# Performance analysis of various path loss models in Wireless Systems

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*Abstract :* In wireless environment, the radio propagation indicates the behavior of the radio waves when they are propagating from transmitter to receiver. These waves are mainly affected by different phenomena such as reflection, diffraction, and scattering. Reflection is a phenomenon; the propagating electromagnetic wave impinges upon an object with bigger dimension compared to the wavelength, for example, wall of building and surface of earth. Diffraction is a phenomenon that occurs when the radio path between the transmitter and receiver is obstructed by a surface with sharp irregularities or small openings and it emerges as a bending of waves around the small obstacles and spreading out of waves through small openings. Scattering is the phenomenon which forces the radiation of propagating wave to deviate from a straight path by more than one local obstacle, like, foliage, street indicating signs, and lamp posts, which are referred to as the scatters. In this paper we will understand impact of these in wireless systems using different fading models. MATLAB is used as a simulation tool.

***IndexTerms* – Path Loss, Reflection, Diffraction, Scattering.**

## I. INTRODUCTION

In wireless systems, the radio propagation indicates the behavior of the radio waves when they are propagating from transmitter to receiver. Due to reflection the transmit signal power forces to be reflected back to its source of transmission, instead of being passed along the path to the receiver. Secondary waves due to diffraction are important for establishing a path between the transmitter and receiver. We can say that the propagation of a radio wave is a complex and less predictable process which has been governed by reflection, diffraction, and scattering, whose intensity changes with different environments at different instances of time [1].The variation of the signal amplitude over time and frequency in a wireless channel is defined as Fading. In the wireless channel the additive noise is the common source of signal degradation, compared to that the fading is another source of signal degradation which is non-additive signal disturbance. Fig 1 illustrates the relationship between large scale (path loss) and small scale fading. Large-scale fading has been marked by the mean path loss that decreases with the distance and shadowing that shows it varies along the mean path loss. Due to the shadowing caused by obstacles on the path at the same distance the received signal strength may be different from a transmitter [2].

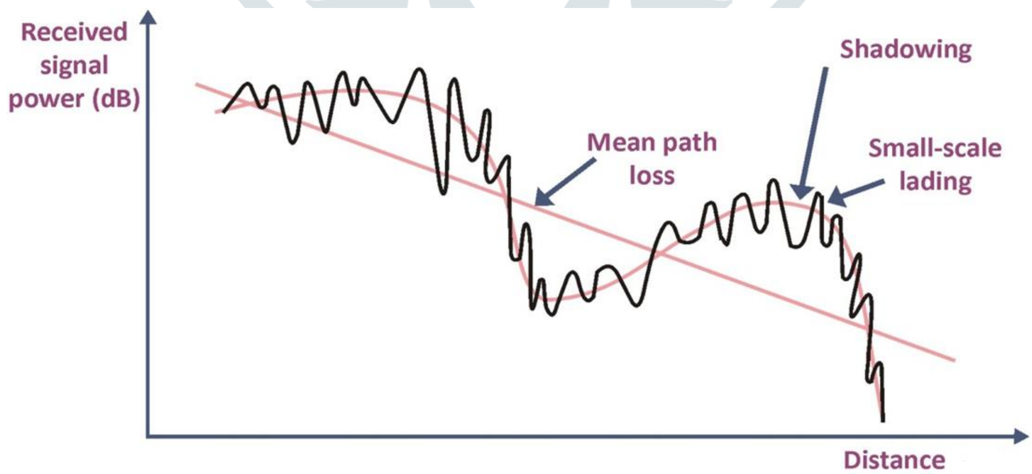


Figure 1: Large - scale and small - scale fading.

In the design of wireless communication systems link budget is an important tool. Accounting gains and losses through the wireless channel to the receiver, it permits for predicting the received signal strength with the required power margin. Fading and path loss are two most important factors to be considered in link budget. A link budget that is affected by these factors is shown in Fig 2. The mean path loss is a deterministic factor. Further it can be predicted with the distance between the transmitter and receiver. Where, shadowing and small-scale fading are random processes, so their effects can only be predicted by their probabilistic distribution. Shadowing is normally modeled by a log-normal distribution.

