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Comparative Study of Radio Channel Propagation and Modeling for 4G Wireless Systems

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Abstract*— This paper concerns about the radio propagation models used for the upcoming 4th Generation (4G) of cellular networks. A comprehensive review of the propagation prediction models for 4G wireless communication systems is presented and computation of path loss due to specific terrain and clutter environment has been carried using MATLAB based simulations for various prediction techniques such as COST-231 Hata model, COST-231 Walfish-Ikegami method, SUI model and ITU-R(1411.1) model for broadband and mobile services. The results showed that COST-231Hata's method gave better agreement in terms of path loss values in urban, suburban and rural areas as compared to COST-231 Walfisch–Ikegami model. COST-231 Hata model shows the lowest path loss in all the terrains whereas ITU-R(NLOS) model has highest path loss values. The prediction errors of the SUI and ITU-R NLOS models are considerably higher than those of the COST-231Hata and COST-231 Walfisch– Ikegami models.

***Index Terms*— LTE , Path loss, Propagation models**

I. INTRODUCTION

The tremendous development in wireless communications leads to the emergence of new ideas and techniques to increase capacity and improve the QoS. The general trend in the development of wireless communication is the use of higher data rates (broader frequency band), propagation in more complex environments, employment of smart antennas, and use of multiple-input multiple-output (MIMO) systems with smaller cell sizes. The 4G system will provide an all-IP network that integrates several services available at present and provides new ones, including broadcast, cellular, cordless, WLAN, and short-range communication systems. Before implementing designs and confirming planning of wireless communication systems, accurate propagation characteristics of the environment should be known. The fast evolution of wireless communications has lead to the use of higher frequency bands, smaller cell sizes, and smart antenna systems, making the propagation prediction issues more challenging since wireless communication channels are inherently frequency dispersive, time varying, and space selective. LTE will be having a downlink speed of 100 Mbps and an uplink of almost 50 Mbps. The channel will be having a scalable bandwidth from 1 MHz to 20 MHz while supporting both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) [1]. These data rates can be further increased by employing multiple antennas both at the transmitter and receiver.

As the demand for mobile communication services increases, deterministic propagation prediction techniques play an important role in the optimization of the coverage and the efficient use of the available resources [2].

The ability to predict the minimum power necessary to transmit from a given base station at a given frequency, and to provide an acceptable quality of coverage over a predetermined service area, and to estimate the effect of such transmissions on existing adjacent services, is crucial for the improvement of frequency reuse and the implementation of band sharing schemes between different services and for the success of cellular systems. There is a need for a better understanding of the influence of the different urban and terrain factors on the mobile radio signal and its variability. In this paper, a comparison is made between different proposed propagation models that would be used for 4G wireless system for different transmitting antenna heights, like Stanford University Interim (SUI) model [3], COST-231 Hata model [4], COST Walfisch-Ikegami model [5] and ITU-R(1411.1) [6] and computation of path loss due to specific terrain and clutter environment has been carried using MATLAB based simulations for various prediction Suitable models have been identified after comparing their mean prediction errors (MEs) and standard deviations (SDs).

In Section II, details of different propagation models have been provided. In Section III, we have analyzed and compared the existing path-loss models . Conclusions are presented in Section IV.

II. PROPAGATION PATH LOSS MODELS

A. SUI Model

The SUI model was developed under the Institute of Electrical and Electronics Engineers (IEEE) 802.16 working group for prediction of path loss in urban, suburban and rural environments [7]. The applicability of this model in the higher frequency has not been validated. However, due to the availability of correction factors for the operating frequency, this model is selected for this study. The path loss in SUI mode [3] is calculated using (1)

$$L = A + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + s \quad \text{for } d > d_0 \qquad (1)$$

where, d is the distance between the base station and the receiver antenna in metres, d_0 = 100 m and s is a lognormal distributed factor that is used to account for the shadow fading owing to trees and other clutter and has a value between 8.2 dB and 10.6 dB . The other parameters are defined as,

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$$A=20\log_{10}\left(\frac{4\Pi d_0}{\lambda}\right) \quad (2)$$

$$\gamma=a-bh_b+c/h_b \quad (3)$$

where, the parameter h_b is the base station height above ground in meters and should be between 10 m and 80 m .The constants used for a, b and c are given in Table I.

