Performance Analysis of Various Path Loss Models for Wireless Network in Different Environments

Imranullah Khan, Tan Chon Eng, Shakeel Ahmed Kamboh

Abstract—This paper aims to investigate the performance of various path loss models in different environments for determination of the signal strength with respect to various receiver antenna heights for wireless network at 2.4GHz unlicensed band. A total of seven path loss models, namely Free Space, COST-231 HATA, ECC-33, SUI, HATA, COST-231 WI, HATA and Ericsson models have been reviewed with different receiver antenna heights in urban, suburban and rural environments. The estimated results produced by Free Space model were used as reference values. All estimated results of reviewed models were compared with the reference model values. It was found that COST-231 HATA model demonstrated highest path loss with 39% more values than reference model in urban environments. Ericson model established highest path loss values with 55% and 77% more estimated results than reference model in suburban and rural environments respectively. COST-231 WI model executed the lowest path loss amount with 12.6% more values than reference model in rural environments. SUI model established the results with 10% difference as compared to reference model at lower receiver antenna heights. It was revealed that the models results were incongruent due to incorporation of different variables and terrain classification. Therefore, a particular model cannot be recommended for the estimation of path loss at various antenna heights in all environments. However, SUI model could be preferred due to better performance in terms of less path loss as compared with the results of reference model at lower receiver antenna heights for suburban and rural environments.

Keywords- path loss; free space model; cost-231 Hata model; ECC-33 model; SUI model; Hata model; cost-231 WI model; Ericsson model.

I. INTRODUCTION

In wireless communication systems, the information is transmitted between transmitter and receiver antenna by electromagnetic waves. The signal strength of electromagnetic waves weakens during propagation through environment [1]. The difference of signal strengths from transmitter (transmitter) to receiver (destination) antenna is termed as path loss. Path loss (PL) at destination is generally determined by the use of different models i.e., stochastic, deterministic and empirical [2], [3], [4], [5], [6], [7]. The major elements causing path loss are free space, absorption, diffraction and multipath signal losses [8], [9], [10], [11].

Various path loss models are available in literature for different types of environments such as urban, suburban, and rural. The majority of researchers standardized the models for all types of environments [8]. However, a few models are standardized for rural environments. It is observed that the most models accommodate only the important parameters such as distance, carrier frequency and antenna heights at various geographical locations for wireless network for unlicensed band whereas, the insignificant parameters are ignored.

II. DESCRIPTION OF SELECTED MODELS

The brief description of the selected models is given in Table 1. For Free Space Path Loss (FSPL, the propagation environment is assumed as free space [1],[9]. HATA model is applicable for a frequency range of 150-1500 MHz [1]. Different correction factors are being used for suburban and rural environments [13]. HATA model used the value of correction factor K from 35.94 for countryside and 40.94 for deserts [16]. HATA model provides extension to Okumura model for distances greater than 1km. However, it does not perform well for modeling of propagations in cellular system with higher frequencies and smaller sizes [14].

COST-231 HATA model is the extension of HATA model. It is used for frequency ranges from 1500-2000 MHz. It incorporates the signal strength prediction up to 20km from transmitter to receiver with the transmitter antenna height of 30 m to 200m and receiver antenna height of 1m to 10m [8]. It is used to predict signal strength in all environments [12].

COST-231 WI model has separate equations both for line sight and non line of sight communications regarding path loss estimation. Different parameters are used to indicate free space loss, roof top to street diffraction and the multi-screen diffraction. It is more appropriate in rural environments when the communication is line of sight [16]. Non line of sight equation is used in suburban and urban environments.

ECC-33 model is one of the most extensively used empirical models, which is based on Okumura model [10], [15]. This model is widely used for urban environments especially in large and medium size cities [12]. This model was formed in Tokyo city having crowded and tallest buildings [16]. Ericsson model is applied for all the three environments such that urban, suburban and rural. In Ericsson model, definite parameters values are provided for specific propagation environments [16], [20]. Stanford University Interim (SUI) model is developed by IEEE 802.16 broadband wireless access working group [16], [17], [18]. It is derived from the

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extension of HATA model with frequency larger than 1900 MHz. The correction parameters are allowed to extend this model up to 3.5GHz band. The transmitter antenna height can be used up to 10-80m and the receiver antenna height from 2m to 10m. SUI model describes three types of terrain namely; terrain A for hilly areas with.

