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Performance Analysis of CIR and Path Loss Propagation Models in the Downlink of 3G Systems

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ABSTRACT
This paper analyses the Carrier to Interference Ratio (CIR) and path Loss (PL) variation in downlink 3G FDD-UMTS mobile system. The evaluation was taken in urban, suburban and rural environments. Also, frequency band of 2110 Hz is used in this work. The received CIR analysis is based on comparative study of seven Path Loss propagation models: COST- 231 Hata, COST-231 WIM (Walfisch-Ikegami Model), SUI (Stanford University Interim), FSM (Free Space Model), PSM (Standard propagation model), Ecricsson and ECC33 (Electronic Communication Committee). Simulation results show that SUI and SPM models showed the lowest Path Loss for all environments. Also, we can show that received CIR is affected not only by the geometry of the UMTS base station location but also by the number of users presented in each cell.

Keywords: *Carrier to Interference Ratio; Path Loss; Propagation models; signal distance; UMTS*

INTRODUCTION

In the recent years, the using of mobile communication systems has become more and more popular. More than one billion users are expected to use high data rate multimedia services through advanced mobile systems [1]. UMTS (universal Mobile Telecommunication System) technology can support a variety of services and applications with different bit rate and quality of service necessities [2]. Consequently, an efficient management of wireless spectrum is becoming more and more important. In this context, radio wave propagation modeling has been used extensively for an efficient planning and optimization of the downlink UMTS systems.

Path Loss models define the signal attenuation between the transmitting and the receiving antenna. So, path Loss is related to many parameters as the operating frequency, the distance between the sender and the receiver and different blocking obstacles [3]. The propagation environment is an important factor that must be studied in the planning and exploitation of base stations [4]. The propagation Loss is considerably related to the type of covered area (urban, suburban, rural, etc.). So, many types of Path Loss propagation models have been predicted for different area of a Mobile system. Besides, the selection of the suitable radio propagation model can reduce the maximum interference sources, achieve a high throughput and optimize the received Carrier to Interference (CIR) at the UMTS user equipment.

This paper analyses a collection of Path Loss models through a comparative study for the downlink UMTS system. The received CIR parameter is analyzed with the suitable Path Loss propagation model. Two parameters are used in this study: the geometry of the UMTS base station location and the number of users presented in inside each cell.

The paper is organized as follows; the Path Loss propagation models used in downlink UMTS Mobile system is described in Section A. Section B details with the calculation of the carrier to Interference Ratio (CIR) at the receiver UMTS system. The scenario and the downlink UMS model used in this work is defined in Section C. Simulation results and discussion are given in the section D. In Section E, we conclude the paper.

A. Signal propagation and Path Loss models

First, if a signal is transmitted through space between two base stations, it diminishes with the distance. Consequently, the received power being considerably less than the transmitted power. This phenomenon is defined as a propagation loss. The Path Loss propagation diagram between the sender and the receiver is shown in the figure 1.The propagation path between the sender and the receiver can give different scenarios includes line-of-sight (LOS) and Non Line of Sight (NLOS) caused by to diffraction (1), reflecting (2) and scattering (3).

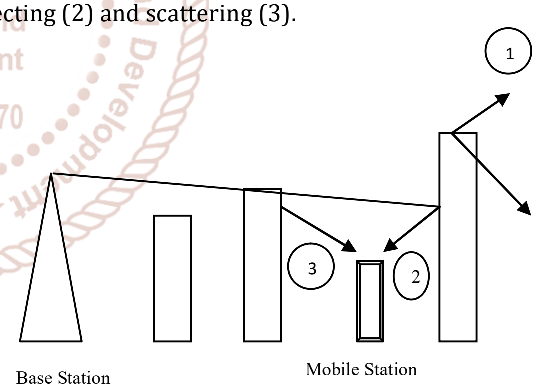

Fig.1: Path Loss propagation mechanism

The Path Loss is defined by the ratio between transmitted and received power and it is expressed by equation (1) [5]:

$$P_L(d) = PL(d_0) + 10n\log_{10}(d/d_0) \quad (1)$$

Where:
d = distance between the sender and the transmitter;
d_0 = the reference point at 1 Km;
n = the Path Loss exponent;

In order to analyze the path Loss, seven propagation models are studied in this work: COST- 231 Hata, COST-231 WIM (Walfisch-Ikegami Model), SUI (Stanford University Interim),FSM (Free Space Model), PSM (Standard propagation model), Ericson and ECC33 (Electronic Communication Committee).

