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EVALUATION OF SUITABLE PROPAGATION MODEL FOR 4G LTE COMMUNICATION IN NIGERIA

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Abstract

This paper concerns about the radio propagation models used for the 4th Generation (4G) of cellular networks known as Long Term Evolution (LTE). The radio wave propagation model or path loss model plays a very significant role in planning of any wireless communication systems. In this paper, a comparison is made between different proposed radio propagation models that would be used for LTE, like Egli model, Ecc-33 path loss model, Log- Normal Shadowing model, Lee model, Stanford University Interim (SUI) model, Cost 231 Hata Model and Experimental Measured path loss. The comparison is made using different terrains such as urban (Victoria Island, Lagos, Nigeria) and suburban (Kurudu, F.c.t. Nigeria). Egli model shows the lowest path loss in all the terrains while illustrates highest path loss in the urban area and model has highest path loss for the suburban environments.

KEYWORDS *Long Term Evolution, LTE, Path loss, Propagation models.*

1. INTRODUCTION

Long Term Evolution commonly marketed as 4G, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is the next step to the cellular 3rd Generation (3G). It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements; it comes as a natural upgrade path for carriers with both GSM/UMTS networks and CDMA networks. This standard is developed by the 3rd Generation Partnership Project (3GPP), only multi-band phones are able to use LTE (Long Term Evolution) in all countries where it is supported. LTE network has a drastic development in the field of telecommunication broadband wireless networks with the main objectives to increased downlink and uplink peak data rates, scalable bandwidth and improved spectral efficiency

The selection of a suitable radio propagation model for LTE is of great importance. A radio propagation model describes the behavior of the signal while it is transmitted from the transmitter towards the receiver. It gives a relation between the distance of transmitter & receiver and the path loss. From this relation, one can get an idea about the allowed path loss and the maximum cell range. Path loss depends on the condition of environment (urban, rural, dense urban, suburban, open, forest, sea etc), operating frequency, atmospheric conditions, indoor/outdoor & the distance between the transmitter & receiver. In this paper, a comparison study is carried out to determine the best agreed model suitable for LTE communication in Nigeria..

2. RADIO PROPAGATION MODELS.

2.1 Egli model

Egli model is a terrain model for radio frequency propagation. it is suitable for use in mobile system in bands of 3GHz and is normally used there is Line Of Sight (LOS) between one fixed antenna and one mobile antenna [Egli, J J 1957] the model takes into consideration the frequency, antenna height and polarization, forcing an agreement between the plain earth loss and the measured values by using the correction factors that consider all these elements. This model predicts the total path loss for a point-to-point link and it is suitable for cellular communication scenarios where the transmission has to go over an irregular terrain. Egli model is not applicable to a scenario where some vegetative obstruction is in the middle of the link . The formulas for Egli's propagation path loss prediction P_L, are given in dB as follows; [jalel chebil, *et al.,*]

$$P_L = 20\log_{10} f_c + P_o + 76.3,\ h_r \le 10$$

$$20\log_{10} fc + P_o + 83.9,\ hr > 10$$

Where

$P_o = 40\log_{10} d - 20\log_{10} h_t - 10\log_{10} h_r$.

fc: frequency of transmission in MHz.

h_t: Height of base station antenna in meter.

h_r: height of the mobile station antenna in meter.

d: Distance from base station antenna in km.

2.2 ECC-33 Model

The ECC-33 model developed by the Electronic Communication Committee (ECC) is

appropriate for suburban and small urban areas.

$$PL\_ECC = PLFS + PLbm - GBS\_ECC - GMS\_ECC$$

$$PLFS = 92.4 + 20\log_{10}(d) + 20\log_{10}(fc)$$

$$PLbm = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(fc) + 9.56(\log_{10}(fc))\ 2$$

$$GBS\_ECC = \log_{10}(hBS/200)\ (13.98 + 5.8\ (\log_{10}(d))\ 2)$$

$$GMS\_ECC = (42.57 + 13.7\log_{10}(fc))(\log_{10}(hMS) - 0.585)$$

Where:

PLFS: free space path loss, PLbm: basic median path loss, GBS_ECC: Gain of Base station.

