Effective Prediction of Mobile Radio Pathloss in Warri City Clutter of Nigeria

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Abstract-The basic task of radio link design requires the operator to foresee the coverage of the proposed system based on the impact of the clutter. This work is aimed at obtaining a suitable path-loss prediction model for the city of Warri by comparing the COST -231 Walfish Ikegami Model (WIM,) Hata Model, CCIR Model and the Free Space Model. Measurement of Received Signal Level (RSL) was conducted in three locations (Enheren, Refinery road, and Okwokuku) representing Urban, Suburban and Rural terrains respectively. The measurement of RSL was carried using Tecno handset with net monitor software running in it while Germin GPS was used for the propagation path-length. The path-loss from field data and that from existing models were analysed and compared using MATLAB (7.5). The result of the analysis showed that the Walfish Ikagami Model (WIMNLOS) gave a very close correlation with the measured path-loss in the three locations considered and therefore is preferred to other prediction models in the city of Warri.

Keywords – Effective, Empirical, MATLAB, Pathloss, WIMNLOS.

1. Introduction

Over a period of time, few large-scale classical propagation models have been invented, that are now utilized to predict large-scale coverage for mobile communication systems design. By using pathloss models to estimate the received signal level as a function of distance, it may be possible to predict the SNR for a mobile communication system [1]. Pathloss is the largest and most variable quantity in the link budget [2]. It depends on frequency, antenna height, receive terminal location relative to obstacles and reflectors, and link distance, among many other factors. Usually a statistical pathloss model or prediction program is used to estimate the median propagation loss in dB. The estimate according to Walter [2] takes into account the situation-line of sight (LOS) or Non-LOS, and general terrain and environment using more or less detail, depending on the particular model.

Pathloss is an important parameter in the analysis and design of a radio communication system and it plays a vital role in the wireless communication at the network planning level [3]. The duo [3] also defined pathloss as an unwanted introduction of energy tending to interfere with power reception and reproduction of the signals during its journey from transmitter to receiver. The strength of electromagnetic wave decreases as it propagates through space, this happens due to losses which are domicile in the signal path. The signal path loss affects many parameters of the radio communication channel. Due to this, it is necessary to recognize the reasons for radio path loss, and to be able to determine the levels of the signal loss for a given radio path [4]. To this end, several pathloss prediction models have been invented and these include: the Free space model, Okumura Hata model, Walfisch – Ikegami model, Cost 231 Hata, CCIR or ITU-R, Stanford University Interim (SUI) model to name a few. The quality of coverage of any wireless network design depends on the accuracy of the propagation model [5]. The wireless propagation channel exhibits impairments far more severe than those inherent in guided wire [1]. Severe impairments mean that the wireless channel yields a poorer signal-to-interference ratio (SIR) and hence, higher transmission bit error rate (BER) at the output of the receiver compared with those in a wire channel. This work is aimed at obtaining a suitable pathloss prediction model for the city of Warri in Nigeria. This was achieved by performing comparative analysis between selected empirical models and measured pathloss model developed from the received signal strength from selected BTSs. Section two discusses the theory of propagation pathloss and four pattloss prediction models used in this work. Section three centres on the research methodology while the results are presented and analysed in section four. The conclusion is located in section five.`

2. Theoretical background

Path loss is unwanted, signal strength reductions that signal suffers when propagating from transmitter to receiver [6]. The losses present in a signal during propagation from base station to receiver may be classical and already existing . We measure this path loss in different areas like rural, urban, and suburban with the help of propagation path loss models. Pathloss is the largest and most variable quantity in the link budget [2]. It depends on frequency, antenna height, receive terminal location relative to obstacles and reflectors, and link distance, among many after factors. Usually a statistical pathloss model or prediction program is used to estimate the median propagation loss in dB. The estimate takes into account the situation – line of sight (LOS) or Non – LOS (NLOS), and general terrain and environment using more or less detail, depending on the particular model [2].

Path loss according to [7], is a major component in the analysis and design of the link budget of a telecommunication system. Path loss models are useful planning tools allow the radio network designer to reach optimal levels for the base station deployment and

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configuration while meeting the expected service level requirements.

Finally, path loss occurs when the received signal becomes weaker and weaker due to increasing distance between mobile station (MS) and base stations (BS), even if there are no obstacles between the transmitting (TX) and receiving (RX) antenna. The path loss problem usually leads to dropped calls because before the problem becomes complex and complicated, a new transmission path is established and setup via another BTS. More so, weather is a physical atmosphere phenomenon that is associated with air masses and their corresponding interactions with the environment. It also includes the state, factor and motion of the masses, including the pressure, winds, temperature, clouds and precipitations produced by them, [8].