Cost-231 HATA Model

The Cost 231 Hata model was designed for use in the frequency band of 1500 MHz to 2000 MHz. Although, UMTS downlink band is between 2110 MHz and 2200 MHz. So, it can be assumed, that the model is also valid in this downlink band after tuning [6] [7].

The base station height 'h_b' range is (30 m – 200 m);
The receiver antenna height 'h_m' is (1m- 10 m);
The distance between two antennas 'd' is from 1km - 2 km.
The path Loss PL in dB is equal to [7]:

$$PL(d) = A - B\log_{10}(d) + C_m \quad (2)$$

Where:

$$A = 46.3 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_b) - a(h_m) \quad (3)$$

$$B = 44.9 - 6.55\log_{10}(h_b) \quad (4)$$

f_c is the carrier frequency in MHz
C_m = 0 for urban and suburban areas;
= 3 dB for rural area;
$a(h_m)$ is defined for urban environment as:

$$a(h_m) = 320(\log_{10}(11.75))^2 - 4.97 \quad (5)$$

For suburban and rural environments, $a(h_m)$ is equal to:

$$a(h_m) = (1.1.\log_{10}(f) - 0.7)h_m - 1.56\log_{10}(f_c) - 0.8 \quad (6)$$

Cost-231 WIM Model

This propagation model describes various areas with different parameters. The cost-231 model has two separate equations for NLOS and LOS line [8].

For Urban environment, the path loss is expressed as [9]:

$$PL(d) = L_{FSL} + L_{rts} + L_{msd} \quad (7)$$

Where:

$$L_{FSL} = 32.45 + 20\log_{10}(d) + 20\log_{10}(f_c) \quad (8)$$

$$L_{rts} = -16.9 - 10\log_{10}(w) + 10\log_{10}(f) + 20\log_{10}(H_{mobile}) + L_{ori} \quad (9)$$

Where:

$$L_{ori} = 2.5 + 0.075(\varphi - 35) \qquad 35 \le \varphi \le 55 \quad (10)$$

$$L_{ori} = -4 - 0.114(\varphi - 55) \qquad 55 \le \varphi \le 90$$

$$L_{ori} = 2.5 + 0.075(\varphi - 35) \qquad 0 \le \varphi \le 35$$

$$L_{msd} = k_e + 20\log_{10}(d) + 20\log_{10}(f_c) \quad (11)$$

For suburban environment, the path loss is given by [9]:

$$PL(d) = L_{FSL} + L_{rts} + L_{msd} \quad (12)$$

With $k_f = -4 + 1.5(f/925) - 1$ (13)

For Rural environment, the path loss is equal to:

$$PL(d) = 42.6 + 26\log_{10}(d) + 20\log_{10}(f) \quad (14)$$

SUI (Stanford University Interim) Propagation Model

The propagation model is derived from the HATA model with frequency greater than 1900 MHz. The transmitter antenna height is between 10 m and 80 m and the receiver antenna height is between 2m and 10m. The model defines three terrain categories of terrain, namely A, B and C.
The path Loss propagation model is given by [10]:

$$PL(d) = A + 10\lambda\log_{10}(d/d_0) + X_f + X_h + S \quad (15)$$

$$A = 20\log_{10}(4\pi d_0/\lambda) \quad (16)$$

$$\lambda = a - bh_b + c/h_b \quad (17)$$

Where:
X_f: The correction for frequency in MHz
X_h: The correction for receiving the antenna height in meters
S: The correction for shadowing in dB;
λ : The path loss exponent; d0=100 m;

a, b and c are constants and they are related to the type of the terrain as defined in the table 1.