GMS_ECC: Gain of Mobile station, d: Distance from base station antenna in km. fc: frequency of transmission in MHz, h_{Bs}: Height of base station antenna in meter, hMS: height of the mobile station antenna in meter.

2.3 LOG NORMAL SHADOWING MODEL:

The majority of radio propagation models are derived employing a combination of empirical and analytical methods. The empirical approach is based on appropriate curves or analytical expressions that recreate a set of measured data. Both theoretical and measurement-based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channel .Such models have been used extensively in the literature. The average large-scale path loss for an arbitrary transmitter receiver (T –R) separation (d), is expressed as a function of the path loss at a reference distance d by using a path loss exponent, (n)

$$P_L(d) = P_L(d_o) + 10\, n \log_{10}(d/d_o)$$

Where

n indicate the rate at which the path loss increases with distance.

d indicate the separation distance from base station to transmitter.

d_o indicate reference distance=1km

The values of n depends on the specific propagation environment. In free space, n is equal to 2 and when obstruction are present, n will have a larger value. This Measurements have shown that at any value of d, the path loss p (d) (in dB) at a particular location is random and distributed log-normally about the mean distance dependent value. That is

$$\overline{P}_L(d) = \overline{P}_L(d_o) + 10\, n \log_{10}(d/d_o) + X_\sigma$$

Where X_σ is a zero-mean Gaussian distributed random variable in dB with standard deviation σ also in dB.

The log-normal distribution describes the random shadowing effect which occur over a large number of measurement locations which have the same T-R separation, but have different levels of clutter on the propagation path. This phenomenon is referred to as lognormal shadowing.

The close –in reference distance (d) the path loss exponent (n) and the standard deviation (o), statistically describe the path loss model for an arbitrary location having a specific T-R separation and this model maybe used in computer simulation to provide received power levels for random locations in communication system design and analysis .In practice, the value of n and o are computed from measured data, using linear regression such that the difference between the measured and estimated path losses is minimized in a mean square error sense over a wide range of measurement locations and T-R separations.

2.4 Cost-231 Hata Model:

COST-231 Hata model is also known as COST Hata model. It is the extension of Hata model and it can be used for the frequencies up to 2000 MHz.

This model is derived by modifying the Hata model, and is used in urban, suburban, and

Rural environments. COST (COopération européenne dans le domaine de la recherche Scientifique et Technique) is a European Union Forum for cooperative scientific research, which has developed this model accordingly to various experiments, and researches.

The COST 231 Hata model is a radio propagation model that extends the urban Hata model (which in turn is based on the Okumura model) to cover a more elaborated range of frequencies. This model is applicable to urban areas. To further evaluate Path Loss in Suburban or Rural Quasi-open/Open Areas, this path loss has to be substituted into Urban to Rural/Urban to Suburban Conversions. This model has a frequency range of 1500 – 2500 MHz, Mobile station antenna height of 1 -10m, Base station antenna height 30 – 200m, Link Distance of 1-20km.

Path loss equation for urban and suburban area as follows:

PLCOSTSU: Suburban

PLCOSTU: Urban

PLCOSTSU = *PLCOSTU* - 2 (log10 (fc / 28)) 2- 5.4

PLCOSTU = 46.3 + 33.9 log10 (fc) - 13.82 log10 (hBS) + (44.9 - 6.55 log10 (hBS)) log10 (d) – a (hMS) +c

MS antenna correction factors *a (hMS)* for all is:

*a (hMS) = (1.11*log*10(fc) -0.7)hMS - (1.56* log*10(fc) - 0.8)*

$$c = \left(\frac{\text{0dB for medium cities and suburban areas}}{\text{3dB for metropolitan areas!}}\right)$$

2.5 Stanford University Interim (SUI) Model

Stanford University Interim (SUI) channel model is developed for IEEE 802.16 broadband wireless access working group based on research results of Stanford University.

This model covers three common terrain categories. Category A is the maximum path-loss category, which represents a hilly terrain with moderate to heavy tree densities. Category B is the intermediate path-loss category suitable for Suburban Environment. The minimum path-loss category for flat terrains with less tree densities is Category C. It is used for frequencies above 1900MHz.

These different terrains and their factors used in SUI model are described in the following table.

Table 1. Different terrains and their parameters.