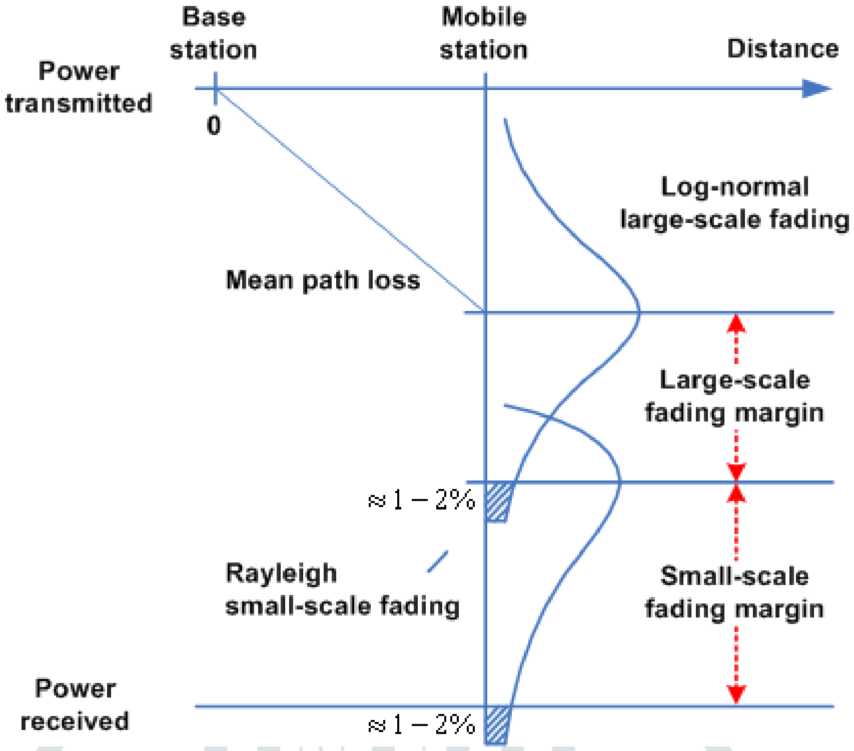


Figure 2: Link budget of the fading channel.

Next section presents the specific channel models for large-scale fading that is required for the link budget analysis.

## II. LARGE –SCALE FADING – FREE SPACE PATH LOSS MODEL

In the line of sight (LOS) environment, the free-space propagation model is used for predicting the received signal's strength. Let $d$ denotes the distance between the transmitter and receiver in meters. Using non - isotropic antennas having a transmit gain of $Gt$ and a receive gain of $Gr$, the received power at distance $d$, $Pr(d)$, is given by the Friis equation [3], as

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad (1)$$

where $Pt$ is the transmitting power in watts, $\lambda$ is the wavelength in meter and $L$ is system's loss factor independent of wave propagation environment. The system loss factor is the overall attenuation or loss in the actual system hardware. In general, $L > 1$, but $L = 1$ assumes no loss in the system hardware. From equation (1) it is obvious that the received power exponentially attenuates with the distance $d$. The free-space path loss, $PL_F(d)$ without any system loss is directly derived from equation (1) with $L = 1$ as

$$PL_F(d)[dB] = 10\log\left(\frac{P_t}{P_r}\right) = -10\log\left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right) \qquad (2)$$

Without antenna gains (i.e., $Gt = Gr = 1$), equation (2.2) is reduced to

$$PL_F(d)[dB] = 10\log\left(\frac{P_t}{P_r}\right) = 20\log\left(\frac{4\pi d}{\lambda}\right) \qquad (3)$$

More generalized form of the path loss model has been developed by modifying the free-space path loss with the path loss exponent $n$ that changes according to the environments. This is known as the log-distance path loss model, and the path loss at distance $d$ is given as

$$PL_{LD}(d)[dB] = PL_F(d_0) + 10\,n\log\left(\frac{d}{d_0}\right) \qquad (4)$$

where $d_0$ is a reference distance.

Table 1: Path loss exponent ($n$), [2].

| Propagation Environment | Path loss exponent ($n$) value |
|---|---|
| Free space | 2 |
| Urban Area ( Cellular Radio ) | 2.7 – 3.5 |
| Shadowed Urban (Cellular Radio) | 3 – 5 |
| Obstructed in Building | 4 – 6 |
| Obstructed in Factories | 2 – 3 |
| In Building LOS | 1.6 – 1.8 |

Table 1 shows that depending on the propagation environment the path loss exponent value varies from 2 to 6. Here it has been shown that $n = 2$ indicates the free space value and it increases when there are more obstructions in the path. Here $d_0$, a reference distance is properly decided for different propagation environments.