2.1 Methods of Radio Propagation Modeling

Radio propagation model is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance, and other dynamic factors. A single model is usually developed to predict the behaviour of propagation for all similar links under similar constraints. Propagation models are developed with the goal of formalizing the way radio waves propagate from one place to another, such models typically predict the path loss along a link or the effective coverage area of the transmitter. Propagation models are not only needed for installation guidelines, but they are a key part of any analysis or design that strives to mitigate interference [9]. Hence, propagation models can be categorized into three types, empirical models, deterministic models and theoretical models. These models are mainly used to predict the path loss, but models that predict rain-fade and multipath have also been proposed [10]. Amongst all, the deterministic models are better to find the propagation path losses.

2.1.1 Deterministic models

The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Deterministic models often require complete 3-D map of the propagation environment. An example of a deterministic model is ray tracing model [11]. This model uses Maxwell's equations along with reflection and diffraction laws [6]. An example is the model developed by W. Ikegami and H. L. Bertoni for radio systems in urban areas, [12].

2.1.2 Statistical models

The Statistical model uses probability analysis By finding the probability density function. Stochastic models, model the environment as a series of random variables, [10]. These models are least accurate but require least information about the environment and use much less processing power to generate predictions. Theoretical models are based on theoretical assumptions about the propagation environments. The Geometrically Based Single Bounce Macrocell (GBSBM) channel model [13] and Quasai-Wide- Sense Stationary Uncorrelated Scattering (Quasai-WSSUS) channel model [14] are examples of theoretical models.

2.1.3 Empirical models

The empirical models use existing equations obtained from results of several measurement efforts .this model also gives very accurate results but the main problem with this type of model is computational complexity. Empirical models can be split into two subcategories namely, time dispersive, e.g the Stanford University Interim (SUI) models and non-time dispersive, e.g ITU-R, Hata and the COST-231 Hata [10].

2.2 Pathloss Prediction Models

There are several prediction models use in the design of radio link. Some of them are discussed below:

2.2.1 Free Space Model

If a radio channel's propagating characteristics are not specified, one usually infers that the signal attenuation versus distance behaves as if propagation takes place over ideal free space. The model of free space treats the region between the transmit and receive antennas as being free of all objects that might absorb or reflect radio frequency (RF) energy. It also assumes that, within this region, the atmosphere behaves as a perfectly uniform and non absorbing medium. The free space model can be expressed as:

$$P_L=32.44+20\log(f)+20\log(d) \qquad (1)$$

2.2.2 The COST 231–Walfish–Ikegami Model

The COST 231 Walfish-Ikegami model is a pathloss model for the case of small distances between MS and BS, and/or small height of the MS. COST231-WI model can be used in the follow scenario, where 800MHz ≤ f ≤ 2000MHz and 0.02Km ≤ d ≤ 5Km [7]. The total pathloss for the LOS case is given as:

$$P_L=42.6+26\log_{10}(d)+20\log_{10}(fc) \qquad (2)$$

for d ≥ 20 m, where again d is in units of kilometers, and fc is in units of MHz.

For the NLOS case, the pathloss consists of the free-space pathloss (L_0), the multiscreen loss(L_{msd}) along the propagation path, and the attenuation from the last roof edge to the MS, (L_{rts}) (roof-top-to-street diffraction and scatter loss):

$$PL = \begin{cases} PL_0 + L_{rts} + L_{msd}, & \text{for } (L_{rts} + L_{msd}) > 0 \\ PL_0, & \text{for } (L_{rts} + L_{msd}) \leq 0 \end{cases} \quad (3)$$

The free-space pathloss is

$$L_0=32.4+20log_{10}(d)+20log_{10}(fc) \quad (4)$$

Ikegami derived the diffraction loss (L_{rts}) as:

$$L_{rts} = -16.9 - 10\log_{10}(w) + 10\log_{10}(fc) + 20\log_{10}(\Delta h_m) + L_{ori} \quad (5)$$

where w is the width of the street in meters, and

$$\Delta h_m = h_{roof} - h_m \quad (6)$$

is the difference between the building height h_{roof} and the height of the MS h_m. The orientation of the street is taken into account by an empirical correction factor:

$$L_{ori} = \begin{cases} -10 + 0.354\varphi, & for\ 0° \leq \varphi \leq 35° \\ 2.5 + 0.075(\varphi - 35), & for\ 35° \leq \varphi \leq 55° \\ 4.0 - 0.114(\varphi - 55), & for\ 55° \leq \varphi \leq 90° \end{cases} \quad (7)$$

where φ is the angle between the street orientation and the direction of incidence in degrees.