PARAMETER S	TERRAI N A	TERRAI N B	TERRAI N C
A	4.6	4	3.6
B(1/m)	0.0075	0.0065	0.005
C	12.6	20	20

The path loss in SUI model can be given as

$$PL = A + 10\gamma \log\left(\frac{d}{d_0}\right) + X_f + X_h + S$$

Where PL is path loss in dBs, d is the distance between the transmitter and receiver, d_0 is the reference distance (Here its value is *100*), Xf is the frequency correction factor , Xh is correction factor for Base station height, A is free space path loss, S is shadowing factor and, γ is the path loss component. The Path loss component is given as:

$$\gamma = a - bh_b + \frac{c}{h_b}$$

Where h_b is the height of the base station and, a, b and c represents the terrain factors for which the values are selected from the above table.

The free space path loss is given as

$$A = 20 \log \left(\frac{4\pi d_0}{\lambda}\right)$$

Where d_0 is the distance between transmitter and receiver and, λ is the wavelength.

The correction factor for frequency is $X_f = 6 \log \left(\frac{f}{2000}\right)$

Where f is frequency in MHz.

The Correction factor for base station height is $X_h = -10.8 \log \left(\frac{h_r}{2000}\right)$

Where h_r is the height of receiver antenna.

The above expression is used for terrain A and B and for terrain C the expression is as given below:

$$X_h = -20 \log \left(\frac{h_r}{2000}\right)$$

The shadowing factor S is given as follow: $S = 0.65 (\log f)^2 - 1.3 \log (f) + \alpha$

Here, α = 5.2 dB for rural and suburban environments (Terrain A and Terrain B) and 6.6 dB for Urban environment (Terrain C).

2.6 LEE MODEL

Lee model is one of the most popular and widely used path loss models. It is known for its simplicity along with its reasonable prediction accuracy. Lee model was initially derived for frequencies around 900 MHz. Later on, the model was extended to frequencies up to 2 GHz. The path loss form of the model is provided relative to reference conditions and is given as:

$$PL_{Lee} = PL_0 + m \log \left(\frac{d}{d_0}\right) - H_T - H_R$$

Where: $H_T = 15\log \left(\frac{h_t}{h_{tref}}\right)$

$H_R = 10\log \left(\frac{h_r}{h_{rref}}\right)$ and

PL_0 = Path loss at reference distance (d_0) in [dB], m = Slope in [dB/ decade], d = Transmitter – receiver separation in [km], d_0 = Reference distance (1.609km), h_t = Transmitter antenna height in [m], h_{tref} = Reference transmitter antenna height (30.48), h_r = Receiver antenna height in (m), h_{rref} = Reference receiver antenna height (3.048 m), The intercept (PL_0) and the slope (m) for different environments at 900 MHz.

Table 2: Intercept and slope values for different environments.

PL_0@ f_0 =900 MHz	PL_0 [dB]	m [dB/decade]
Open Area	95	43.5
Suburban	107.7	38.4
Urban	116	36.8

Whereas the slope (m) remains the same for frequencies different than f_0, frequency correction factor for the intercept (PL_0) is given by: $PL_0(f) = PL_0(f_0) + 20 \log \frac{f}{f_0}$

3. Materials and Method

3.1 Description of the Area under Investigation

Victoria Island (URBAN) is a city in Lagos State, Southwestern part of Nigeria, with an estimated population of about Three Hundred Thousand (300,000) and landmark of 80km. The project work would cover an area in Victoria Island, where we would test for the best model suitable for LTE propagation.

Kurudu (SUBURBAN) is a residential town in the outskirt of Abuja city, in the North Central part of Nigeria, with an estimated of about Fifty thousand (50,000) and landmark of 50km. Houses mostly below 20 meters and an average road width of about 20 meters. Attenuation is caused by multiple reflections, absorption and multiple diffractions off roof tops, trees, cars etc. The concrete ground and tarred roads have very relative poor electrical conductivity, and therefore, cause attenuation by absorption. Ground reflected waves are blocked by buildings and trees.