TABLE I SUI MODEL PARAMETER

Model Parameter	Terrain type A	Terrain type B	Terrain type C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

B. COST-231 Hata Model

This model has been developed based on experimental measurements conducted by Okumura in Tokyo (Japan) region [4], [8], [9], [10]. Experimental formula for propagation path loss L in dB by Hata [4]

$$L\{urbanarea\}=69.55+26.16\log_{10} f-13.82\log_{10} h_b-c(h_m)+(44.9-6.55\log_{10} h_b)\log_{10} d \quad (4)$$

where f is the frequency (in MHz) from 150 MHz to 1500 MHz, h_b is the effective transmitter (base station) antenna height (in meters) ranging from 30m to 200m, h_m is the effective receiver antenna height (in meters) ranging from 1m to 10m, d is the T-R separation distance (in km) ranging from 1 to 10 km, and $c(h_m)$ is the correction factor depending on the mobile station antenna height which is function of the size of the coverage area. For small to medium sized city, the mobile antenna correction factor is defined as

$$c(h_m)=(1.1\log_{10} f-0.7)h_m-(1.56\log_{10} f-0.8)\,dB$$

(5)and for a large city, the correction factor $c(h_m)$ is defined as

$$c(h_m)=8.29(\log_{10}1.54h_m)^2-1.1 \quad for\ f\le 300\,MHz \quad (6)$$

$$c(h_m)=3.2(\log_{10}11.75h_m)^2-4.97 \quad for\ f\ge 300\,MHz \quad (7)$$

The path losses L_S and L_O in dB for suburban and open areas are given in equations (8) and (9) respectively.

$$L_S=L\{urbanarea\}-2\{\log_{10}(f/28)\}^2-5.4 \quad (8)$$

$$L_O=L\{urbanarea\}-4.78\{(\log_{10} f)^2\}+18.33\log_{10} f-40.94 \quad (9)$$

This model is well suited for large cell mobile systems, but not personal communications systems (PCS) which have cell on the order of 1 km radius.

C. COST Walfisch-Ikegami Model

Walfisch-Bertoni method is combined with the Ikegami model [5], to improve path loss estimation through the inclusion of more data. Four factors height of buildings, width of roads, building separation, road orientation with respect to the LOS path are included. In the non-LOS case the basic transmission loss comprises the free space path loss L that is same as in equation (2.5), the multiple screen diffraction loss L_{msd} and the rooftop to street diffraction and scatter loss L_{rts}. Thus the path loss L in non LOS is defined as

$$L=\begin{cases} L+L_{rts}+L_{msd} & L_{rts}+L_{msd}>0 \\ L & L_{rts}+L_{msd}<0 \end{cases} \quad (10)$$

The determination of L_{rts} is based on the principle given in the Ikegami model, but with a different street orientation function .The values of L_{rts} are as follows

$$L_{rts}=-16.9-10\log_{10} w+10\log_{10} f_{MHz}+20\log_{10}(h-h_m)+L_{ori} \quad (11)$$

where w, h and h_m are gap between buildings, height of building and height of mobile stations respectively.

$$L_{ori}=\begin{cases} -10+0.354\psi & 0^0\le\psi<35^0 \\ 2.5+0.075(\psi-35) & 35^0\le\psi<55^0 \\ 4.0-0.114(\psi-55) & 55^0\le\psi<90^0 \end{cases} \quad (12)$$

where L_{ori} is a factor which has been estimated from only a small number of measurements, ψ is street orientation angle. The multiple screen diffraction loss was estimated by Walfisch and Bertoni for the case when the base station antenna is above the rooftops i.e. $h_b>h$.

