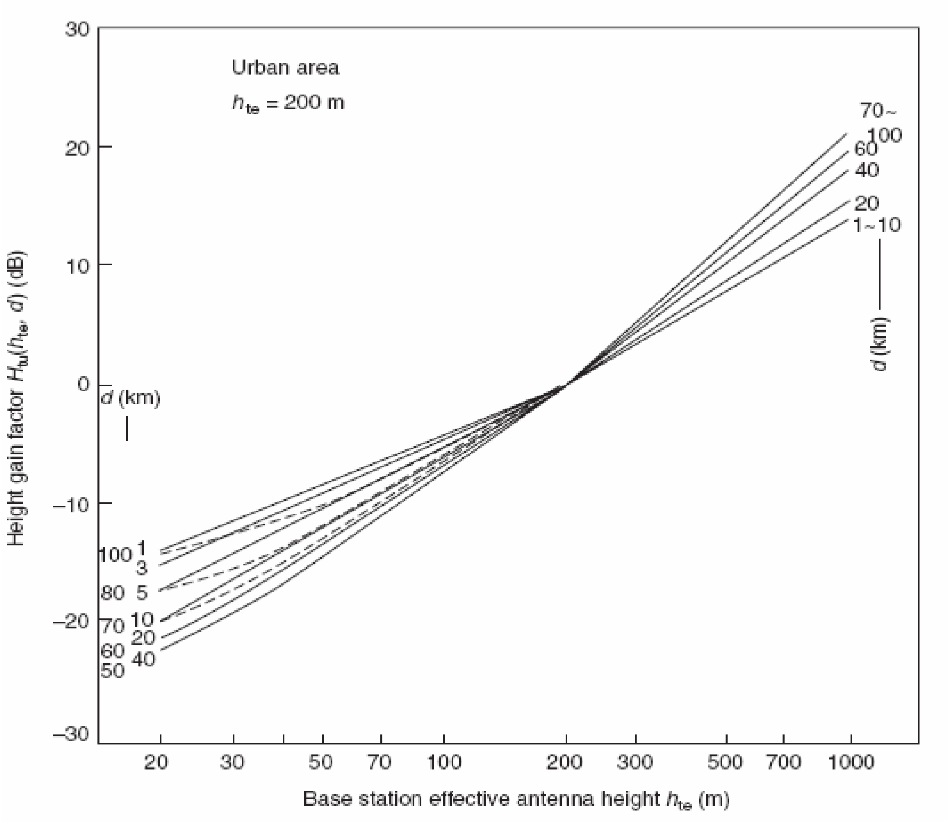
H_{BG} = Base station antenna height gain factor.

Caution: The signs on the gain factors are very important.

Notice that, Okumura model does not provide a mean to measure the Free space loss. However, any standard method for calculating the free space loss can be used.



versus frequency for use with Okumura model.A_{mu} **Fig.2** Plot of



, the base station height correction factor for the Okumura model. Fig.3 Plot of H_{BG}

In Figure.3, It shows the base station height gain factor in urban areas versus effective height for various distances.

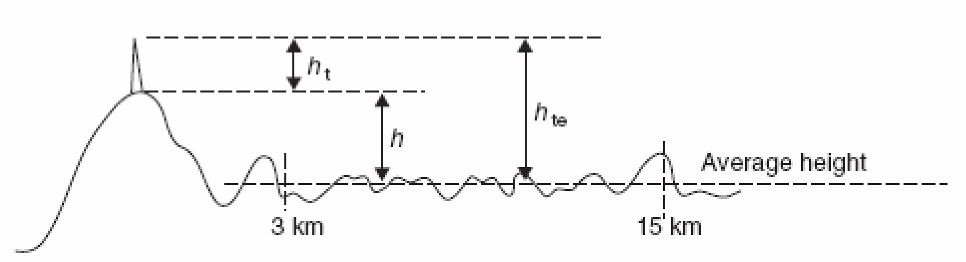


Fig.4 Measuring effective transmitter height.

In Figure 4, It shows how the base station antenna height is measured relative to the mean terrain height between 3 and 15 km in the direction of the receiver.