3.2. Measurement Procedure

Measurements were taken from a Base Station of a mobile network service provider (Swift Networks for Urban Terrain) and (Spectranet Networks for the Suburban Terrain) in 2300 MHz Network using Huawei equipment, situated within the terrain. The testing tool used in the measurement was 4g LTE test phone handset in the Net Monitor mode capable of measuring signal strength (P_r) in decibel milliwatts (dBm), in conjunction with a Digital Global Positioning System receiver antenna to determine distance (d) from the Base Station (BS). Readings were taken within the 2300MHz frequency band at intervals of 0.2 km for Urban terrain and 0.1 km for Suburban , after an initial separation of 0.1km away from the Base Station up to 1 km fixed length. Base Station parameters obtained from 4G LTE 2300MHz Network Provider such us mean transmitter height (h_{BS}) is 21m for Urban and 20m for suburban, mean Effective Isotropically Radiated Power (*EIRP*)is 152 dBm, transmitting frequency for 2327.5MHz and 2347.5MHz respectively. Received power (P_r) values were recorded at various distances from each of the terrains. For every received power value, the corresponding path loss measured was computed using the formula:

$$PL_{Measured} = EIRP - P_r$$

3.3. **Path Loss Model Optimization.**

Several existing path loss models was explained in Section 2 are chosen for comparison with measurement data path loss. The best existing path loss model with smallest mean error to the measured path loss data will be chosen as a reference for the development of the optimized path loss model. The optimized path loss model will be tested during the validation process by comparing the RMSE calculated path loss to the measured path loss in the chosen Urban and Suburban Terrains of the 2300 MHz system.

Path loss model optimization is a process in which a theoretical propagation model is adjusted with the help of measured values obtained from test field data. The aim is to get the predicted field strength as close as possible to the measured field strength.

In order to optimize and validate the effectiveness of the proposed model, the Mean error (μ_e), and RMSE ($\square_e$) were calculated between the results of the proposed closest model and the measured path loss data of each area. These mean error (μ_e), and root mean square error, RMSE ($\square_e$) are defined by the expression below:

$$\mu e = (1/N) \ (PLMeasured - PLPredicted)$$

$$\square_e = \sqrt{\mu_e^2}$$

Where $PL_{Measured}$ is measured Path loss (dB), $PL_{Predicted}$ ispredicted path loss (dB), and N is number of measured data points.

4. Results and Analysis

The performance of the empirical models was evaluated based on five different statistical parameters that measure the variations of the prediction results from the actual field measured data. The performance analysis is based on the calculation of received signal strength, path loss between the base station and mobile from the propagation model. The parameters used in the calculation of the Empirical models include: the Antenna height, mobile station height, Gain of Transmitter, Gain of Receiver, Path loss (dB), RSRP,RSRQ, Frequency, all these which are measured data and they are compared against the calculated data to predict the best prediction model for path loss in Victoria Island Lagos.

From Figure 1, it is observed that in all five empirical models, the Hata model overestimates the propagation path loss values, however for the first three distances taken 200m, 400m, 600m the measured path losses are close to Egli model. For smaller distances the Okumura hata model is close to the measured path loss, unlike the lee model, the hata model, which are largely dispersed from the measured path loss.

Table 3 shows the percentage error, root mean square error and the standard deviation of each of the models for the area, from the table we see the results of measurements, Egli model with the prediction error standard deviation of 3.72 and root mean square error of 3.85, the Okumura hata model with the prediction error standard deviation of 11.02 and root mean square error of 9.85, the Cost231 Hata model with the prediction error standard deviation of 11.71 and root mean square error of 10.47, the Lee model with the prediction error standard deviation of 12.15 and root mean square error of 10.86, the Hata model with the prediction error standard deviation of 14.41 and root mean square error of 12.88. The Egli model gave the closest prediction results when compared to the measured data with root mean square error of 3.85 and standard deviation 3.72. It also gives the smallest root mean square error and standard deviation values. Therefore the results show that Egli model can be used to estimate path loss in LTE for Victoria Island Lagos.