Table1. Description of selected reviewed models

Models	Environment	Mathematical Formulae with Antenna Height Correction Factors
Free Space	LOS	$PL = 32.45 + 20\log_{10}(d) + 20\log_{10}(f)$
HATA	Urban	$PL = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + (44.9 - 6.55\log_{10}(h_t))\log_{10}(d)$
	Suburban	$PL = PL(urban) - 2[\log_{10}(f_c/28)]^2 - 5.4$
	Rural	$PL = PL(urban) - 4.78[\log_{10}(f_c)]^2 + 18.33\log_{10}(f_c) - K$
COST-231 WI	Urban	$PL = L_{FSL} + L_{rts} + L_{msd} + s$ $L_{FSL} = 32.45 + 20\log(d) + 20\log(f)$ $L_{rts} = -16.9 - 10\log(w) + 10\log(f) + 20\log(\Delta H_{mobile}) + L_{ori}$ $\Delta H_{mobile} = h_{roof} - h_{mobile}$, $L_{ori} = -10 + 0.354\varphi$, $k_f = -4 + 0.7(f/925) - 1$ $L_{msd} = L_{bsh} + k_a + k_d\log_{10}(d) + k_f\log_{10}(f) - 9\log_{10}(f) - 9\log_{10}(B)$ $L_{bsh} = -18\log_{10}(1 + \Delta h_{base})$ and $\Delta h_{base} = h_{base} - h_{roof}$
	Suburban	$PL = L_{FSL} + L_{rts} + L_{msd} + s$ with $k_f = -4 + 1.5(f/925) - 1$
	Rural	$PL = 42.6 + 26\log(d) + 20\log(f)$
COST-231 HATA	Urban	$PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10}d + c_m$ with $ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.79$ for $f > 400MHz$
	Suburban & Rural	$PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10}d + c_m$ with $ah_m = (1.11\log_{10}f - 0.7)h_r - (1.5\log_{10}f - 0.8)$
SUI	All Types	$PL = A + 10\gamma\log_{10}(d/d_0) + X_f + X_h + s$, for $d > d_o$ $X_f = 6.0\log_{10}(f/2000)$, $X_h = -10.8\log_{10}(h_r/2000)$ For type A and B $X_h = -20.0\log_{10}(h_r/2000)$ For type C
ECC-33	Urban	$PL = A_{fs} + A_{bm} + G_b - G_r$ $A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f)$ $A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56[\log_{10}(f)]^2$ $G_b = \log_{10}(h_b/200)\{13.958 + 5.8[\log_{10}(d)]^2\}$ $G_r = [42.57 + 13.7\log_{10}(f)][\log_{10}(h_r) - 0.585]$ For medium cities $G_r = 0.759h_r - 1.862$ For large cities
Ericsson	Urban	$PL = a_0 + 30.2\log_{10}(d) + 12\log_{10}(h_t) + 0.1\log_{10}(h_t).\log_{10}(d) - 3.2(\log_{10}(11.75h_r)^2) + g(f)$
	Suburban	$PL = 43.2 + 68.9\log_{10}(d) + 12\log_{10}(h_t) + 0.1\log_{10}(h_t).\log_{10}(d) - 3.2(\log_{10}(11.75h_r)^2) + g(f)$
	Rural	$PL = 45.9 + 100.6og_{10}(d) + 12\log_{10}(h_t) + 0.1\log_{10}(h_t).\log_{10}(d) - 3.2(\log_{10}(11.75h_r)^2) + g(f)$ $g(f) = 44.49\log_{10}(f) - 4.78(\log_{10}(f))^2 + s$

very dense vegetation, terrain B for hilly areas with rare vegetation, terrain C for flat terrain or rural with light vegetation. Different correction factors are used for different parameters like frequency, transmitter and receiver antennas' heights. The value of shadowing factor (S) normally ranges between 8.2 dB and 10.6 dB depending on the condition of the vegetation. The values for constants *a*, *b* and *c* regarding path loss exponent are shown in table 2. It is indicated from the literature review that all models could not perform well in every environment due their characteristics, inbuilt features and model parameters.