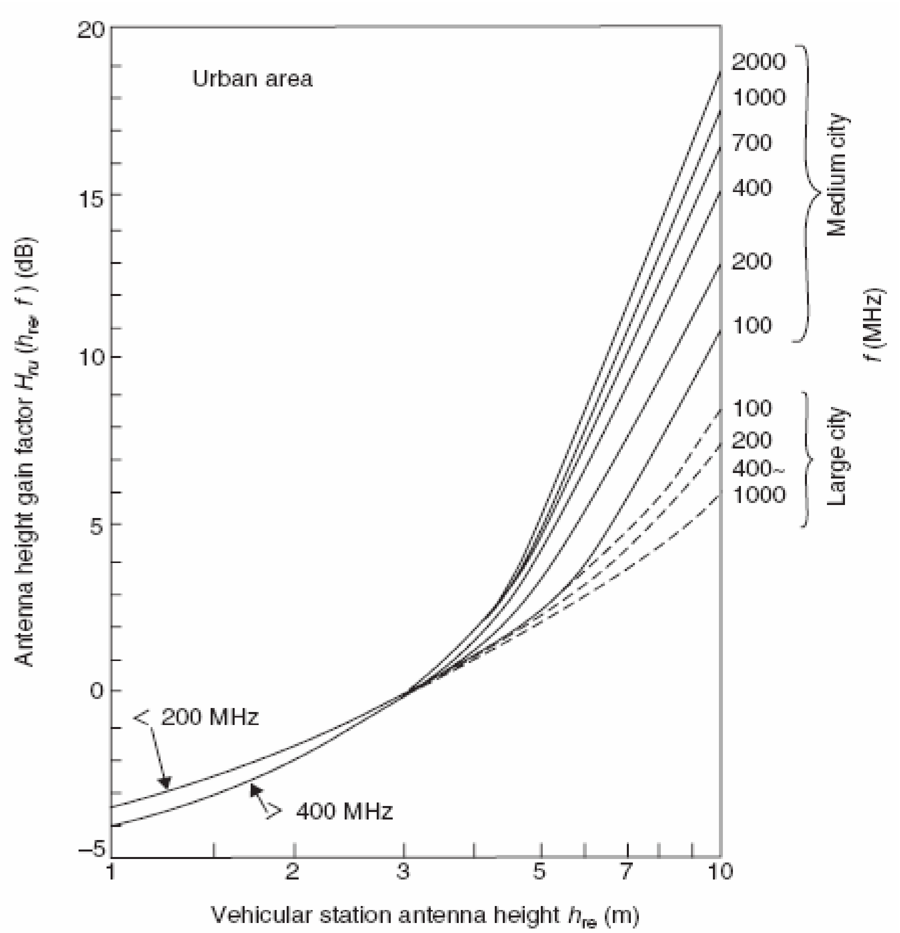


Fig.5 Plot of h_M, the mobile station height correction factor for Okumura model.

In Figure 5, It shows the vehicle antenna height gain factor versus effective antenna height for various frequencies and levels of urbanization.

3.3 Hata Model:

The Hata formulation makes the Okumura model much easier to use, and is usually the way the Okumura model is applied.

3.3.1 Hata Model for Urban Areas:

It is also knows as the Okumura-Hata model for being a developed version of the Okumura Model, is the most widely used model in radio frequency propagation for predicting the behavior of cellular transmissions in built up areas. This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures. This model also has two more varieties for transmission in Suburban Areas and Open Areas. Hata Model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications.

This particular version of Hata model is applicable to the transmissions inside cities. In addition to this model is suited for both point-to-point and broadcast transmissions. PCS is one more extension to the hata model. Walfisch and bertoni Model is further advanced.

3.3.1.A Coverage:

- Frequency: 150 MHz to 1500 MHz
- Transmitter Height: up to 200 m
- Link distance: less than 20 km

3.3.1.B Mathematical Formulation:

Hata Model for Urban Areas is formulated as,

$$L_U = 69.55 + 26.16 \log f - 13.82 \log h_B - C_H + [44.9 - 6.55 \log h_B] \log d$$

For small or medium sized city,

$$C_H = 0.8 + (1.1 \log f - 0.7) h_M - 1.56 \log f$$

and for large cities,

$$C_H = \begin{cases} 8.29\,(\log(1.54h_M))^2 - 1.1 & \text{, if } 150 \le f \le 200 \\ 3.2\,(\log(11.75h_M))^2 - 4.97 & \text{, if } 200 < f \le 1500 \end{cases}$$

Where,

L_U = Path loss in Urban Areas. Unit: decibel (dB)

h_B = Height of base station Antenna. Unit: meter (m)

h_M = Height of mobile station Antenna. Unit: [meter(m)

f= Frequency of Transmission. Unit: megahertz(MHz).

