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A Review on Wireless Propagation Models

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Abstract— In wireless communication, path loss is caused by different obstacles between the transmitter and receiver that absorb power due to which signal strength is reduced. To calculate the path loss between the transmitter and receiver, different path loss models are used like okumara, hata, cost 231 etc. These path loss models may give different results in urban, suburban and rural areas. In this paper, different outdoor and indoor propagation models are surveyed. These models depend on various parameters like mobile-station antenna height, transmitter-receiver distance, base- station antenna height.

***Index Terms*—Path loss in mobile system, indoor and outdoor path loss model, hata model, sui model.**

I. INTRODUCTION

The Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. A message is transmitted through open space by EM waves called radio waves. Radio waves are radiated from transmitter in open space through a device called Antenna. A receiving antenna intercepted the radio waves at receiver. With radio waves distances can be short, such as a few meters for television or as far as thousands or even millions of kilometers for deep-space radio communications.

During this transmission, some losses occur between the transmitter and receiver is known as propagation path loss. Path loss is the unwanted reduction in power density of the signal which is transmitted. In wireless communications, the term path loss is commonly used. This path loss may be arising by various effects such as Reflection, Refraction, diffraction, scattering. Different propagation phenomena's are shown in *fig.1*.

A. Reflection

When propagating electromagnetic waves encounters a surface which has very large dimensions relative to the wavelength of the propagating wave, reflection occurs. It occurs due to the surface of the earth, buildings and walls.

B. Diffraction

Diffraction occurs when propagating electromagnetic waves encounters at edges of an impenetrable body that is large compared to the wavelength of the radio waves.

C. Scattering

Scattering occurs when the medium through which the wave travels consists of obstacles with dimensions that are small compared to the wavelength of the propagating signals.

Scattered waves produced by rough surfaces, small obstacles or by irregularities in channel.[7,19]

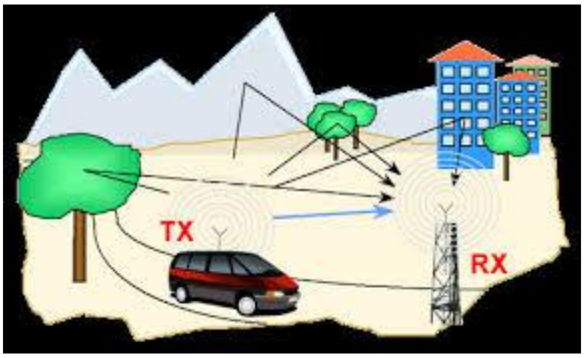

Fig.1: Phenomena of reflection, diffraction and scattering.

II. PROPAGATION PATH LOSS MODELS

To measure this path loss in different environment different path loss models are used. These models are based on theoretical data service in urban, sub-urban and rural areas. These path loss models can be categorized into two types: - Outdoor propagation models and Indoor propagation path loss models. Outdoor propagation models- To predict the signal strength at a particular receiving point over irregular terrain for a large range of T-R separation. These models are based on measured data in the service area. Indoor propagation models- To predict the signal strength for a much smaller range of T-R separation and the variability of environment are much greater as shown in *fig.2*.[5,15]

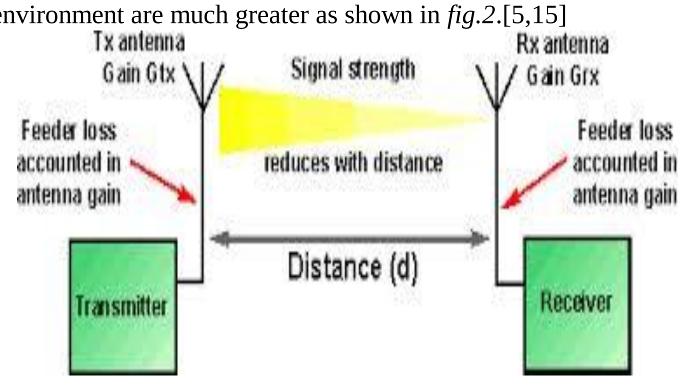

Fig.2: Basic path loss phenomenon

III. INDOOR PROPAGATION MODEL

The model which are used for smaller of T-R separation and the distance covered are much smaller and the variability of the environment is much greater .These models also have mechanisms such as reflection, diffraction and scattering. In Indoor, radio propagation is affected by the layout in a building not affected by the terrain profile indoor channels generating classified as line of sight or obstructed with varying degrees of clutter. Various types of losses occur in indoor propagation models-

