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Performance & Evaluation of Propagation Models for Sub-Urban Areas

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ABSTRACT: Radio wave propagation models are extremely important in radio network planning, design as well as in interference planning. Radio propagation is essential for emerging technologies with appropriate design, deployment and management strategies for any wireless network. It is heavily site specific and can vary significantly depending on terrain, frequency of operation, velocity of mobile terminal, interface sources and other dynamic factor. Accurate characterization of radio channel through key parameters and a mathematical model is important for predicting signal coverage, achievable data rates, BER and Antenna gain. Path loss models for macro cells such as Okumura, Hata and COST 231 models are analyzed and compared their parameters.

KEYWORDS: Radio propagation, Antenna gain, frequency band, Okumura model, Receiver, Base Transceiver Station (BTS), Mobile Station (MS).

I. INTRODUCTION

Wireless access network has becoming vital tools in maintaining communications especially at home and workplaces due to communication models. Propagation models help to understand the interferences in the network, which results in developing a well structured network with better quality. Those can be classified mainly into two extremes, i.e. fully empirical models and Deterministic models. There are some models which have the characteristics of both types. Those are known as Semi-empirical models. Empirical models are based on practically measured data. Since few parameters are used, these models are simple but not very accurate. The models which are categorized as empirical models for macro-cellular environment. These include Hata model, Okumura model, and Cost-231 Hata model. On the other hand, deterministic models are very accurate. Some of the examples include Ray Tracing and Ikegami model. As mentioned earlier, semi-empirical models are based on both empirical data and deterministic aspects. Cost-231W.I. model is categorized as a semi empirical model. All these models estimate the mean path loss based on parameters such as antenna heights of the transmitter and Receiver, distance between them, etc. These models have been extensively validated for mobile networks. Most of these models are based on a systematic interpretation of measurement data obtained in the service area [1][2][4][5].

II. LITERATURE SURVEY

Medeisis and A. Kajackas formulated that Okumura-Hata model provided good results in urban areas but significant errors in rural areas which need necessary changes to the Okumura- Hata model through statical analysis. H.H. Xia, H.L. Bertoni & N. Madaya reported the loss measurements made in urban and sub - urban areas where the receiving mobile was driven along pre-selected Line of Sight. A. Neskovic, N. Neskovic & G. Paunovic worked on review of popular Propagation models for wireless communication channels in Macrocell, Microcell and Indoor system. . The model for urban areas was built first and used as the base for others. Clutter and terrain categories for open areas are there are no tall trees or buildings in path, plot of land cleared for 200-400m. For examples at farmland, rice fields and open fields. For suburban area the categories is village or highway scattered with trees and houses, few obstacles near the mobile. Urban area categories is built up city or large town with large buildings and houses with two or more storey or larger villager with close houses

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III. METHODOLOGY

Accurate characterization of radio channel through key parameters and a mathematical model is important. Previous research described communication models (Okumura, Hata, Cost-231 etc.) on the basis of path loss. In this work the evaluation of communication models on the basis of signal strength, probability of error, path loss, BTS and MS antenna gain. The signal strength is described in terms of received power (Pr) at the receiver section. The comparison of communication models by taking probability of error into consideration is done by calculating probability of error (BER) of Binary phase shift keying (BPSK) modulation technique because in this work the BPSK modulation is taken for transmission for all communication models. The Base transceiver station (BTS) antenna gain and Mobile station (MS) antenna gain depends on the transmitter and receiver antenna height.

IV. PROPAGATION MODELS

A. OKUMURA MODEL

This is the most popular model that being used widely The Okumura model for Urban Areas 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. Okumura model was built into three modes which are urban, suburban and open areas. The model for urban areas was built first and used as the base for others. Clutter and terrain categories for open areas are there are no tall trees or buildings in path, plot of land cleared for 200-400m. For examples at farmland, rice fields and open fields. For suburban area the categories is village or highway scattered with trees and houses, few obstacles near the mobile. Urban area categories is built up city or large town with large buildings and houses with two or more storey or larger villager with close houses and tall, thickly grown trees[4][6][7][8].

Formula for Okumura Model is expressed below:

$L_m(dB) = L_F(d) + A_{mu}(f,d) – G(h_r) – G(h_t) – G_{AREA}$

Where;

L_m = (i.e., median) of path loss

$L_F(d)$ = free space propagation path loss.

$A_{mu}(f,d)$ = median attenuation relative to free space

$G(h_b)$ = base station antenna height gain factor

$G(h_m)$ = mobile antenna height gain factor

$G(h_b)$ = $20\log(h_b/200)$ $1000m > h_b > 30m$

$G(h_m)$ = $10\log(h_m/3)$ $h_m <= 3m$

$G(h_m)$ = $20\log(h_m/3)$ $10m > h_m > 3m$

GAREA: gain due to type of environment given in suburban, urban or open areas Correction factors like terrain related parameters can be added using a graphical form to allow for street orientation as well as transmission in suburban and open areas and over irregular terrain. Irregular terrain is divided into rolling hilly terrain, isolated mountain, general sloping terrain and mixed land-sea path. The terrain related parameters that must be evaluated to determine the various corrections factors.