For the computation of the multiscreen loss L_{msd}, building edges are modeled as screens. The multiscreen loss is then given as:

$$L_{msd} = L_{bsh} + k_a + k_d\ log_{10}(d) + k_f\ log_{10}(fc) - 9log_{10}b \quad (8)$$

where b is the distance between two buildings (in meters). Furthermore:

$$L_{bsh} = \begin{cases} -18\ log(1 + \Delta h_b), & for\ h_b > h_{roof} \\ 0, & for\ h_b \leq h_{roof} \end{cases} \quad (9)$$

$$k_a = \begin{cases} 54, & for\ h_b > h_{roof} \\ 54 - 0.8\Delta h_b, & for\ d \geq 0.5km\ and h_b \leq h_{roof} \\ 54 - 0.8\Delta h_b \frac{d}{0.5}, & for\ d < 0.5km\ and h_b \leq h_{roof} \end{cases}$$
(10)

where

$$\Delta h_b = h_b - h_{roof} \quad (11)$$

And h_b is the height of the BS. The dependence of the pathloss on the frequency and distance is given via the parameters k_d and k_f

$$k_d = \begin{cases} 18, & for\ h_b > h_{roof} \\ 18 - 15\frac{h_b}{h_{roof}}, & for\ h_b \leq h_{roof} \end{cases} \quad (12)$$

$$k_f = -4 + \begin{cases} 0.7\left(\frac{fc}{925} - 1\right), & for\ medium\ cities, suburban\ area\ with\ average\ vegetation. \\ 1.5\left(\frac{fc}{925} - 1\right), & for\ metropolitan\ areas \end{cases} \quad (13)$$

Furthermore, the model does not include the effect of wave guiding through street canyons, which can lead to an underestimation of the received field strength. [15]

2.2.3 CCIR Model

An empirical formula for the combined effects of free-space path loss and terrain induced path loss was published by the CCIR (Comite' Consultatif International des Radio-Communication, now ITU-R) [2]. The CCIR model is expressed in as:

$$L_{ccir} = 69.55 + 26.16Log_{10}(f_{MHz}) - 13.82Log_{10}(h_b) \quad (14)$$

$$-a(h_m)+[44.9-6.55Log_{10}(h_b)]Log_{10}(d_{km})-B$$

Where:

$$a(h_m)=[1.1Log10(f_{MHz})-0.7]h_m-[1.56Log10(f_{Mhz})-0.8] \quad (15)$$

$$B=30-25Log_{10}(\%\ of\ area\ covered\ by\ buildings) \quad (16)$$

The term B is such that the correction B = 0 is applied for an urban area, one that is about 15% covered by buildings; for example if 20% of the area is covered by buildings, then B = 30-25log10 20 (Joseph, 2014).

2.2.4 The Okumura–Hata Model

The more common form is a curve fitting of Okumura's original results. In that implementation, the path-loss is given in [15] as:

$$P_L = A + B\ log(d) + C \quad (17)$$

Where A, B, and C are factors that depend on frequency and antenna height.

$$A=69.55+26.16log(f_c)-13.82log(h_b)-a(h_m) \quad (18)$$

$$B=44.9-6.55log(hb) \quad (19)$$

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Where fc is given in MHz and d in km.

The function a(hm) and the factor C depend on the environment:

- small and medium-size cities:

$$a(h_m)=(1.1\log(f_c)-0.7)h_m-(1.56\log(f_c)-0.8)$$
(20)

C = 0

- metropolitan areas:

For f ≤ 200 MHz,

$$a(h_m)=8.29(\log(1.54h_m)^2)-1.1$$
(21)

For f ≥ 400 MHz,

$$a(hm)=3.2(\log(11.75hm)2)-4.97 \quad (22)$$

$$C=0 \quad (23)$$

- suburban environments

$$C = -2[\log(fc / 28)]2 - 5.4 \quad (24)$$

rural area

$$C=-4.78[\log(fc)]2+18.33\log(fc)-40.98 \quad (25)$$

The function a(hm) in suburban and rural areas is the same as for urban (small and medium-sized Cities) areas.