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A. *Partition Losses*

Partition losses occur when buildings have a wide variety of partitions and obstacles which form the internal and external structure. These losses occur when the partitions between walls or in open area are constructed with either plaster board or by using moveable partitions in which metal is used. Partition that are formed as part of buildings structure are called hard partition and partitions that may be moved and do not span to the ceiling are called soft partitions. These losses are determined by various parameters such as by external dimensions and materials of the buildings, type of construction used to create the floors, external surroundings and even by the number of windows in a building. Different floor attenuation factor in two office buildings in different floors is shown in Table 1

Table 1: Average Floor Attenuation Factor in dB for ONE, TWO, and THREE Floors in TWO Office Floors. [19]

BUILDING	FAF(dB)	σ(dB)	Number of Locations
Office Building 1:			
Through one Floor	12.9	7	52
Through two Floors	18.7	2.8	9
Through three Floors	24.4	1.7	9
Office Building 2:			
Through one Floor	16.2	2.9	21
Through two Floors	27.5	5.4	21
Through three Floors	31.6	7.2	21

B. *Signal Penetration into buildings*

When a signal is received from the external transmitter inside buildings the strength of the signal is reduced because it shares its frequency with other buildings or outdoor system. The signal strength increases as the height of the building increases. At higher floor of buildings, a Line Of Sight path may exist that causing a stronger incident signal at the exterior walls of the buildings. At lower floor of buildings the urban clutter induces greater attenuation and reduces the level of penetration. So the RF penetration is a function of frequency as well as height within the building.

C. *Attenuation*

The signal strength falls off with distance over any transmission medium. The strength of signal is reduced and it is a logarithmic function for guided media attenuation is a more complex of distance.

D. *Free space loss*

Free space losses are the losses in which the signals disperse with distance. In this the signal power is reduced between the transmitting and receiving antenna. Due to free space losses the transmitted signal attenuates over distance because the signal is spread over larger and larger area.

E. *Fading*

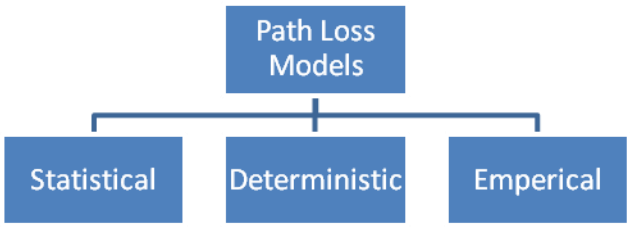
Fading is defined as the time variation of received signal power caused by changes in the transmission medium or path. When there is a fixed environment .fading is affected by changes in atmospheric condition where in a movable environment either the transmitting or receiving antenna is in motion, this changing in position causes complex transmission effects.

F. *Multipath*

Multipath is a propagation phenomenon in which the radio signals reaching the receiving antenna by two or more path in which there are two paths direct path and reflected path they both are opposite in phase. Due to differences in path length of direct and reflected waves. The signal can be either smaller or larger than the direct signal. Multipath is also caused by reflection, diffraction and scattering. This propagation effect depending on local condition and medium.