C_H = Antenna height correction factor

d= Distance between the base and mobile stations. Unit: kilometer (km).

Notice that, The term '"small city"' means a city where the mobile antenna height not more than 10 meters. i.e. $1 \le h_M \le 10m$. Moreover, Though based on Okumura Model, Hata model does not provide coverage to the whole range of frequencies covered by Okumura Model. Hata model does not go beyond 1500 MHz while Okumura provides support for up to 1920 MHz

3.3.2 Hata Model for Suburban Areas:

It is also knows as the Okumura-Hata model for being a developed version of the Okumura Model, is the most widely used model in radio frequency propagation for predicting the behavior of cellular transmissions in city outskirts and other rural areas. This model incorporates the graphical information from Okumura model and develops it further to better suite the need.

Hata Model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications. And is a function of transmission frequency and the average path loss in urban areas.

This particular version of Hata model is applicable to the transmissions just out of the cities and on rural areas where man-made structures are there but not so high and dense as in the cities. To be more precise, this model is suitable where buildings exist, but the mobile station does not have a significant variation of its height. In addition to This model is suited for both point-to-point and broadcast transmissions.

3.3.2.A Coverage:

- Frequency: 150 MHz to 1.5 GHz

3.3.2.B Mathematical Formulation:

Hata Model for Suburban Areas is formulated as,

$$L_{SU} = L_U - 2(\log \frac{f}{28})^2 - 5.4$$

Where,

L_{SU} = Path loss in suburban areas. Unit: decibel (dB)

L_U = Average Path loss in urban areas. Unit: decibel (dB)

f = Frequency of Transmission. Unit: megahertz (MHz).

Notice that, This model is based on Hata Model for Urban Areas and uses the median path loss from urban areas

3.3.3 Hata Model for Open Areas:

It is also knows as the Okumura-Hata model for being a developed version of the Okumura Model, is the most widely used model in radio frequency propagation for predicting the behavior of cellular transmissions in open areas. This model incorporates the graphical information from Okumura model and develops it further to better suite the need.

Hata Model for open areas predicts the total path loss along a link of terrestrial microwave or other type of cellular communications. And is a function of transmission frequency and the median path loss in urban areas. In addition to This particular version of Hata model is applicable to the transmissions in open areas where no obstructions block the transmission link. Finally, This model is suited for both point-to-point and broadcast transmissions.

3.3.3.A Coverage:

- Frequency: 150 MHz to 1.5 GHz

3.3.3.B Mathematical formulation:

Hata model for open areas is formulated as,

$$L_O = L_U - 4.78\,(\log f)^2 + 18.33\,\log f - 40.97$$

Where,

L_O = Path loss in open area. Unit: decibel (dB)

L_U = Path loss in urban area. Unit: decibel (dB)

f = Frequency of transmission. Unit: megahertz(MHz).

[edit] Points to note

This model is dependent on the Hata Model for Urban Areas.

3.3.4 Cost 231 Model :

It is also called the Hata Model PCS Extension, is a radio propagation model that extends the Hata Model and Okumura Model to cover a more elaborated range of frequencies. In addition to this model is applicable to Open, Suburban and Urban Areas.

3.3.4.A Coverage:

- Frequency: 1500 MHz to 2000 MHz
- Mobile Station Antenna Height: up to 10m
- Base station Antenna Height: 30m to 100m
- Link Distance: up to 20 km

3.3.4.B Mathematical Formulation:

The COST 231 model is formulated as,

$$L = 46.3 + 33.9\log f - 13.82\log h_B - C_H + [44.9 - 6.55\log h_B]\log d + C$$

$$C = \begin{cases} 0\ dB \text{ for medium cities and suburban areas} \\ 3\ dB \text{ for metropolitan areas} \end{cases}$$

Where,

L = Median path loss. Unit: Decibel (dB)

f = Frequency of Transmission. Unit: Megahertz (MHz)

h_B = Base Station Antenna effective height. Unit: Meter (m)

d = Link distance. Unit: Kilometer (km)

C_H = Mobile station Antenna height correction factor as described in the Hata Model for Urban Areas.

Remarks:

- This model is suitable for using in the same scenarios for Hata and Okumura Models.
- This model is restricted to applications where the base station antenna is above the adjacent roof tops, Hata and COST 231 are central to most commercial RF planning tools for mobile telephony.