Table II. Sui Model Terrain Parameters Values for Different Environments

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

Therefore, it is crucial to select the appropriate path loss model for the required location. The aim of this study is to examine the performance of selected empirical path loss models in different environments with respect to various receiver antenna heights for wireless network at 2.4 GHz unlicensed band. This initial investigation of model performance could be helpful for the planning and designing of preliminary deployment of wireless network at rural areas of Sarawak.

III. SYSTEM MODEL AND METHODOLOGY

The system model consists of a source and destination. The source acts as transmitter or base station and destination acts as receiver as shown in Fig.1. A point to point topology is considered between source and destination. The communication between theses two points is assumed as line of sight (LOS).The non line of sight (NLOS) communication is only accounted in COST-231 WI model.The receiver is fixed and the path loss is estimated with respect to transmitter at different distances from the source.

The system model is considered in three different environments such as urban, suburban and rural and the performance of the model is being investigated in each environment, in terms of signal strength. The operating frequency was fixed at 2.4 GHz. The distance between source and destination was fixed at 10km. The shadowing correction S is taken 9dB for rural and suburban and 10 dB in urban area. For the case of non line of sight regarding COST-231 WI model, the building to building distance is taken 60m; average building height is taken 20m, street width 30m, street orientation angle 40^0 for urban and suburban environments. A total of 7 path loss models such as Free Space model, HATA Okumura Extended model or ECC-33 model, Stanford University Interim (SUI) model, HATA model, COST-231 HATA model, Ericsson model and COST-231 WI model were reviewed. The terrain A of the SUI model was considered for urban environments, terrain B was for suburban environments and terrain C was chosen for rural environments. Different receiver antenna heights such as 6m, 9m and 12m were chosen with respect to various distances. The height of the source antenna is taken as 40m for all three environments.

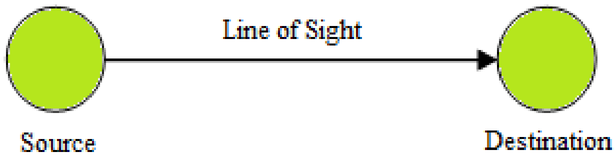

Fig.1 System model using point to point topology

IV. RESULTS AND DISCUSSION

The predicted path loss values of Free Space model was considered as the reference values for all reviewed models. The distance between source and destination was fixed at 5km. The estimated path loss values of examined models for urban environments at 6m, 9m and 12m receiver antenna heights are shown in Fig. 2, Fig. 3 and Fig. 4 respectively. It was observed that the highest path loss value was shown by COST-231 HATA model with 159.83 dB, 157.65 dB, and 155.98 dB at 6m, 9m and 12m receiver antenna heights respectively with respect to reference model. It is due to the fact that COST-231 HATA model has no additional factors incorporated to account the effects of various environments and only a single correction factor used for receiver antenna height. The lowest path loss values were shown by COST-231 WI model with 139.45 dB at 6m receiver height owing to the addition of extra parameters like L_{msd}, L_{bsh}, k_a, k_d and k_f. However, at 9m and 12m heights HATA model showed the lowest estimation of path loss with 137.19 dB and 128.13 dB respectively. It is due to the fact that the use of correction factor $a(h_r)$ is more effective along with the frequency at high receiver antenna heights. Moreover, Ericsson, ECC-33, HATA and SUI models showed 144.43 dB, 157.73 dB, and 146.24 dB and147.83 dB estimated path loss values at 6m height respectively. Furthermore, Ericsson, ECC-33, HATA and SUI models demonstrated 143.31 dB, 149.31 dB, 137.19 dB

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and 149.31 dB at 9m height respectively with respect to the Free Space model. At 12m receiver antenna height, Ericsson, ECC-33, COST-231 WI and SUI models showed 142.51 dB, 143.34 dB, 136.95 dB and 141.81 dB respectively.