IV. OUTDOOR PROPAGATION MODEL

The model which are used for larger T-R separation and the distance covered are much larger and the variability of the environment is much smaller .These models also have same mechanisms as indoor such as reflection, diffraction and scattering. They are further classified as:-



A. *Statistical models*

The statistical models depend on probability analysis. In this model, the environment used as a series of random variables. These models are least accurate and they require the least information about environment & use much less power to create predictions. Probability analysis used probability density function to find out predictions of path loss. Statistical models are different in different environment. It generally depends on surrounding condition at the time of measurement.

B. *Deterministic models*

Deterministic models use Maxwell's equation along with reflection & diffraction laws. Deterministic models are better to find the propagation path loss. These models use basic physically approaches according to the existing theoretical

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explanations & theorems. These models require a complete 3-D map of the propagation environment. Ray tracing model is example of deterministic models.

C. Empirical models

Empirical models use existing equation which is obtained from the several measured result. This model gives accurate result but the main problem of this model is its complexity. Okumara model, hata model, SUI etc.are the examples of Empirical models. [10] Here, our focus is on Empirical path loss models.

V. EMPPIRICAL PATH LOSS MOSELS

The different types of Empirical path loss models are discussed below:-

A. Okumura model

Okumura's model is widely used for signal prediction in urban areas. This model is applicable for frequencies range for 150MHz to 1920MHz and distances of 1km to 100km. It can also be used for base station antenna heights ranging from 30m to 1000m. This model uses a base station antenna height (h_t) of 200m and a mobile station antenna height (h_r) of 3m. To determine path loss using this model, the free space path loss between the points is first determined, and then the value of A_{mu} (f, d) is added to it along with correction factors to account for the type of terrain.[5] This model can be expressed as

$$PL_{50}\,(dB) = L_F + A_{mu}\,(f, d) - G\,(h_t) - G\,(h_r) - G_{AREA} \quad (1)$$

Where PL_{50} is the 50^{th} percentile value of propagation path loss, L_F is the free space propagation path loss, A_{mu} is the median attenuation relative to free space, $G(h_t)$ is the base station antenna height gain factor, $G(h_r)$ is the mobile station antenna height gain factor, G_{AREA} is the gain due to the type of environment(urban, sub-urban, and rural). The values of A_{mu} and G_{AREA} can be find out by empirical plots of okumura model.

$$G(h_t) = 20 \log (h_t/200) \qquad 1000m > h_t > 30m \quad (2)$$
$$G(h_r) = 10 \log (h_r/3) \qquad h_r \le 3m \quad (3)$$
$$G\,(h_r) = 20 \log (h_r/3) \qquad 3m<h_r<10m \quad (4)$$

$G(h_t)$ and $G(h_r)$ varies at a rate of 20dB/decade and 10dB/decade for heights less than 3m. okumura model is totally based on measured data and does not provide any analytical explanation .It is simplest and best in terms of accuracy in path loss prediction for mobile system in cluttered environments. The main disadvantage slow response to rapid changes. This model is good for urban and sub-urban areas but not good for rural areas. [

B. Hata model

Hata model is an formulation of the graphical path loss given by okumura model, and has a frequency range from 150MHz to 1500MHz. Hata presented the propagation path loss as a standard formula for urban areas.[1] The standard formula for median path loss in urban areas is given as

$$PL_{50}(dB) = 69.55+26.16\log f_c-13.82\log h_t-a(h_{re}) +(44.9-6.55\log h_t)\log d \quad (5)$$

Where PL_{50} is the 50^{th} percentile value of propagation path loss, f_c is the frequency from 150MHz to 1500MHz, h_r is the receiver antenna height ranging from 30m to 200m, h_t is the transmitter antenna height ranging from 1m to 10m, d is the distance between the transmitter and receiver(in km), $a(h_{re})$ is the correction factor for mobile antenna height which depends on the size of the coverage area. The mobile antenna correction factor for a small and medium sized city is given as

$$a(h_{re}) = (1.1\log f_c - 0.7)h_r - (1.56\log f_c - 0.8)\ dB \quad (6)$$

for a large city correction factor is given as

$$a(h_{re}) = 3.2(\log 11.75h_r)^2 - 4.97\ dB \quad \text{for } f_c \ge 300MHz \quad (7)$$
$$a(h_{re}) = 8.29(\log 1.54h_r)^2 -1.1\ dB \quad \text{for } f_c \le 300MHz \quad (8)$$