B. HATA MODEL

Hata established empirical mathematical relationships to describe the graphical information given by Okumura. Hata's formulation is limited to certain ranges of input parameters and is applicable only over quasi-smooth terrain. The mathematical expression and their ranges of applicability as [2][6][7][9][10].

Carrier Frequency: $150 \text{ MHz} \le f_c \le 1500 \text{ MHz}$

Base Station (BS) Antenna Height: $30 \text{ m} \le h_b \le 200 \text{ m}$

Mobile Station (MS) Antenna Height: $1 \text{ m} \le h_m \le 10 \text{ m}$

Transmission Distance: $1 \text{ km} \le d \le 20 \text{ km}$

$A + B \log_{10}(d)$ for urban areas

$L_p(dB) = A + B \log_{10}(d) – C$ for suburban area

$A + B \log_{10}(d) – D$ for open area

Where:

$A = 69.55 + 26.161\log_{10}(f_c) – 13.82 \log_{10}(h_b) – a(h_m)$

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$B = 44.9 – 6.55 \log_{10} (h_b)$
$C = 5.4 + 2 [\log_{10} (f_c / 28)]^2$
$D = 40.94 + 4.78 [\log_{10} (f_c)]^2 – 18.33 \log_{10} (f_c)$
Where, $a (h_m)$ =

$[1.1\log_{10} (f_c) –0.7] h_m – [1.56\log_{10} (f_c) –0.8]$	for medium or small cities
$8.29[\log_{10} (1.54 h_m)]^2 – 1.1$	for large city and $f_c \leq 200$ MHz
$3.2 [\log_{10} (11.75h_m)]^2 – 4.97$	for large city and $f_c \geq 400$ MHz

C. COST-231 MODEL

Most future PCS systems are expected to operate in the 1800-2000 MHz frequency band. It has been shown that path loss can be more dramatic at these frequencies than those in the 900 MHz range. Some studies have suggested that the path loss experienced at 1845 MHz is approximately 10 dB larger than those experienced at 955 MHz, all other parameters being kept constant. The COST231-Hata model extends Hata's model for use in the 1500-2000 MHz frequency range, where it is known to underestimate path loss. The model is expressed in terms of the following parameters [7][8][11][12][13]

Carrier Frequency (f_c) 1500-2000 MHz
BS Antenna Height (hb) 30-200 m
MS Antenna Height (h_m) 1-10 m
Transmission Distance (d) 1-20 km
The path loss according to the COST-231-Hata model is expressed as:
$L_p (dB) = A + B \log10 (d) +C$
Where;
$A = 46.3+ 33.9 \log10 (f_c) – 13.28 \log10 (h_b) – a (h_m)$
$B = 44.9 – 6.55 \log 10 (h_b)$
C= 0 for medium city and suburban areas
3 for metropolitan areas

D. Calculation of Path loss

The common representation formula of different communication models is [1][2][15]

$PL (d) = PL (d0) + 10n\log10 (d/d_0)$ ...…… (1)

d= Distance between Transmitter station and Mobile station
d_o= Reference point
n= Path loss exponent

E. Calculation of probability of error

Probability of error is a performance measurement that specifies the number of bit corrupted or destroyed as they are transmitted from its source to its destination. Several factors that affect probability of error include bandwidth, SNR, transmission speed and transmission medium [3][13][14][15][16]

$P_e = ½\{1\text{-erf} [\text{sqrt} (E_b/N_o)]\}$ ……………….. (2)

E_b/N_o = Bit energy per noise spectral density.

F. Calculation of signal strength

Received signal strength is a strength which is used to measure the power between the received radio signals. The received signal strength for Okumara, Hata and Cost-231 models is calculated as [17][20][21]

$P_r = P_t + G_t + G_r –PL – A$ ……………….. (3) Where

P_r is received signal strength in dB_m.
P_t is transmitted power in dB_m.
G_t is transmitted antenna gain in dB_m.
G_r is received antenna gain in dB_m.
PL is total path loss in dB_m.
A is connector and cable loss in dB_m.
In this work, connector and cable loss are not taken into consideration

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G. Calculation of BTS antenna gain

The antenna gain for free space model can be given as

$G = 4\wedge Ae/\lambda^2$

Where

A_e = Effective aperture of an antenna.