It was shown that COST-231 HATA model showed highest percentage of path loss with 40.16%, 38.25%, and 36.79% at 6m, 9m and 12m receiver antenna heights respectively with respect to reference model. COST-231 WI indicated lowest percentage of path loss with 22.29% at 6m receiver height. At 9m and 12m of receiver antenna heights HATA model executed the lowest estimation of path loss percentage with 20.31% and 12.36% respectively. Moreover, at 6m height Ericsson, ECC-33, HATA and SUI models demonstrated 26.66%, 38.31%, 28.25% and 29.64% path loss respectively. Furthermore, Ericsson, ECC-33 and SUI models displayed 25.67%, 30.94% and 26.55% at 9m height respectively with respect to Free Space model. At 12m receiver antenna height, Ericsson, ECC-33, COST-231 WI and SUI models showed 24.97%, 27.50%, 20.10% and 24.36% respectively.

The estimated results of reviewed models for suburban environments at 6m, 9m and 12m receiver heights are shown in Fig. 5, Fig. 6 and Fig. 7 respectively. It was revealed that the highest path loss value was shown by Ericsson model with 178.50 dB, 177.38 dB and 176.58 dB path loss at 3m, 6m and 9m heights respectively. It is due to the fact that Ericsson model uses high values for the constants a_0 and a_1 in suburban environments. The lowest path loss values were executed by SUI model with 128.57 dB, and 126.67 dB at 6m and 9m height respectively owing to the use of constants *a*,*b*,*c* and correction factor X_h. However, HATA model indicated lowest path loss estimation at 12m receiver height with 120.53 dB owing to the use of correction factor $a(h_r)$, which is much effective at high receiver antenna heights along with the frequency for both the urban and suburban environments. Moreover, COST-231 WI, HATA, COST-231 HATA and ECC-33 models showed path loss estimation with 133.35 dB, 138.52 dB, 148.75dB and 157.73 dB at 6m height with respect to Free Space model. Furthermore, COST-231 WI, HATA, COST-231 HATA and ECC-33 models revealed 132.21 dB, 129.59 dB, 139.59 dB and 149.31 dB respectively at 9m height with respect to free space model. Similarly, COST-231 WI, SUI, COST-231 HATA and ECC-33 models expressed 130.87 dB, 125.32 dB, 130.44 dB and 143.34 dB respectively at 12m receiver antenna height.

It was observed that Ericsson model showed highest percentage of path loss with 56.54%, 55.55% and 54.85% at 6m, 9m and 12m receiver antenna heights respectively with reference to Free Space model. SUI model executed lowest with 12.74%, and 11.08% at 6m and 9m height respectively.

HATA model indicated lowest path loss estimated results at 12m receiver height with 5.70%. Moreover, at 6m receiver antenna height COST-231 WI, HATA, COST-231 HATA and ECC-33 models demonstrated 31.71%, 21.47%, 30.44% and 38.31% more values than reference model. Furthermore, COST-231 WI, HATA, COST-231 HATA and ECC-33 models estimated 31.78%, 13.59%, 22.41% and 30.94% respectively at 9m height with respect to Free Space model. At 12m receiver antenna height COST-231 WI, SUI, COST-231 HATA and ECC-33 models showed 31.78%, 9.89%, 14.39% and 25.70% percentage path loss respectively.

The estimated results of reviewed models for rural environments at 6m, 9m and 12m receiver antenna height are shown in Fig. 8, Fig. 9 and Fig. 10 respectively. It was found that that the highest path loss values were established by Ericsson model at all receiver antenna heights with 203.39 dB, 202.26 dB and 201.46 dB respectively. It is due to the fact that Ericsson model considered highest values of the constants a_o and a_1 to incorporate the effects of various factors for rural environments. The lowest values were demonstrated by COST-231 WI model with 128.37 dB for the three receiver antenna heights. COST-231 WI model executed similar results

as given by Free Space model. The second lowest values were indicated by SUI model with 146.23 dB at 6m receiver antenna height. The reason being is that SUI model incorporated the lowest values for the constants *a* and *b* in rural environments as compared to urban and suburban environments.