Table 1: SUI Model terrain parameters

Parameters	Terrain A	Terrain B	Terrain C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	126	17.1	20

FSM (Free Space Model)

The propagation environment for this model is assumed as a free space and there are no obstacles in the alleyway between the transmitter and receiver. Free Space Model is various on frequency and distance and the Path Loss equation is defined as [11]:

$$PL(d) = 32.45 + 20log_{10}(d) + 20log_{10}(f_c) \quad (18)$$

SPM (Standard Propagation Model)

The standard propagation model is derived from the formula Hata. It is suitable for frequencies between 150 MHz and 3500 MHz and for long distance between 1 km and 20 km. The Path Loss equation in dB in equal to [12]:

$$PL(d) = A_1 + A_2\log_{10}(f_c) + A_3\log_{10}(h_b) + [B_1 + B_2og(h_b) + B_3h_b] .\log_{10}(d) - a(h_m) - C_{cluster} \quad (19)$$

Where:
A_1, A_2, A_3, B_1, B_2, and B_3: *Hata parameters*
h_b defines the transmitter antenna height;
$C_{cluster}$ is the cluster correction function;
h_m is the receiver antenna height;
d is the distance in km;
f_c is the carrier frequency in MHz.

The Hata parameters of different terrain for SPM models are detailed in the table 2.

Table 2: Hata Parameters of SPM model

Parameters	Urban	Suburban	Rural
A_1	24,45	16,45	9,45
A_2	44,900002	44,900002	44,900002
A_3	5,83	5,83	5,83
B_1	0	0	0
B_2	-6,55	-6,55	-6,55
B_3	0	0	0
$C_{cluster}$	0	0	0

Ericsson Propagation Model

This model is an extension of Okumara hata Model. It is used for three environments such as urban, suburban and rural. The path Loss equation of the Ericson model is done by [13]:

$$PL(d) = a_0 + a_1\log_{10}(d) + a_2\log_{10}(h_b) + a_3Log_{10}(h_b).\log_{10}(d) - 3.2.[\log_{10}(11.75h_m)^2] + g(f_c) \quad (20)$$

Where

$$g(f) = 44.49\log_{10}(f_c) - 4.78[\log_{10}(f_c)]^2 \quad (21)$$

h_b defines the transmitter antenna height;
h_m define the receiver antenna height;
f_c is the carrier frequency in MHz ;
d is the distance in km;

Table3. Default values of Parameters in Ericson Model

Environment	a_0	a_1	a_2	a_3
Urban	36.20	30.20	-12.0	0.1
Suburban	43.20	68.90	12.0	0.1
Rural	45.95	100.6	12.0	0.1

The different parameters (a_0, a_1, a_2, a_3) for various type of terrain are given in table 3.

ECC33 (Electronic Communication Committee) Model
The ECC-33 propagation model is used for the high frequencies. The path Loss equation for the ECC-33 model is defined as [14]:

$$PL = A_{fs} - A_{hm} - G_b - G_r \tag{22}$$

Where:
A_{fs} is the free space attenuation;
A_{hm} is the basic median Path Loss;
G_b is the base station height gain;
G_r is the received antenna height gain.
Then, A_{fs}, A_{hm}, G_b and G_r are, respectively, defined as:

$$A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f_c) \tag{23}$$

$$A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.89\log_{10}(f_c) + 9.56[\log_{10}(f_c)]^2 \tag{24}$$

$$G_b = \log_{10}(h_b/200)[13.958 + 5.8[\log_{10}(d)]^2 \tag{25}$$

For medium city, G_r is equal to:

$$G_r = [42.57 + 13.7\log_{10}(f_c)][\log_{10}(h_m) - 0.585] \tag{26}$$

And For large city G_r is defined as:

$$G_r = 0.759 h_m - 1.5682 \tag{27}$$

Where:
h_b defines the transmitter antenna height;
h_m defines the receiver antenna height;
f_c is the carrier frequency in MHz;
d is the distance in km.