The relevant equations are

$$L_{msd}=L_{bsh}+k_a+k_d\log_{10} d_{km}+k_f\log_{10} f_{MHz}-9\log_{10} b \quad (13)$$

where

$$L_{bsh}=\begin{cases} -18\log_{10}[1+(h_b-h)] & h_b>h \\ 0 & h_b\le h \end{cases} \quad (14)$$

$$k_a=\begin{cases} 54 & h_b>h \\ 54-0.8(h_b-h) & h_b\le h\ and\ d_{km}\ge 0.5km \\ 54-0.8(h_b-h)\dfrac{d}{0.5} & h_b\le h\ and\ d_{km}<0.5km \end{cases} \quad (15)$$

$$k_d=\begin{cases} 18 & h_b>h \\ 18-15\dfrac{(h_b-h)}{h} & h_b\le h \end{cases} \quad (16)$$

$$k_f=-4+\begin{cases} 0.7\left(\dfrac{f_{MHz}}{925}-1\right) & for\ medium\ sized\ cities\ and\ suburban\ centres\ with\ medium\ tree\ density \\ 1.5\left(\dfrac{f_{MHz}}{925}-1\right) & for\ metropolitan\ centres \end{cases} \quad (17)$$

The term k_a represents the increase in path loss when the base station antenna is below rooftop height. The term k_d and k_f allow for the dependence of the diffraction loss on range and frequency, respectively.

D. ITU-R (P.1411-1)

NLOS [6] signals can arrive at the BS or MS by diffraction mechanisms or by multipath which may be a combination of diffraction and reflection mechanisms. In the model for transmission loss in the NLOS for roof-tops of similar height, the loss between isotropic antennas is expressed as the sum of free-space loss, L_{bf}, the diffraction loss from roof-top to street

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L_{rts} and the reduction due to multiple screen diffraction past rows of buildings, L_{msd}. In this model L_{bf} and L_{rts} are independent of the BS antenna height, while L_{msd} is dependent on whether the base station antenna is at, below or above building heights. In the non-LOS case the basic transmission loss comprises the free space path loss L, the multiple screen diffraction loss L_{msd} and the rooftop to street diffraction and scatter loss L_{rts}. Thus the path loss L_b in non LOS is defined as

$$L_b = \begin{cases} L_B + L_{rts} + L_{msd} & L_{rts} + L_{msd} > 0 \\ L_B & L_{rts} + L_{msd} < 0 \end{cases} \quad (18)$$

The term L_{rts} describes the coupling of the wave propagating along the multiple-screen path into the street where the mobile station is located. It takes into account the width of the street and its orientation. The values of L_{rts} are as follows

$$L_{rts} = -8.2 - 10\log_{10} w + 10\log_{10} f_{MHz} + 20\log_{10}(h - h_m) + L_{ori}$$

(19)

where w, h and h_m are gap between buildings, height of building and height of mobile stations respectively. L_{ori} is the street orientation correction factor, which takes into account the effect of roof-top-to street diffraction into streets that are not perpendicular to the direction of propagation and same as (12). The multiple screen diffraction loss from the BS due to propagation past rows of buildings depends on the BS antenna height relative to the building heights and on the incidence angle. The relevant equations are same as given above. The details of simulation parameters are given in Table II.