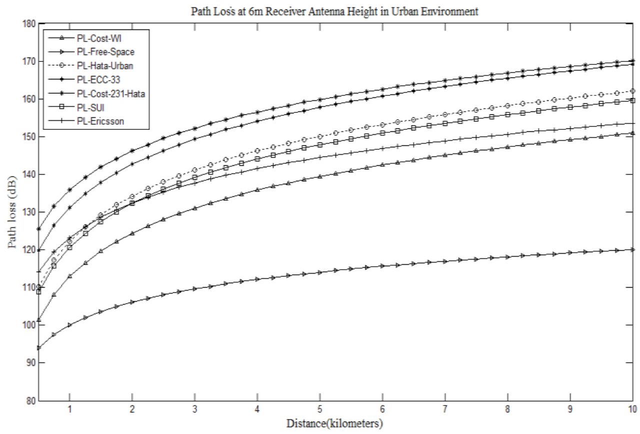

Fig. 2 Estimated Path Loss Values of Different Models at 6m Receiver Antenna Height for Urban Environments

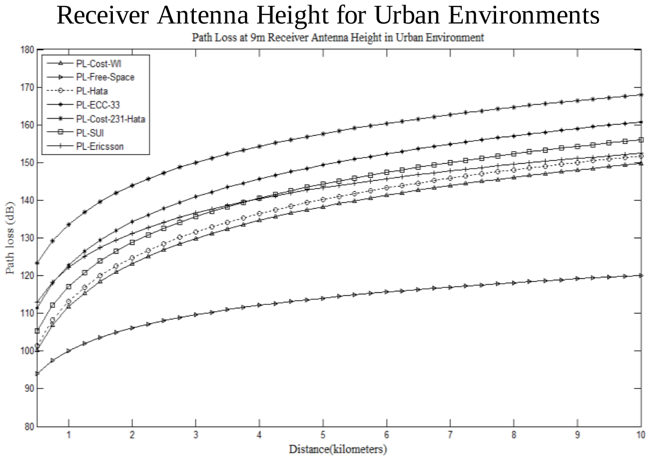

Fig. 3 Estimated Path Loss Values of Different Models at 9m Receiver Antenna Height for Urban Environment

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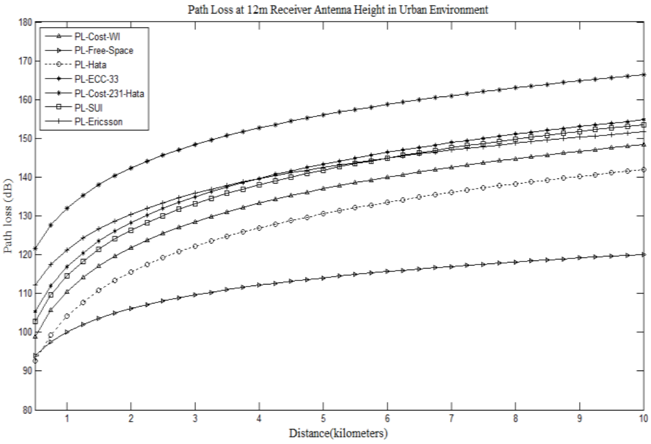

Fig. 4 Estimated Path Loss Values of Different Models at 12 m Receiver Antenna Height for Urban Environments.

HATA and COST-231 HATA models displayed 151.59 dB and 148.57 dB respectively at 6m receiver antenna height. Furthermore, HATA, SUI and COST-231 HATA models indicated 142.53 dB, 142.71 dB and 139.59 dB respectively at 9m receiver antenna height with respect to the reference model. Similarly, HATA, SUI and COST-231 HATA models showed 133.48 dB, 140.46 dB and 130.44 dB respectively at 12m height.

It was revealed that Ericsson model indicated the highest percentage path loss with 78.36%, 77.37% and 76.67% at 6m, 9m and 12m receiver antenna heights respectively. COST-231 WI model demonstrated lowest estimation with 12.57% for all

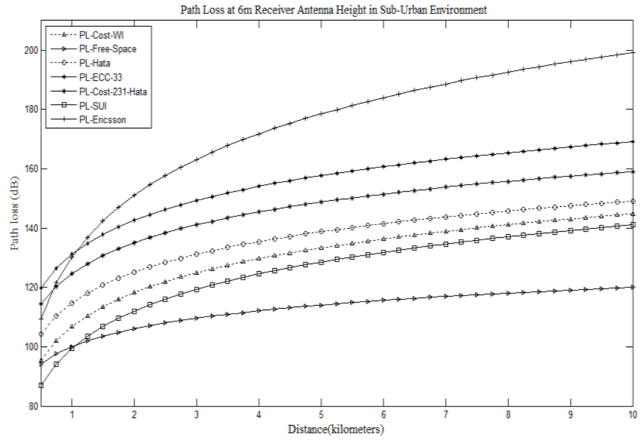

Fig. 5 Estimated Path Loss Values of Different Models at 6m Receiver Antenna Height for Suburban Environments