For more practical situations the log-*normal* shadowing model is useful. Let $X_\sigma$ signify a Gaussian Random Variable with a zero mean and $\sigma$ is a standard deviation. Equation (5) represents the log-normal shadowing model.

$$PL(d)[dB] = \overline{PL}(d) + X_\sigma = PL_F(d_0) + 10\, n \log\left(\frac{d}{d_0}\right) + X_\sigma \qquad (5)$$

This model allows the receiver at the same distance $d$ and has a different path loss, which further changes with the random shadowing effect $X_\sigma$. Figure 2.21 presents the path loss it follows the log-normal shadowing model. It has been observed at carrier frequency $fc = 1500$ MHz with $\sigma = 3$ dB and $n = 2$. It has been clearly observed that the random effect of shadowing in the log-distance path loss model.

## III. SIMULATION RESULTS

Fig 3 illustrates the free-space path loss at the carrier frequency of $fc = 1500$ MHz for different antenna gains with the varying distances. It has been observed that the path loss increases as reducing the antenna gains.

At the carrier frequency, $fc = 1500$ MHz, log-distance path loss using equation (4) has been represented in Fig 4. It has been observed that the path loss increases with the path loss exponent $n$. Further it has been observed that distance between the transmitter and receiver is equal and each path may have different path loss as the nearby environments also changing with the position of the receiver.

Using equations (2), (3), (4) and (5) the computer programs have been written to compute the path losses and simulated using Matlab® to generate the plots shown in Figures 3 to 5.

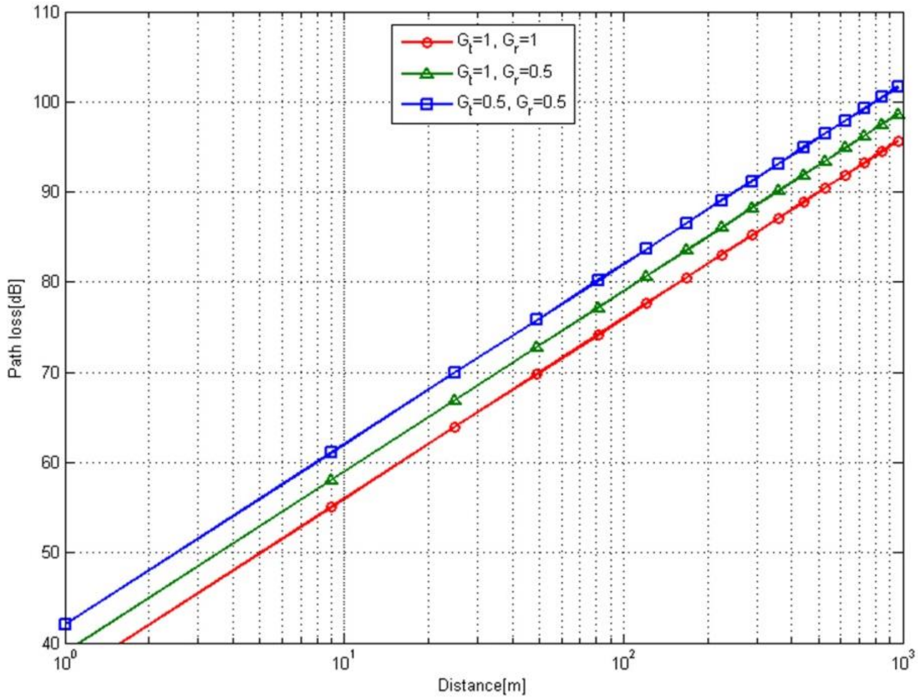


Figure 3: Simulation Results for Free-space path loss model.