A. CIR and Path Loss propagation
The Carrier To Interference Ratio, CIR, is the most important parameter to evaluate the performance of mobile communication systems. A sufficient CIR must be guaranteed at the receiver in order to diminish the signal attenuation that occurs with radio propagation. CIR is defined as the ratio between the received wanted carrier signal power and the sum of all received interference power. The CIR is calculated as:

$$CIR = \frac{C}{I} = \frac{C}{\sum_n I_n + P_N} \tag{28}$$

Where:
C is the carrier power happening in the Mobile receiver;
I is the total interference I_n that takes place in the receiver from others base stations;

P_N represents the total thermal noise power in the receiver and n is the number of interfering base stations.

In our present work, we will study the downlink UMTS –FDD system (base station sends and mobile station receives) as described in the figure 2. Then, the source of interference will be the other base stations that transmit on the same frequency and the radio signal of which will be received by the studied mobile station.

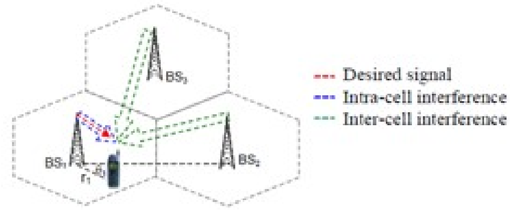

Fig.2: Intra and Inter cell interferences

The total interference I is composed by two parts: intra-cell interference and inter-cell interference. Intra-cell interference is caused the partial loss of orthogonality between the different codes attributed by the Base station to all users in the same cell. However, the interference inter-cell that is the power received by mobile station from Base station in adjacent cells.

The mathematical model to calculate the intra-cell interference on mobile station, MS_i served by the base station, BS_j is given by [15]:

$$I^{DL}_{intra,i} = (P_{total,j} - P_{j,i}).\alpha.PL_{i,j} \tag{28}$$

Where:
$P_{total,j}$ is the total power transmitted by the base station BS_j;
$P_{j,i}$ is the the transmitted power from BS_j to MS_i, α the orthoganality factor and $PL_{i,j}$ define the Path Loss between the MS_i and the BS_j;

Assuming that the transmitted power by the base station BS_j to the each mobile station k, MS_k, placed in the same cell of MS_i are equals to $P_{j,i}$. Then, we can write equation (28) as:

$$I^{DL}_{intra,i} = \alpha.PL_{i,j}.\sum_{k=1,k\neq i}^{N_k} P_{j,k} = (N_k - 1)\alpha.PL_{i,j}.P_{j,i} \tag{29}$$

Where:
$P_{j,k}$ is the power transmitted by BS_j to each mobile station MS_k;
N_k is the number of mobile station MS_k.
The mathematical model of the inter-cell interference on mobile station, MS_i served by the base station, BS_j, is given by:

$$I^{DL}_{inter,i} = \alpha\sum_{j=1}^{N_s}(P_{total,j} - P_{j,i}).PL_{i,j}) \tag{30}$$

Where:
N_s is the number of all adjacent cell j served by base station BS_j;
$P_{total,j}$ is the power transmitted by BS_j to mobile station MS_i;
$PL_{i,j}$ defines the Path Loss between the MS_i and the each base station BS_j.
Assuming that all users have the same bit rate and all base stations BS_j transmit the same power $P_{total,j}$ to the mobile station), then:

$$P_{total,1=P_{total,2}} = ... = P_{total,N_s} = N_k.P_{j,i} \tag{31}$$

Then, using equations (30)-(31), we have:

$$I^{DL}_{inter,i} = (N_k - 1)\sum_{j=1}^{N_s}(P_{j,i}.PL_{i,j})$$

The final expression of C/I using (28)-(31) is equal to:

$$CIR = \frac{C}{I} = \frac{P_{j,i}}{[(N_k - 1)\alpha.PL_{i,j}.P_{j,i}] + (N_k - 1)\sum_{j=1}^{N_s}(P_{j,i}.PL_{i,j}) + P_N} \quad (32)$$

It is clear that the CIR at the mobile receiver is inversely proportional to the path Loss.

B. Downlink UMTS model

In this paper, the study should focus on the downlink UMTS/FDD system with multi-cell environment. The present model is shown in figure 3. Simulation parameters used in this scenario are given in table 4.