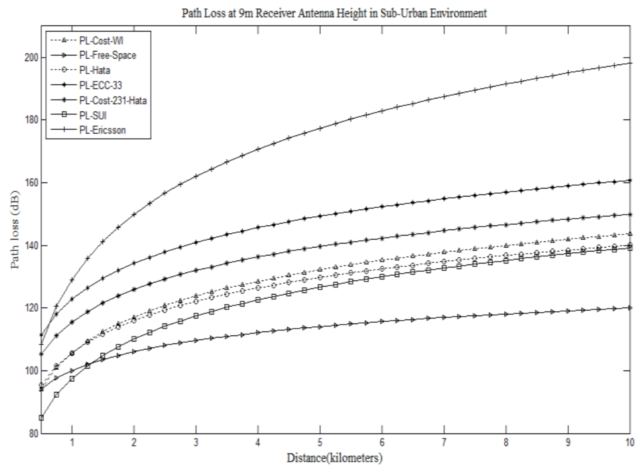

Fig. 6 Estimated Path Loss Values of Different Models at 9m Receiver Antenna Height for Suburban Environments.

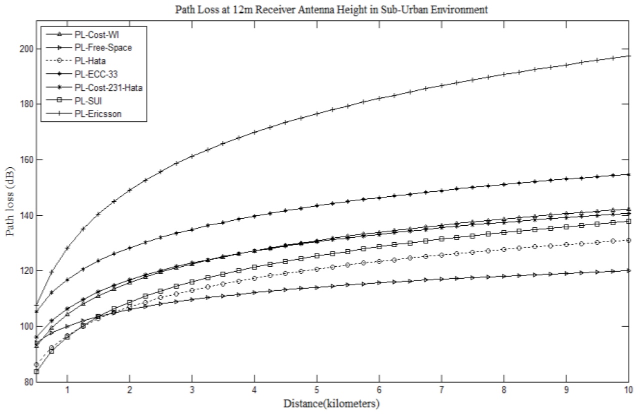

Fig. 7 Estimated Path Loss Values of Different Models at 12m Receiver Antenna Height for Suburban Environments.

The receiver antenna heights. Moreover, at 6m receiver antenna height HATA and COST-231 HATA models revealed 32.93% and 30.44% respectively. Furthermore, HATA, SUI and COST-231 HATA models indicated 24.99%, 25.15% and 22.41% respectively at 9m receiver antenna height with respect to the reference model. Similarly, at 12m receiver antenna height HATA, SUI and COST-231 HATA models expressed 17.05, 22.96 and 14.39 respectively.

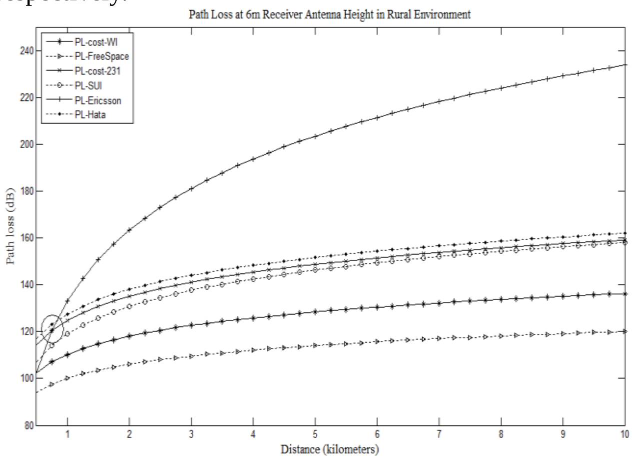

Fig. 8 Estimated Path Loss Values of Different Models at 6m Receiver Antenna Height for Rural Environments