3.4 Lee Models:

The Lee model was originally developed for use at 900 MHz and has two modes: area-to-area and point-to-point. Even though the original data are somewhat restrictive in its frequency range, the straightforward implementation, ability to be fitted to empirical data, and the results it provides make it an attractive option. The model includes a frequency adjustment factor that can be used to increase the frequency range analytically.

3.4.1 Area to Area Lee Model:

It is a Radio propagation model that operates around 900 MHz. Built as two different modes, this model includes an adjustment factor that can be adjusted to make the model more flexible to different regions of propagation. In addition to this model is suitable for using in data collected in a specific area. The model predicts the behavior of all links that has ends in specific areas.

3.4.1.A Coverage:

- Frequency: 900 MHz Band

3.4.1.B Mathematical formulation:

3.4.1.B.1 The model:

The Lee Model is formally expressed as:

$$L = L_0 + \gamma \log d - 10 \log F_A$$

where,

L = The median path loss. Unit: decibel (dB)

L_0 = The reference path loss along 1 km. Unit: decibel] (dB)

γ= The slope of the path loss curve. Unit: decibels per decade

d = The distance on which the path loss is to be calculated.

F_A = Adjustment factor.

3.4.1.B.2 Calculation of reference path loss:

The reference path loss is usually computed along a 1 km or 1 mile link. Any other suitable length of path can be chosen based on the applications.

$$L_0 = G_B + G_M + 20 (\log \lambda - \log d) - 22$$

where,

G_B = Base station antenna gain. Unit: decibel with respect to isotropic antenna (dBi)

λ = Wavelength. Unit: meter (m).

G_M = Mobile station antenna gain. Unit: Decibel with respect to isotropic antenna (dBi).

some empirical values for the reference median path loss at 1 km and the slope of the path loss curve are given in Table 1. The basic setup for collecting this information is as follows:

$$f = 900\ Mhz$$

$$G_b = 6\ dBd = 8.14\ dBi$$

$$G_m = 0\ dBd = 2.14\ dBi$$

TABLE 1 Reference Median Path Loss for Lee's Model

Environment	L_o (dB)	γ
Free space	85	20
Open (rural) space	89	43.5
Suburban	101.7	38.5
Urban areas		
Philadelphia	110	36.8
Newark	104	43.1
Tokyo	124	30.5

*d adjusted to 1 km

To see how the L_o are computed, first consider the free space case:

$$L_o = 20\log\left(\frac{\sqrt{G_b G_m}}{4\pi d}\lambda\right)$$

or, in dB,

$$L_o(dB) = G_b(dB) + G_m(dB) - 22 + 20\log(\lambda) - 20\log(d)$$

where λ and d are in the same units. Substituting the appropriate values from above and using $d - 1000\ m$ yields

$$L_o = -81.2\ dB$$

Lee's empirical data suggest the $L_o - -65\ dB$, which is likely a result of the antenna not being ideal or the test not being ideally free space.

3.4.1.B.3 Calculation of adjustment factors:

It allow the user to adjust the model for the desired configuration. Notice that, the numbering of factors is not universal.

The adjustment factor is calculated as:

$$F_A = F_{BH}\, F_{BG}\, F_{MH}\, F_{MG}\, F_F$$

where,

F_{BH} = Base station antenna height correction factor.

F_{BG} = Base station antenna gain correction factor.

F_{MH} = Mobile station antenna height correction factor.

F_{MG} = Mobile station antenna gain correction factor.

F_F = Frequency correction factor

3.4.1.B.4 The base station antenna height correction factor:

$$F_{BH} = \left(\frac{h_B}{30.48}\right)^2$$

where,

h_B = Base station antenna height. Unit: meter (m).

or

$$F_{BH} = \left(\frac{h_B}{100}\right)^2$$

where,

h_B = Base station antenna height. Unit: foot (ft).

3.4.1B.5 The base station antenna gain correction factor:

$$F_{BG} = \frac{G_B}{4}$$

where,

G_B = Base station antenna gain. Unit: decibel with respect to half wave dipole antenna (dBd)

3.4.1.B.6 The mobile station antenna height correction factor:

$$F_{MH} = \begin{cases} \frac{h_M}{3} & \text{if, } h_M > 3 \\ \left(\frac{h_M}{3}\right)^2 & \text{if, } h_M \leq 3 \end{cases}$$

where,

h_M = Mobile station antenna height. Unit: meter(m).