In this work the BTS antenna gain can be calculated as [5][10][18][19]

$G_b = 20\log (h_b/200)$ ………………. (4)

Now the BTS antenna gain with correction factor can be calculated as:

$G_b = 20\log (h_b/200) - c_f$

Where,

$c_f=31$ For okumura model

$c_f = [1.1\log_{10} (f_c) - 0.7]\, h_m - [1.56\log_{10} (f_c) - 0.8]$
For Hata and cost-231model

V. RESULT AND DISCUSSION

A. Comparison of Okumura, Hata and Cost-231 model based on Path Loss

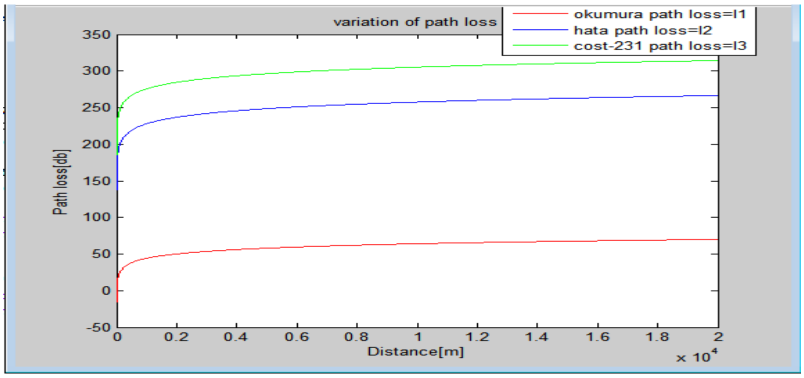

Fig1. Comparison of path loss of propagation models with respect to coverage distance.

In Sub –Urban areas the path loss in [db] of different commuication models for the same communication link when transmission distance is upto 10000 meters. Among three communication models such as Okumura model, Hata model and Cost-231 model, the Okumura model shows the least loss of signal i.e below 50db along the transmission ditance and Cost – 231 model shows highest path loss i.e about 300db.

Table1.Comparison of path loss of propagation models.

Distace(km)	Okumura path loss(db)	Hata path loss(db)	Cost 231 path loss(db)
1	44.03	227.74	275.51
10	64.03	257.57	305.34
20	70.05	266.54	314.32

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B. Comparison of Okumura, Hata and Cost-231 models based on probability of error

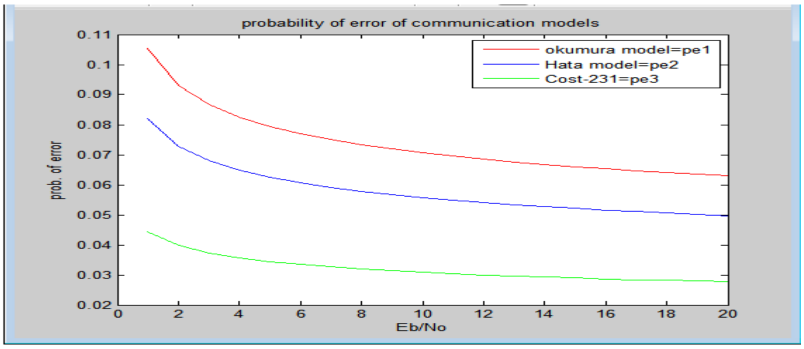

Fig 2. Comparison of propagation models based on probability of error.

The probability of error along the transmission distance for the same transmission link for different communication models such as Okumura model, Hata model and Cost-231 model. Among the three communication models Cost – 231 model shows the least Probability of error as compared to Okumura model which has the highest Probability of error.

Table 2. Comparison of propagation models based on probability of error.

Eb/No	Probability of error (Okumura model)	Probability of error (Hata model)	Probability of error (Cost-231 model)
5	0.079	0.062	0.034
10	0.070	0.055	0.030
15	0.066	0.052	0.029
20	0.062	0.049	0.027

C. Comparison of Okumura, Hata and Cost -231 models based on signal strength

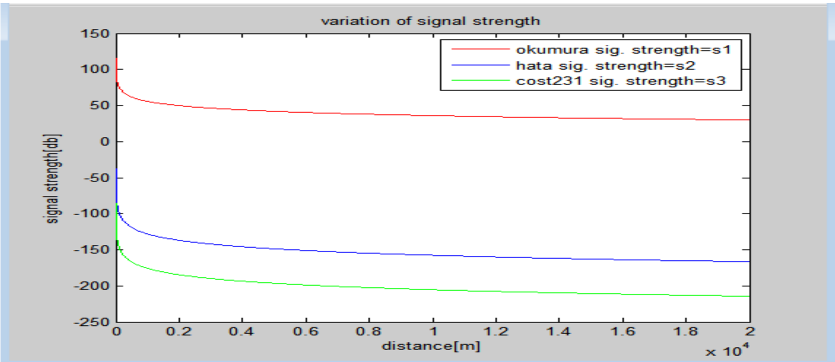

Fig 3. Comparison of signal strength of propagation models with respect to distance travelled (d)

In Sub –Urban areas the Signal Strength in [db] of different commuication models for the same communication link when transmission distance is upto 10000 meters. Among three communication models such as Okumura model, Hata model and Cost-231 model, the Okumura model shows the greatest Signal Strength i.e above 50db along the transmission ditance and Cost – 231 model shows least Signal Strength i.e about - 200db.