III. PATH LOSS ANALYSIS

Figures 1 to 3 show the comparison of path loss values for COST-231 Hata model at frequencies 1900 MHz, 2100 MHz and 2300 MHz for different terrains. In figure 1, close to transmitter path losses varied from 100-120 dB and at distances beyond 500 m, path loss was confined between 110-160 dB. It is observed that as frequency increases path loss values are decreasing in proportion. It is observed from the Fig. 4 that path loss values are less for suburban and open rural areas as compared with urban scenario. In Fig. 5, COST-WI model is compared at frequencies 1900 MHz, 2100 MHz ans 2300 MHz. Fig. 6 shows the path loss values of different models at 2300 MHz. It is observed that COST-WI and COST-231 Hata methods have least path loss values. In Table III the corresponding error statistics in terms of mean prediction error, μ, and the standard deviation of the prediction errors, σ, are given for each model for different transmitting antenna heights. An examination of the table III shows that path loss exponents from SUI method are around 4.0 for all base stations and around 3.8 for ITU-R (NLOS). Mean prediction error of COST-WI model and COST-231 Hata is less then that of mean prediction error of SUI model and ITU-R(NLOS) model. Abhayawardana *etal.* [3] observed that SUI model showed large mean path loss prediction errors. They felt that it is highly recommended for urban environments and should be applicable for lightly built European cities. Mardeni [11] based on 2.3GHz measurements in the suburban and open urban environments in the Malaysia observed that out of SUI, COST-231 Hata, Egli, COST-231 Hata showed closest agreement with observations in terms of path loss exponent prediction and standard deviation error analysis. As transmitting antenna height increases, error's standard deviation decreases from 0.8 to 0.9 for different prediction methods.

IV. CONCLUSION

A comprehensive review of the propagation prediction models for 4G wireless communication systems is presented and computation of path loss values due to specific terrain and clutter environment has been carried using MATLAB based simulations for various prediction techniques such as COST-231 Hata model, COST Walfish-Ikegami method, SUI model and ITU-R(1411.1) model for broadband and mobile services. A comparison of different prediction methods showed that COST-231 Hata's prediction method gave least path loss. The advantage of this method lies in its adaptability to different environments by incorporating correction factors for various environments. The prediction errors of the SUI and ITU-R NLOS models are considerably higher than those of the COST-231Hata and COST Walfisch– Ikegami models.

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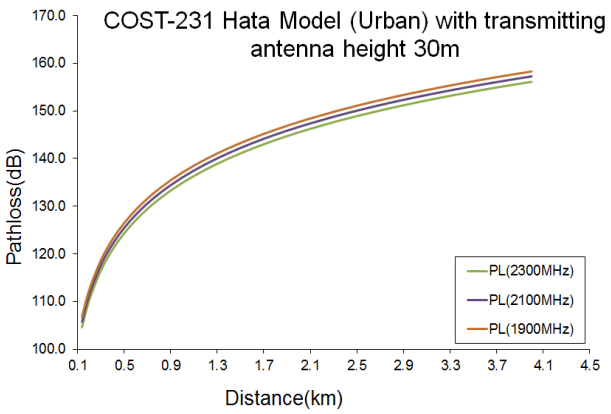

Fig.1. Comparison of path losses for COST-231 Hata model (Urban) at different frequencies

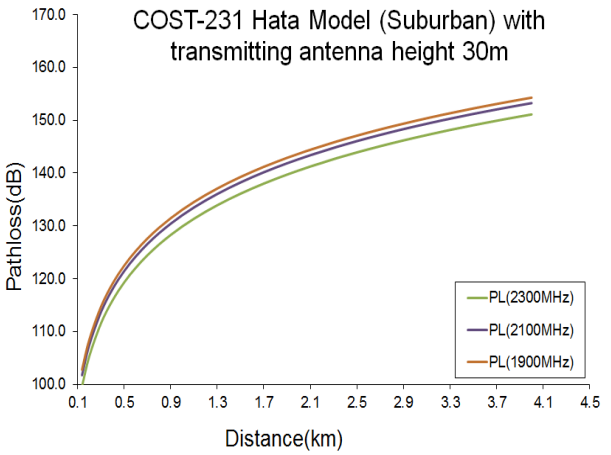

Fig.2. Comparison of path losses for COST-231 Hata model (Suburban) at different frequencies