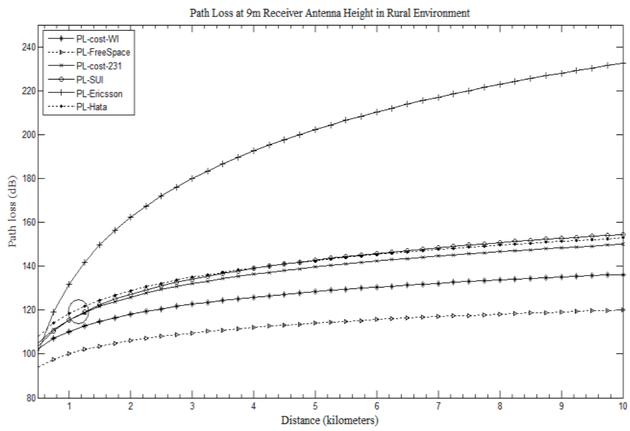

Fig. 9 Estimated Path Loss Values of Different Models at 9m Receiver Antenna Height for Rural Environments

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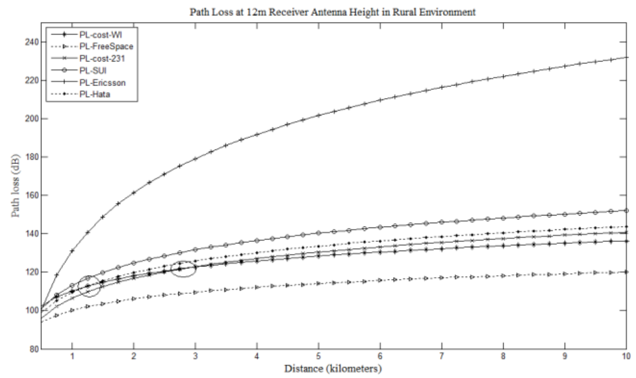

Fig. 10 Estimated Path Loss Values of Different Models at 12m Receiver Antenna Height for Rural Environments.

IV. CONCLUSION

It is concluded that COST-231 WI model demonstrated the lowest path loss value at 6m receiver antenna height and with 139.4 dB, at 6m height in urban environments, which is 22.2% more than that of reference model values. HATA model demonstrated the lowest path loss values with 20.31% at 9m height and 12.36% more values than reference model results at 12m height. COST-231 HATA model demonstrated highest path loss estimated values for urban environments with 40.16%, 38.25% and 36.79% more values than reference model at 6m, 9m and 12m receiver antenna height respectively. In suburban environments, SUI model demonstrated the lowest path loss with 12.74% at 6m and 11.08% at 9m more estimated results as compared to Free Space model. However, Ericson model executed the highest path loss with 56.54%, 55.55% and 54.85% more values than reference model at 6m, 9m and 12m height respectively. In rural environments, COST-231 WI model predicted the lowest path loss values at all the receiver antenna heights with 12.57% more values than reference model. SUI model demonstrated the second lowest path loss values with 28.24% at 6m and COST-231 HATA model indicated lowest path loss values with 22.41% at 9m and 14.39% at 12m more values than Free Space model results. Ericsson model executed the highest path loss estimated values with around 77% in rural environments. SUI model established the results with 10% difference as compared to reference model at lower receiver antenna heights in suburban and rural environments. It is concluded that the models results were incongruent due to incorporation of different variables and terrain classification. Therefore, a particular model cannot be selected for the estimation of path loss at various antenna heights in all environments. However, SUI model could be preferred due to less path loss values at lower receiver antenna heights for suburban and rural environments as compared to other reviewed models with reference to estimated values of Free Space model.

V. NOMENCLATURE

d	Distance between transmitter and receiver (km)
f_c	Carrier frequency (Hz,
h_r	Receiver or destination antenna height (m)
h_b	Base station or source antenna height (m)
$a(h_r)$	Correction factor for receiver antenna height
L_{FSL}	Free Space Loss (dB)
L_{rts}	Roof top to street diffraction
L_{msd}	Multi-screen diffraction loss
c_m	Correction factor for environment
$a(h_m)$	Correction factor for receiver antenna height
A_{fs}	Free space attenuation (dB)
A_{bm}	Median path loss (dB)
G_b	Transmitter antenna height gain factor
G_r	Receiver antenna height gain factor
X_f	Correction factor for frequency
X_h	Correction factor for receiver antenna height
λ	Wavelength
γ	Path loss exponent
$g(f)$	Correction factor for frequency

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