Table 3: Final Comparison of Results for Urban terrain

Site Id	Distance(m)	Measured Data(dB)	Egli Model(dB)	Cost 231 Hata Model(dB)	Hata Model(dB)	Okumura Hata Model(dB)	Lee Model(dB)
IHS_LAG_021	200	88	87.90	100.2	114.1	104.6	100.0
IHS_LAG_021	400	99	99.83	113.8	119.0	109.2	112.4
IHS_LAG_021	600	102	102.42	122.7	124.7	116.0	120.5
IHS_LAG_021	800	85	112.70	125.1	128.2	123.9	127.9
IHS_LAG_021	1000	100	114.23	129.3	132.1	130.5	134.7
Mean Value			103.42	118.22	123.62	116.84	119.1
Percentage Error (%)			-8.33	-19.81	-18.86	-23.31	-20.40
RMSE			3.85	10.47	12.88	9.85	10.86
Standard Deviation			3.72	11.71	14.41	11.02	12.15

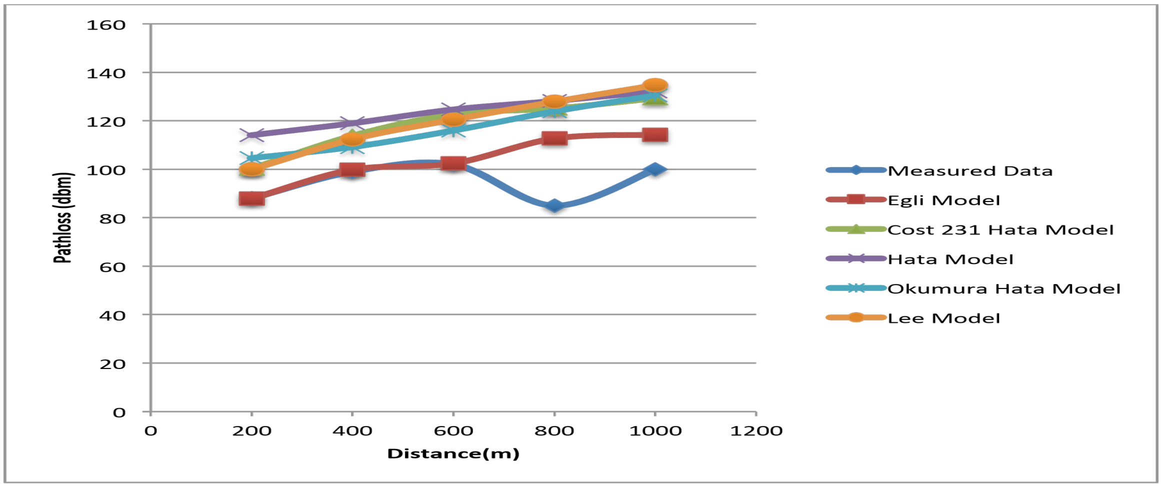

Figure 1: Plot of pathloss as a function of distance

From Table 2, Egli model shows the minimum path loss when compared to the measured path loss value, then the Log normal shadowing model and Lee model also show a close value to the Measured path loss which make them also suitable for the prediction models of the environment in question. CostHata_231 Model and Sui Model showed an intermediate path loss value but the Ecc-33 model path loss value doesn't seem to fit in to the prediction of this environment.

Table 2: Mean Path loss for Suburban terrain.

MEASURED	EGLI MODEL	LEE MODEL	COSTHATA-231 MODEL	SUI MODEL	LOG NORMAL MODEL	ECC-33 MODEL
74	75.75	95	103.54	112.16	77.28	112.2
75	87.79	96.4	114.5	123.3	87.1	133.73
77	94.83	97.83	120.9	129.81	95.7	145.95
78	99.83	100.9	125.45	134.43	100.1	154.63
82	103.71	104.54	128.97	138.02	103.96	161.35
76	106.87	107.66	131.86	140.95	107.13	166.86
109	109.55	110.65	134.29	143.42	109.81	171.48
85	111.88	111.7	136.4	145.57	111.13	175.52
92	113.92	112.67	138.27	147.47	113.17	179.07
95	115.75	115.84	142.17	149.16	115.08	182.22
84.3	**101.988**	**105.319**	**127.635**	**136.429**	**102.046**	**158.301**

5.0. Conclusion

A comprehensive review of the propagation prediction models for 4G Long Term Evolution network system is presented and computation of path loss values due to specific terrain and clutter environment has been carried out for various prediction techniques such as Egli model, Hata model, COST-231 Hata model, Okumura Hata model and LEE model for Long Term Evolution network. A comparison of different prediction methods showed that Egli method gave least path loss. The advantage of this method lies in its suitability for cellular communication scenarios where one antenna is fixed and another is mobile. The model is applicable to scenarios where the transmission has to go over an irregular terrain. The prediction errors of the Hata model and LEE models are considerably higher than those of the COST-231 Hata and Okumura Hata models.