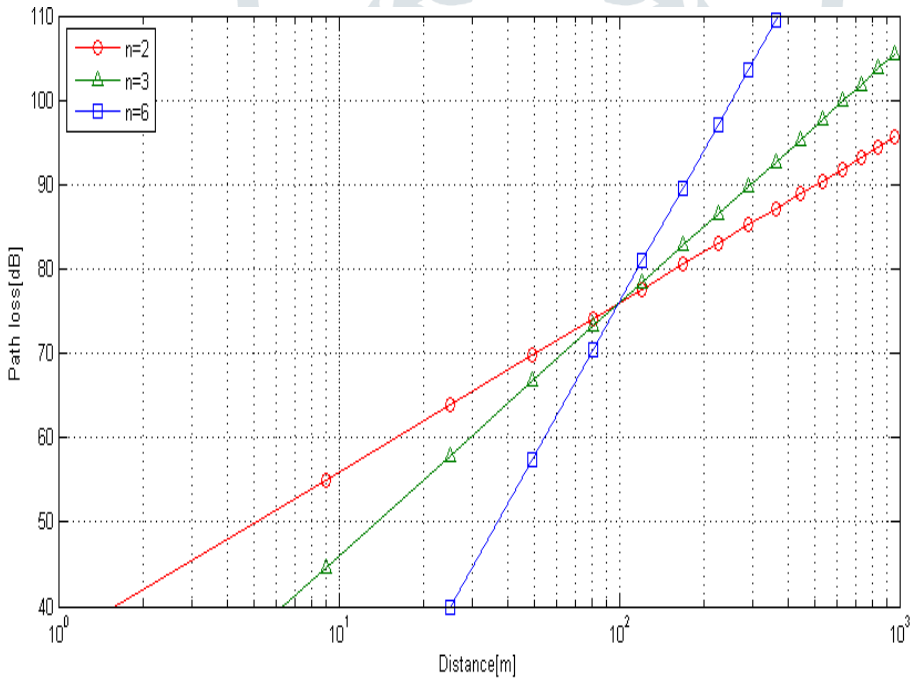


Figure 4: Simulation results for Log-distance path loss model.

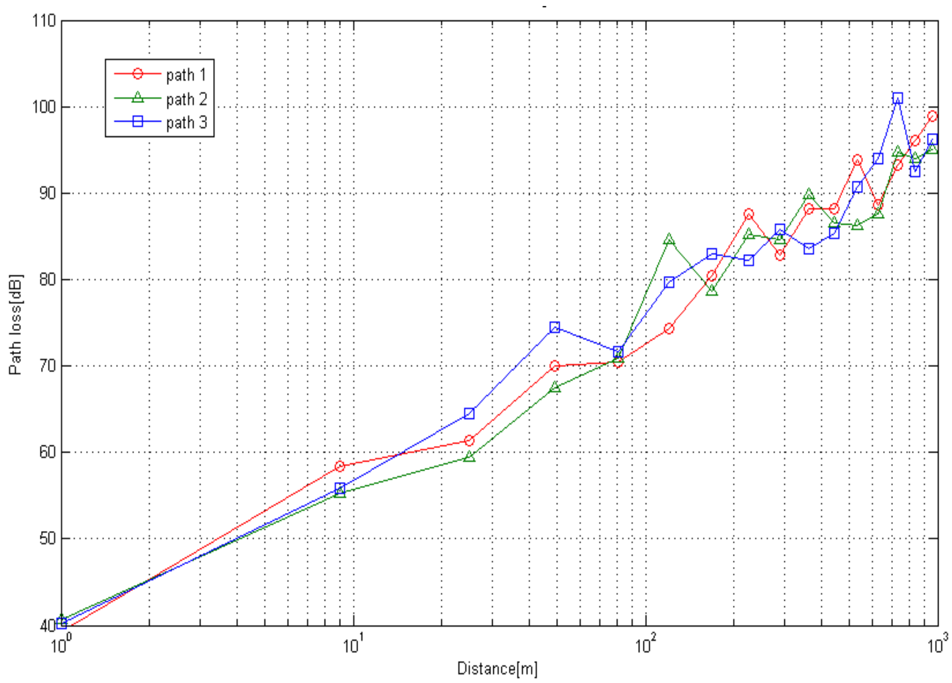


Figure 5: Simulation Results of Log-normal shadowing path loss model.

## IV. Okumura and Hata model

Through prevalent experiments for computing the specific coverage area and transmitting and receiving antenna height for mobile communication systems the Okumura model has been developed [4]. This path loss model has been adopted worldwide and it can predict the path loss specifically in an urban area. This model works with a frequency band of 500 to 1500 MHz, with an antenna height in the range of 30 m to 100 m and cell radius of 1 to 100 km.