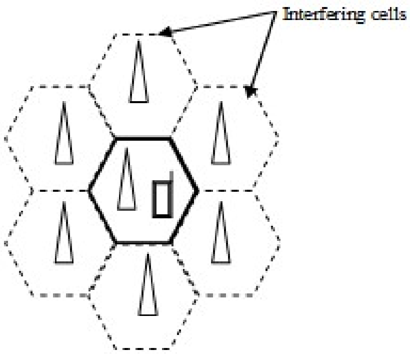

Fig.3: Proposed FDD/UMTS scenario

Table 1: FDD/UMTS model parameters

Parameter	Value
Cell number N_s	6
Mobiles number N_k	30
BS Transmission Power [dBm]	43
Frequency Band [MHz]	2110
Noise Figure [dB]	9
Orthogonality factor, α	0.7
chip rate	3.84 Mcps
Cell radius, R	20 Km
Processing gain	25

In order to calculate the distance between the mobile and each base station, we use the model in figure 4 to simplify the calculation:

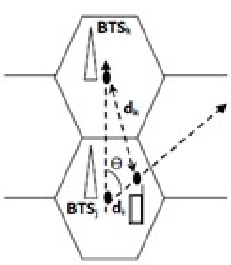

Fig.4: Modeling of distance between Mobile and base station

Where d_j is the distance between MS_i and the suitable base station BS_j. d_k define the distance between MS_i and other base station BS_k.Using the formula of EL Kashi [16], we can write:

$$d_i = \sqrt{d_k^{\,2} + (\sqrt{3}R)^2 - 2\sqrt{3}R\cos\theta} \qquad (33)$$

Where:

R is the radius of each cell; θ is the angle between axis formed by BS_j and BS_j with MS_i.

C. Simulation results and discussion

The measured data was taken in urban, suburban and rural environments at 2100 MHz all propagation models are calculated using MATLAB Software. Figures 5-7 shows the variation in path loss with the distance *d* respectively for Urban, suburban and rural areas. All studied propagation models are simulated.

So, by observing the path loss variation for urban area in figure 5, it is clear that SPM propagation model have the least path loss and ECC33 propagation model have the highest value in different distances compared with all others propagation models.

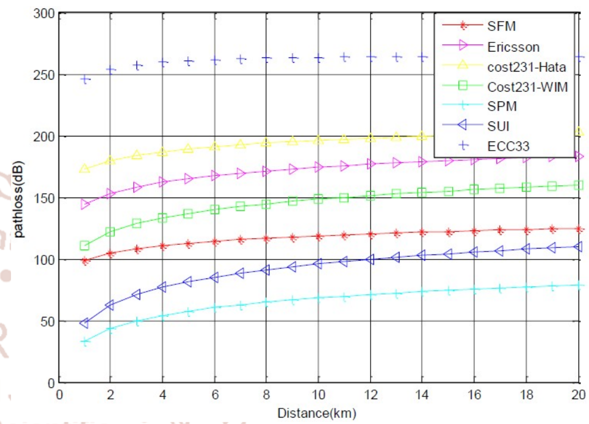

Fig.5: Comparison of path loss model variation from urban area

Figure 6 shows the variation of path loss for suburban location. It is clear that SPM model provides the better prediction across all distances compared with others propagation model. However,

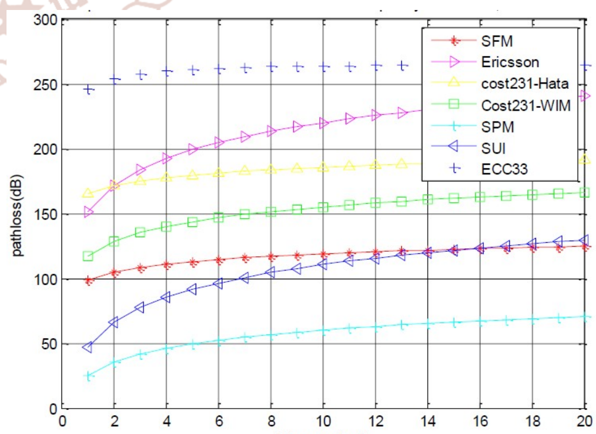

Fig.6: Comparison of Path Loss model variation from suburban area

The simulation results of reviewed models for rural environments are shown in figure 7. IT can be observed that SPM model in rural have the smallest path loss at the same distance compared with results obtained in urban and suburban area.