REFERENCES

Amarasinghe K.C., Peiris K.G.A.B., Thelisinghe L.A.D.M.D., Warnakulasuriya G.M., and Samarasinghe A.T.L.K "", Fourth International Conference on Industrial and Information Systems*, ICIIS* 2009, 28 - 31 December 2009, Sri Lanka.

Borko Furht, Syed A. Ahson, "Long Term Evolution: 3GPP LTE Radio and Cellular Technology", Crc Press, 2009, *ISBN* 978-1-4200-7210-5.

B. Ramakrishnan, R. S. Rajesh and R. S. Shaji "An Efficient Vehicular Communication Outside the City Environments", International Journal of Next Generation Networks. *(IJNGN)*, volume 2, December 2010.

COST Action 231, "Digital mobile radio towards future generation systems, final report", tech. rep., European Communities, *EUR* 18957, 1999.

F. D. Alotaibi and A. A. Ali, April 2008, "Tuning of lee path loss model based on recent RF measurements in 400 MHz conducted in Riyadh city, Saudi Arabia," *The Arabian Journal for Science and Engineering*, Vol 33, no 1B, pp. 145–152.

G. E. Athanasiadou, A. R. Nix, and J. P. McGeehan, "A microcellular ray-tracing propagation model and evaluation of its narrowband and wideband predictions," IEEE Journal on Selected Areas in Communications, Wireless Communications series, vol. 18, pp. 322–335, March2000.

Hata, M, "Empirical Formula for Propagation Loss in Land Mobile Radio Services", IEEE Trans. Vehicular Technology, VT-29, pp. 317 - 325, 1980.

H. R. Anderson, "Fixed Broadband Wireless System Design", John Wiley & Co., 2003.

Josip Milanovic, Rimac-Drlje S, Bejuk K, "Comparison of propagation model accuracy for WiMAX on 3.5GHz," 14th IEEE International conference on electronic circuits and systems, Morocco, pp. 111-114. 2007.

Khaled Elleithy and Varun Rao, "Femto Cells: Current Status and Future Directions" International Journal of Next Generation Networks (IJNGN), volume 3, March 2011.

LTE an Introduction, White paper, Ericsson AB, 2009.

M. A. Alim, M. M. Rahman, M. M. Hossain, A. Al-Nahid, "Analysis of Large-Scale Propagation Models for Mobile Communications in Urban Area", International Journal of Computer Science and Information Security (IJCSIS), Vol. 7, No. 1, 2010.

M. Shahjahan, A. Q. Abdulla Hes-Shafi, "Analysis of Propagation Models for WiMAX at 3.5 GHz," MS thesis, Blekinge Institute of Technology, Karlskrona, Sweden, 2009.

N. Shabbir, H. Kasihf, "Radio Resource Management in WiMAX," MS thesis, Blekinge Institute of Technology, Karlskrona, Sweden, 2009.

Okumura, Y. a kol, "Field Strength and its Variability in VHF and UHF Land-Mobile Radio Service", Rev. Elec. Comm. Lab, No.9-10, pp. 825 - 873, 1968.

Simic I. lgor, Stanic I., and Zrnic B., "Minimax LS Algorithm for Automatic Propagation Model Tuning," Proceeding of the 9th Telecommunications Forum (TELFOR 2001), Belgrade, Nov.2001.

Stefania Sesia,Issam Toufik, and Matthew Baker, "LTE - The UMTS Long Term Evolution - from Theory to Practice", John Wiley & Sons, 2009, ISBN 978-0-470-69716-0.

T.S. Rappaport, "Wireless Communications Principles and Practice", Prentice-Hall, India, 2006.

V.Erceg, L. J. Greenstein, *et al.,.*, "An empirically based path loss model for wireless channels in suburban environments," IEEE Journal on Selected Areas of Communications, vol. 17, pp. 1205–1211, July1999.

V.S. Abhayawardhana, I.J. Wassel, D. Crosby, M.P. Sellers, M.G. Brown, "Comparison of empirical propagation path loss models for fixed wireless access systems," 61th IEEE

Technology Conference, Stockholm, pp. 73-77, 2005.