To obtain the path loss in a sub-urban and rural areas, the formula is modified as

$$PL_{50}(\text{sub-urban})(dB) = L_{50}(\text{urban}) - 2[\log(f_c/28)]^2 -5.4 \quad (9)$$
$$PL_{50}(\text{rural})(dB) = L_{50}(\text{urban}) - 4.78(\log f_c)^2 + 18.33\log f_c - 40.94 \quad (10)$$

As long as *d* exceeds 1km, the predictions of hata model is very close with the original Okumura model. Hata model is suited for large cell mobile systems, but not good for personal communications having cells of 1km radius.

C. Cost- 231 Model

It is the PCS extension to the Hata model which is used for calculating path loss in mobile wireless system. It has a frequency range from 500 MH_Z to 2000 MH_Z. To predict path loss for the distance from the Transmitter to receiver antenna (d) up to 20Km, this model is used. The transmitters antenna height is considered to be 30m to 200m and receiver antenna height is 1m to 10m[4].The standard formula to calculate path loss in urban area is

$$PL\ (db) = 46.3 + 33.9\log f_C -13.82\log ht-a\ (h_{re}) + (44.9-6.55\log h_t)\ \log d+cm \quad (11)$$

Correction factor for urban area is

$$a\ (h_{re}) = 3.2(\log 11.75h_r)^2 -4.97db \quad (12)$$

cm is defined two environments

For sub-urban cm = 0db

For urban cm = 3db

d =distance between frequency access point (AP) and CPE antennas height ranging from 1km to 20 km.

h_t is the AP antenna height ranging from 30 to 200m.

h_r =CPE antenna height from 1m to 10m.

It has a limitation that is requires the base station antenna is higher than all rooftops.

D. ECC-33 Model

The ECC path loss model is Extrapolated from original measurements by Okumura which is developed by electronic

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communication committee (ECC)[17].The standard formula for path loss is given as-

$$PL\ (db) = A_{fs} + A_{bm} - Gt - Gr \quad (13)$$

Where A_{fs} is the free space attenuation in db, A_{bm} is the basic median path loss in db, Gt is transmitter antenna height gain factor in db and Gr is receiver antenna height gain factor in db.

These parameter are individually defined as

$$A_{fs} = 92.4 + 20\log(d) + 20\log(f) \quad (14)$$

$$A_{bm} = 20.41 + 9.831\log d + 7.894\log f + 9.56(\log(f))^2 \quad (15)$$

For medium cities

$$Gt = \log(h_b/200)(13.98 + 5.8(\log d)^2) \quad (16)$$

$$Gr = (42.57 + 13.7\log(f))(\log(h_r) - 0.585 \quad (17)$$

For large cities

$$G_r = 0.759h_r - 1.892 \quad (18)$$

f is the frequency in GH_Z , d is the distance between base station and mobile station (km) , h_b is the base station antenna height (m) and h_r is the mobile station antenna height (m).

E. Sui model

This model is recommended by IEEE 802.16 broad band wireless acess working group. They proposed the channel models for frequency band below 11 GH_Z whih is proposed by Stanford University interim (SUI).The SUI model is derived for the multipoint microwave distribution system (MMDS) for the frequency range from 2.5 GH_Z to 2.7 GH_Z.

This model is categorized for three types of terrain. Terrain A for hilly area in which path loss is maximum .terrain B is categorized either mostly flat terrains or hilly terrains. Terrain c is for flat or open area in which path loss is minimum.

$$PL\ (db) = A + 10\lambda \log10(d/d_O) + X_f + X_h + S \quad \text{for } d > d_O \quad (19)$$

Where d is the distance between access point and customer promises equipment antenna in meters , d_O is 100m , S is a log normally distributed factor that is used to account for the shadow fading owing to trees and other obstacles and has a value between 8.2db and 10.6 db[20].