3.4.1.B.7 The mobile antenna gain correction factor:

$$F_{MG} = G_M$$

where,

G_M = Mobile station antenna gain. Unit: Decibel with respect to half wave dipole antenna (dBd). By other meaning, it is the gain of the mobile antenna relative to a half wave dipole.

3.4.1.B.8 The frequency correction factor:

$$F_F = (\frac{f}{900})^{-n} \text{ for } 2 < n < 3$$

where,

f= Frequency. Unit: megahertz (MHz)

3.4.2 Point to Point Lee Model:

It is a radio propagation model that operates around 900 MHz. Built as two different modes, this model includes an adjustment factor that can be adjusted to make the model more flexible to different regions of propagation. In addition to this model is suitable for using in data collected in a specific area for Point to Point links.

3.4.2.A Coverage:

- Frequency: 900 MHz band

3.4.2.B Mathematical formulation:

3.4.2.B .1 The model:

The point-to-point mode of the Lee model includes an adjustment for terrain slope. The median path loss is given by:

$$L'_{50}(dB) = L_{50}(dB) - 20\log(\frac{h_{eff}}{30})$$

or

$$L = L_0 + \gamma g \log d - 10(\log F_A - 2\log(\frac{H_{ET}}{30}))$$

where,

L (L_{50})= The median path loss. Unit: decibel (dB)

L_0 = The reference path loss along 1 km. Unit: decibel (dB)

γ= The slope of the path loss curve. Unit: decibels per decade

d = The distance on which the path loss is to be calculated. Unit: kilometer (km)

F_A = Adjustment factor.

H_{ET}(h_{eff}) = Effective height of terrain. Unit: meter(m)

3.4.2.B .2 Calculation of reference path loss:

The reference path loss is usually computed along a 1 km or 1 mi link. Any other suitable length of path can be chosen based on the applications.

$$L_0 = G_B + G_M + 20\,(\log\lambda - \log d\,) - 22$$

where,

G_B = Base station antenna gain. Unit: Decibel with respect to isotropic antenna (dBi)

λ = Wavelength. Unit: meter (m).

G_M = Mobile station antenna gain. Unit: decibel with respect to isotropic antenna (dBi).

3.4.2.B.3 Calculation of adjustment factors:

The adjustment factor is calculated as:

$$F_A = F_{BH}\,F_{BG}\,F_{MH}\,F_{MG}\,F_F$$

where,

(F1)F_{BH}= Base station antenna height correction factor.

(F2)$_{BG}$ = Base station antenna gain correction factor.

(F3)F_{MH} = Mobile station antenna height correction factor.

(F4)F_{MG} = Mobile station antenna gain correction factor.

(F5)F_F = Frequency correction factor

3.4.2.B .4 The base station antenna height correction factor:

$$F_1 = (\frac{h_B}{30.48})^2$$

where,

h_B = Base station antenna height. Unit: meter.

3.4.2.B .5 The base station antenna gain correction factor:

$$F_2 = \frac{G_B}{4}$$

where,

G_B = Base station antenna gain. Unit: decibel with respect to half wave dipole (dBd)

3.4.2.B .6 The mobile station antenna height correction factor:

$$F_3 = \begin{cases} \frac{h_M}{3} \text{ if,} h_m > 3 \\ (\frac{h_M}{3})^2 \text{ if,} h_M \leq 3 \end{cases}$$

where,

h_M = Mobile station antenna height. Unit: meter.

3.4.2.7 The mobile antenna gain correction factor:

$$F_4 = G_M$$

where,

G_M = Mobile station antenna gain. Unit:Decibel with respect to half wave dipole antenna (dBd).

3.4.2..B .8 The frequency correction factor:

$$F_5 = (\frac{f}{900})^{-n} \text{ for } 2 < n < 3$$

where,

f = Frequency. Unit: megahertz (MHz)