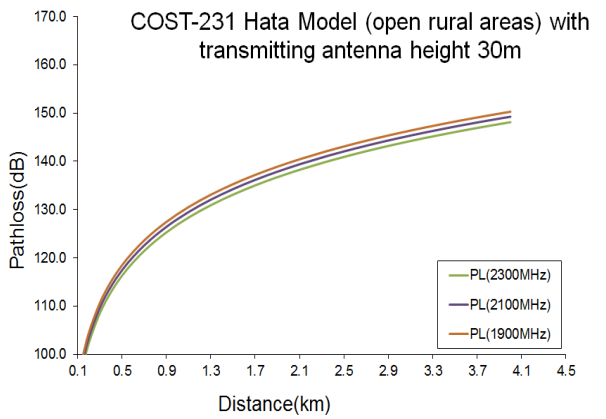

Fig.3. Comparison of path losses for COST-231 Hata model (open rural) at different frequencies

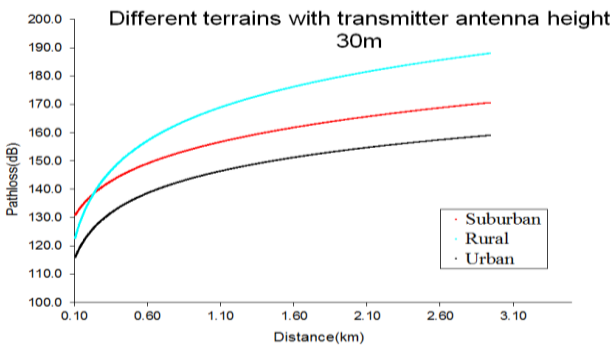

Fig.4. Comparison of path losses for COST-231 Hata model for different terrains

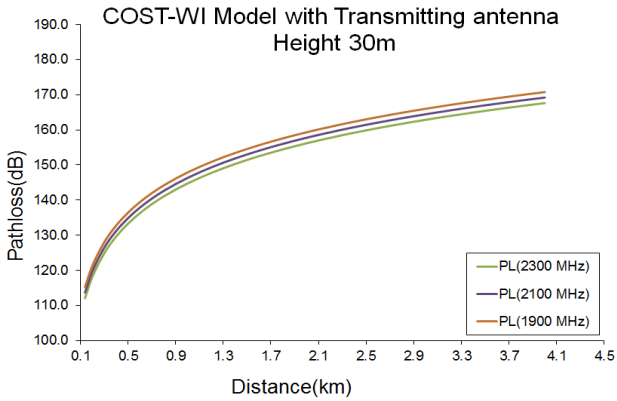

Fig.5. Comparison of path losses for COST-WI model (Urban) at different frequencies

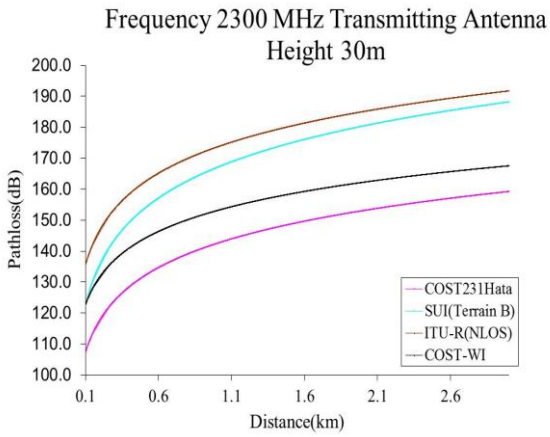

Fig.6. Comparison of path losses for different propagation model

TABLE II
DETAILS OF SIMULATION PARAMETERS

S.No.	Details	
1.	Height of receiving antenna	1.5m
2.	Transmitted power	43dBm
3.	Average Height of building	25m
4.	Average street width	15m
5.	Average separation between buildings	30m
6.	Street orientation angle	90 degrees

TABLE III
COMPARISON OF STATISTICAL PARAMETERS

Ht.	COST-231HATA			COST-WI			SUI			ITU-R(NLOS)		
	n	μ	σ	n	μ	σ	n	μ	σ	n	μ	σ
30m	3.5	-0.2	6.7	3.2	-12.9	6.8	4.3	-23.3	7.1	3.8	-28.4	6.8
40m	3.5	4.9	5.9	3.3	-6.7	5.9	4.4	-20.1	6.2	3.8	-26.6	6.0

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