The other parameter A is given as:-

$$A = 20\log10(4\pi d_O/\lambda) \quad (20)$$

And the path loss exponent Y is given as

$$Y = a - bh_b + c/h_b \quad (21)$$

Where h_b is the base station antenna height above ground in meters and has a range from 10m to 80m and A,B,C are the constants depend on terrain a,b,c.

The numerical values of SUI model in different areas.

Model parameters	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

In SUI, the frequency correction factor X_f and the receiver antenna height correction factor X_h

$$X_f = 6.0\log(f/2000) \quad (22)$$

$$X_h = -10.8\log(h_r/2000) \text{ for terrain A and B} \quad (23)$$

$$X_h = -20\log(h_r/2000) \text{ for terrain C} \quad (24)$$

Where f is frequency in MH_Z and h_r is the mobile antenna height in meters.

This model is suitable to all three areas urban, suburban and rural areas for determine the path loss. [10]

F. Walfisch and bertoni model

This model considers the impact of buildings height and rooftops by using diffraction to predict average signal strength at steet level and is developed by walfilsch bertoni [26]. The model considers the path loss, PL, to be a product of three factors.

$$PL = P_o Q^2 P_1 \quad (25)$$

Where P_o represents free space path loss between isotropic antennas. Q^2 gives the rooftop signal due to the row of buildings which immediately shadow the receiver at street level. The term P_1 is based upon diffraction and the signal loss from the rooftop to the street.

The free space path loss between isotropic antennas P_o is given by

$$P_o = (\lambda / 4\pi R) \quad (26)$$

The path loss in dB is given by

$$PL(dB) = L_o + L_{rts} + L_{ms} \quad (27)$$

Where L_o is the free space path loss, L_{rts} is the “rooftop to street diffraction and scatter loss”, and L_{ms} is the multiscreen diffraction loss due to the rows of buildings.

G. *Longley –Rice Model*

The Longley-Rice Model is also referred to as ITS irregular terrain model and is applicable to point –to-point communication systems in the frequency range from 40MHz to 100MHz in the range from 1- 2000 Km for different kinds of terrain. It operates in two modes. When terrain path profile is available and specific parameters are determined then the prediction is Point- to – Point prediction. And if the terrain profile is not available, then Longley Rice model provide some techniques to determine specific parameters, then the prediction is Area mode prediction. The limitation of this model is that it does not take any account of buildings and foliage.

H. Free space path loss model

It defines how much received power is lost during propagation between transmitter and receiver in free space. In this there is only one path with any obstruction between transmitter and receiver. The standard formula for this is given as:-

$$PL_{FSPL}(dB) = 32.45 + 20\log_{10}(d) + 20\log_{10}(f) \quad (28)$$

Where d is the distance between transmitter and receiver (m) and f is the frequency in MHz

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I. Two ray ground model

This model is based on geometric optics in which two paths are considered. First, a direct path between the transmitter and receiver and a second path with one ground reflection between the same transmitter and receiver.

$$P_r(d) = P_t\, G_t G_r h_t^2 h_r^2 / d^4\, L \qquad (29)$$

The h_t and h_r are heights of the antenna which are important parameters and d is the distance between the transmitter and receiver

VI. CONCLUSION

Different models are used to calculate path loss in three types of environment urban, sub-urban and rural areas with the help of the received the received. The Okumura –Hata model used in urban area due to buildings consider .Hata model is suited for large cell mobile system, but not good for personal communication having cells of 1 K.M radius. The Longley- Rice model gives accurate result and has applications over very tough terrain because it does not take any account of building and foliage.Sui model is suitable to all three area urban, suburban and rural. The conclusion of this survey is that different path loss models give different result in different environment.

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