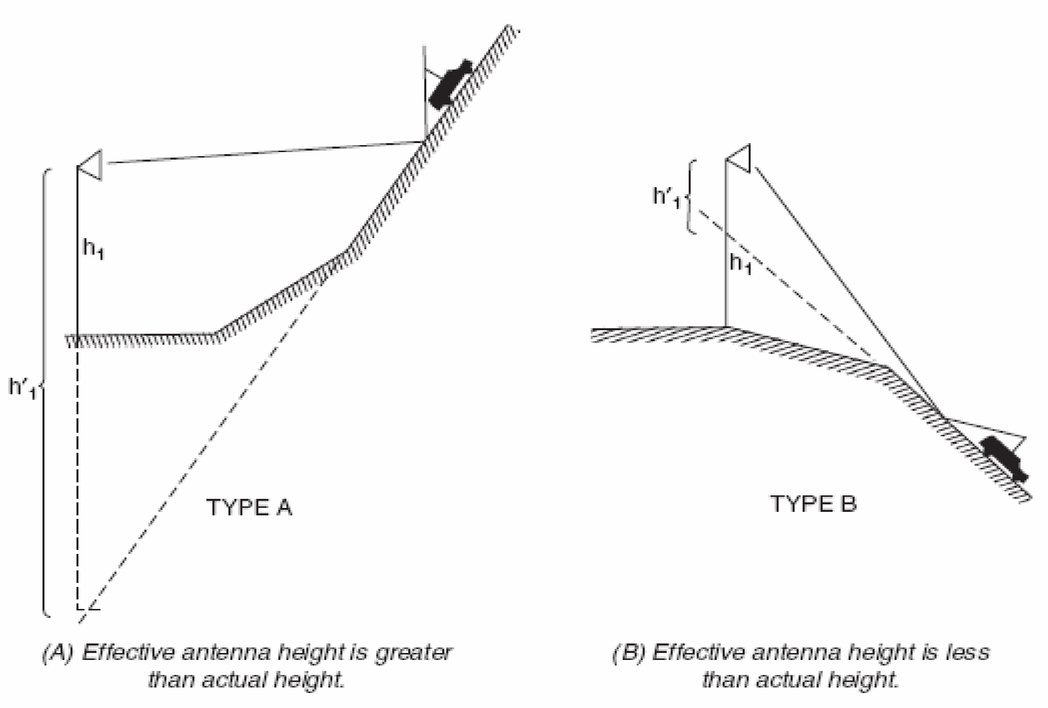
3.4.2. B .9 Effective terrain slope calculation:

This is computed in the following way:

1. Extrapolate terrain slope at the mobile station to the base station.

2. Compute the vertical antenna height over the extrapolation line.

By other meaning, $H_{ET}(h_{eff})$ is determined by extrapolating the terrain slope at the mobile back to the base station antenna and then computing the antenna height (vertically) above the extrapolated line, see Figure.6.



(A) Effective antenna height is greater than actual height.

(B) Effective antenna height is less than actual height.

Fig.6 Determination of the effective base station antenna height for the Lee model.

Keep that, Lee indicates that the standard deviation of the error in the area-to-area mode is 8dB and that for the point-to-point mode is 3dB. The frequency adjustment coefficient for F_4 is $n=2$ for suburban or open areas with $f<450$ MHz and $n=3$ for urban area and $f>450$ MHz. Other cases must be determined empirically.

5. Notations:

- For practical cases the path loss is calculated using a variety of approximations.
- Deterministic methods are expected to produce more accurate and reliable predictions of the path loss than the empirical methods; however, they are significantly more expensive in computational effort and depend on the detailed and accurate description of all objects in the propagation space. For these reasons they are used predominantly for short propagation paths.
- Some easy to remember approximations for calculating the path loss over distances significantly shorter than the distance to the radio horizon:

i. In free space the path loss increases with 20 dB per decade (one decade is when the distance between the transmitter and the receiver increases ten times) or 6 dB per octave (one octave is when the distance between the transmitter and the receiver doubles). This can be used as a very rough first-order approximation for SHF (microwave) communication links;

ii. For signals in the UHF/VHF band propagating over the surface of the Earth the path loss increases with roughly 35 -- 40 dB per decade (10 -- 12 dB per octave). This can be used in cellular networks as a first guess.

- In cellular networks, such as UMTS and GSM, which operate in the UHF band, the value of the path loss in built-up areas can reach 110 -- 140 dB for the first kilometer of the link between the BTS and the mobile. The path loss for the first ten kilometers may be 150 -- 190 dB Notice that, These values are very approximate and are given here only as an illustration of the range in which the numbers used to express the path loss values can eventually be, these are not definitive or binding figures -- the path loss may be very different for the same distance along two different paths and it can be different even along the same path if measured at different times.

- Hata and COST 231 are central to most commercial RF planning tools for mobile telephony.

6. References:

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- Okumura, Y. a kol.: Field Strength and its Variability in VHF and UHF Land-Mobile Radio Service. Rev. Elec. Comm. Lab. No.9-10pp. 825 - 873, 1968.
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