The path loss at distance $d$ in the Okumura model has been given by

$$PL_{ok}(d)[dB] = PL_F + A_{MU}(f,d) - G_{R_x} - G_{T_x} + G_{Area} \quad (6)$$

where $A_{MU}(f,d)$ is medium attenuation factor at $f$, $G_{T_x}$ and $G_{R_x}$are the gains of $Tx$ and $Rx$ antennas, and the gain for the propagation environment is $G_{Area}$for the particular area. This Okumura model has been further extended to cover up the different propagation environments, which includes urban, suburban, and open area. This is presently known as the Hata model [5]. For transmit antenna's height, $h_{TX}$ (meter), and the carrier frequency of $f_c$ (MHz), the path loss at particular distance $d$ (meter) in an urban area has been given by the Hata model as ,

$$PL_{Hata,U}(d)[dB] = 69.55 + 26.16 \log f_c - 13.82 \log h_{TX} - C_{RX} + (44.9 - 6.55 \log h_{TX}) \log d \quad (7)$$

where $C_{RX}$ signify the correlation coefficient of the receiver antenna. For small to medium-sized coverage, $C_{RX}$ is given as

$$C_{RX} = 0.8 + (1.11 \log f_c - 0.7) h_{RX} - 1.56 \log f_c \quad (8)$$

the path loss at distance $d$ in suburban and open areas are respectively given by the Hata model as

$$PL_{Hata,SU}(d)[dB] = PL_{Hata,U}(d) - 2\left(\log \frac{f_c}{28}\right)^2 - 5.4 \quad (9)$$

and

$$PL_{Hata,O}(d)[dB] = PL_{Hata,U}(d) - 4.78 (\log f_c)^2 - 18.33 \log f_c - 40.97 \quad (10)$$

## V. SIMULATION RESULTS

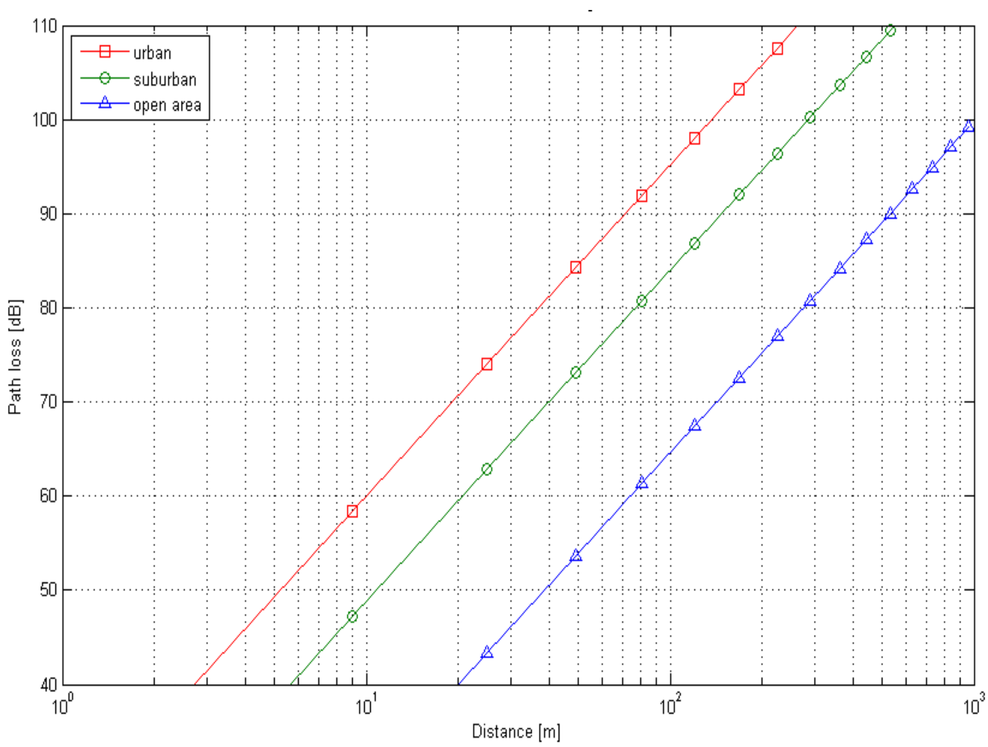


Figure 6: Simulation Results of Hata path loss model.

## VI. CONCLUSION

In this paper we have observed different path loss models with their mathematical equations and then it has been observed the simulations for Free-space path loss model, Log-distance path loss model, Log-normal shadowing path loss model and Hata path loss model. It has been observed from the simulations that Hata path loss models are more appropriate for all three areas i.e. Rural, Suburban and Urban. It is also verified in simulations that as the distance between transmitter and receiver is increased then overall path loss is increased. From Table 1 we get the idea about the impact of path loss exponent value. When value is higher the impact on path loss is higher. This phenomenon can be observed from figure 4 simulation results. Hata Model for Urban, Suburban and Rural area has been observed in Figure 6 Simulation results. Hata model is basically extension of existing Okumura Model which was only suitable for urban area.

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