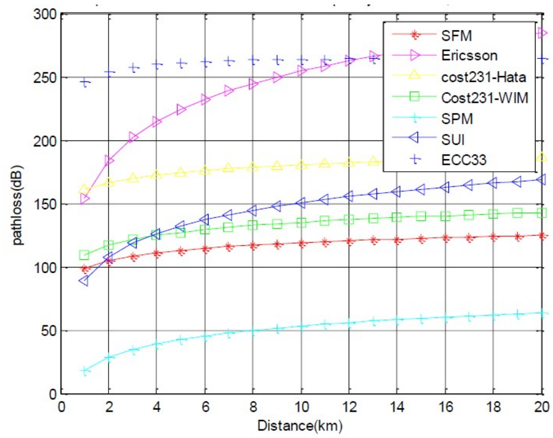

Fig.7: Comparison of path loss model variation from rural area

The SPM model is used in figure 8 in order to simulate the variation of CIR with distance for different angles θ. It can be observed that the With the smallest distance d, the variation of angle has not effect on the CIR at received signal; however, for long distance, a small angle can increase the interference and will degrade CIR. The best CIR value is taken with an angle of 120° in this case.

Figure 9 shows the variation of CIR with the number of user in the same cell. An angle of 120° has been chosen for this simulation

The SPM model is used in figure 8 in order to simulate the variation of

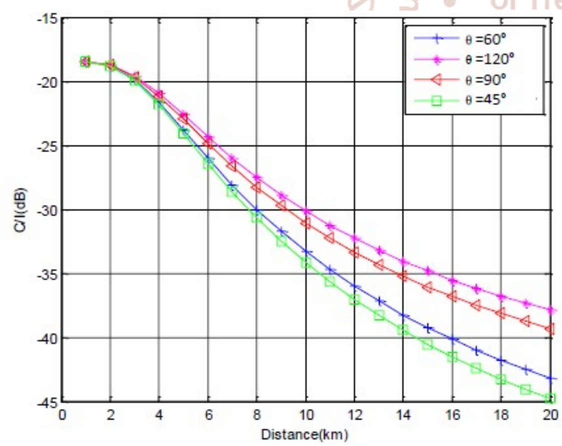

Fig.8: CIR variation with angle θ for different distances

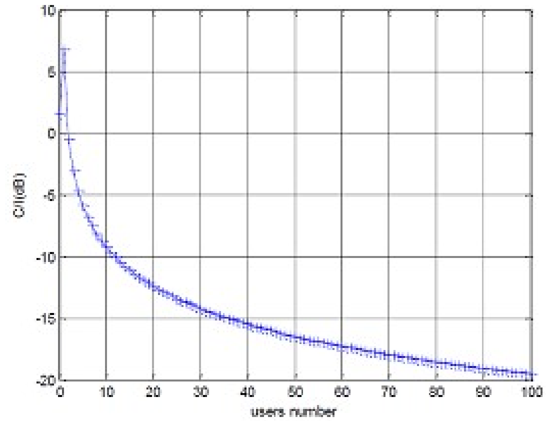

Fig.9: CIR variation with the number of user.

If we increase the number of user in the same cell, the total interference will be increase. Consequently, the CIR at received system is inversely proportional to the number of user. The interference level is directly related to the user's density in the same cell.

D. Conclusion

The main objective of this research is to analyze the path loss propagation models and CIR effects for urban, suburban and rural environments in FDD/UMTS system. The path loss has been simulated using seven models, COST- 231 Hata, COST-231 WIM (Walfisch-Ikegami Model), SUI (Stanford University Interim),FSM (Free Space Model), PSM (Standard propagation model), Ericson and ECC33 (Electronic Communication Committee) models. Path loss values of different models are analyzed and compared in urban, suburban and rural environments at 2110 MHz It can be concluded that SPM model gives better results for all environments. The CIR calculation and simulation with SPM model is detailed for a FDD/UMTS scenario. Simulation results show that the CIR at received system is inversely proportional to the number of user in the cell and it is affected by the position of mobile.

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