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Table 3. Comparison of propagation models based on signal strength with respect to distance travelled (d)

Distance (km)	Okumura model signal strength (db)	Hata model signal strength (db)	Cost-231 model signal strength (db)
5	41.98	-148.59	-196.36
10	35.96	-157.57	-205.34
15	32.44	-162.82	-210.59
20	29.94	-166.54	-214.32

D. **Comparison of Okumura , Hata and Cost-231 models based on BTS antenna gain.**

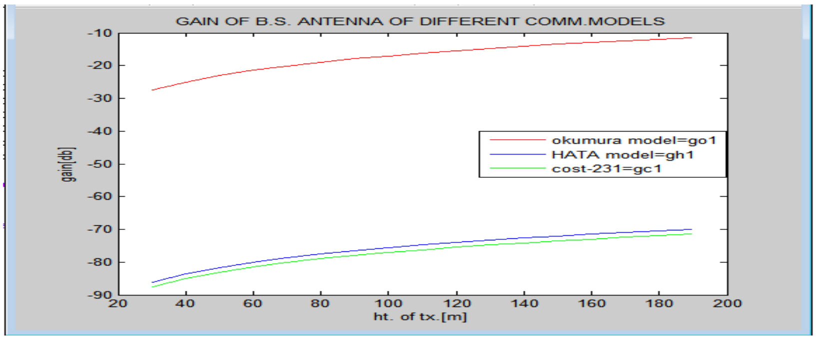

Fig 4.Comparison of communication models based on BTS antenna gain.

The BTS Antenna Gain in [db] for three different communication models such as Okumura model, Hata model and Cost-231 model. The Okumura model shows the highest Antenna Gain [-10db] in comparison to other two communication models. Hata model and Cost – 231 model has almost the similar Antenna Gain i.e [--80db].

Table 4. comparison of BTS antenna gain of comm. Models

Ht. of BTS Antenna(m)	Gain of Okumura(db)	Gain of hata(db)	Gain of cost(db)
50	-23.04	-81.60	-83.06
100	-17.02	-75.58	-77.04
150	-13.49	--72.05	-73.52

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E. Comparison of propagation models based on MS antenna gain

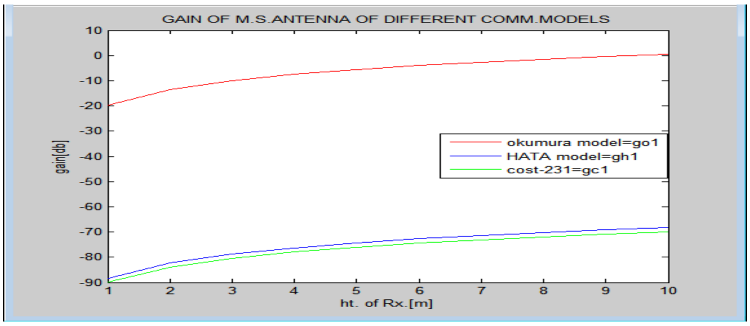

Fig 5.Comparison of communication models based on MS antenna gain.

The MS Antenna Gain in [db] for three different communication models such as Okumura model, Hata model and Cost-231 model. The Okumura model shows the highest Antenna Gain in comparison to other two communication models. Hata model and Cost – 231 model has almost the similar MS Antenna Gain.

Table 5.Comparison of MS antenna gain of comm. models.

Ht.of MS antenna(m)	Okumura gain(db)	Hata gain(db)	Cost231 gain(db)
1	-19.54	-88.30	-89.96
5	-5.56	-74.32	-75.98
10	-0.45	-68.30	-69.96

VI. CONCLUSION

In the present work, among the three communication models Okumura model shown the least path loss and Cost-231model shown the highest path loss for specified transmission distance. As the path loss for Cost-231model is high so the probability of error is less and vice-versa Okumura model has high probability of error from eqn. (1) and (2). The individual gain of Okumura , Hata and Cost 231 model shows increasing trend. Among them the okumura model shows heighest gain i.e both BTS and MS antenna gain. As for as the signal strength parameter is considered Okumura model shown the highest results because of lowest path loss and Cost-231model shown the least signal strength among the communication models .The Hata model act as the intermediate between Okumura model and Cost-231 model for the results obtained from the path loss, signal strength and probability of error.

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