The value of C also changes for metropolitan areas. All values of C for other areas remain the same.

I.e C = 3 for metropolitan areas.

3.0 Methodology

At GSM frequency of 900 MHz RF signal, measurements were performed during May and June 2015 and the measurement campaign consisted of three locations namely Enerhen as terrain 1, Refinery Road, as terrain 2 and Okuokuku as terrain 3 all in the City of Warri. In each case the downlink, received signal level (RSL) was measured using a mobile phone equipped with net monitor software (Transmission Monitoring System (TEMS)). The software provided various parameters such as the operator code of the network, the operator's brand name, the location Area Code (LAC), and the cell identification number (CID). The software also displays GPS Parameters the received signal level (RSL) in decibel milliwatt (dBm), and the location of the base transceiver station from which the phone is obtaining service at that instant.

For every cell in the environment investigated, received signal level at intervals of 100m was measured. The RSL at distance interval of 100m from the foot of the base transceiver station up till the distance of beyond 1000m was measured. The global positioning system (GPS) was used to read the geographic coordinate and distance. The measurement was carried out using MTN Nigeria GSM Network on three BTS Cell sites selected in the locations of study with the aid of the test tool (Mobile handset) running on the transmission Evaluation Monitoring System mode. Calls were initiated at each test point (i.e. intervals of 100m) and the signal strength information sent over the air interface within the propagation channel bounded by the base station and the mobile station were read and recorded.

The distances of each measurement points from the reference point of the base transceiver station were recorded using the global positioning system (GPS). The GPS showed the path length. The GPS was first switched on at the foot of the BTS tower, before the ENTER button was pressed. We first moved a distance from the reference BTS and when the radial distance on the GPS reads the value equal to the desired close in reference distance, the transmission evaluation monitoring system platform was unveiled on the screen and the readings of received signal level (RSL) in decibel milliwatt, taken. The measurement set up is as shown in Fig. 3.1.

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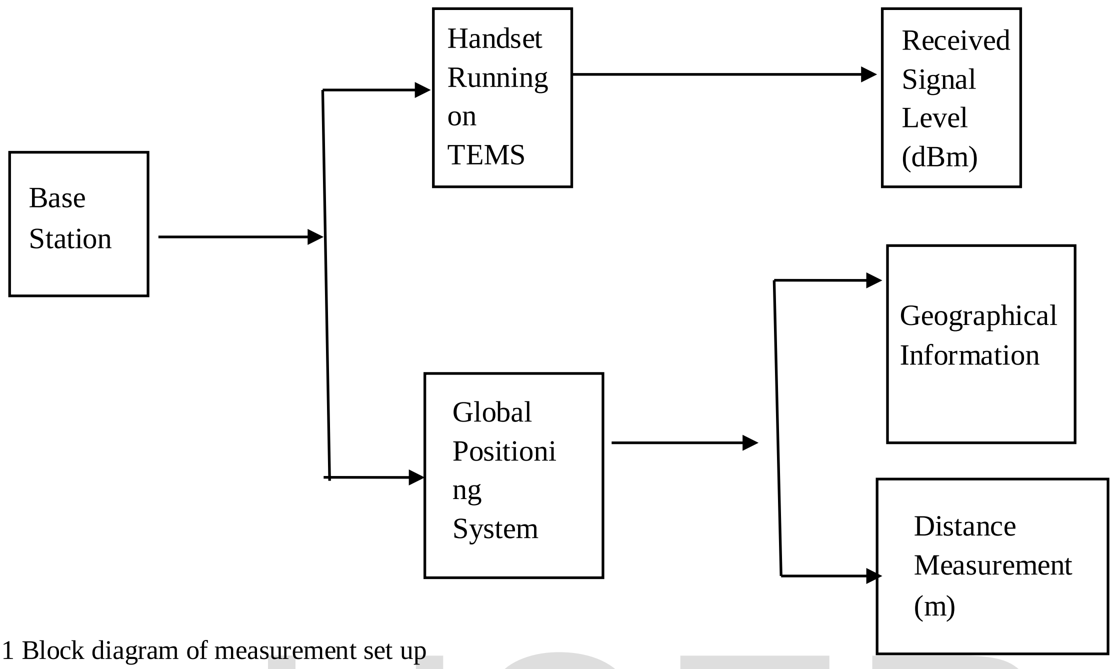

Fig. 3.1 Block diagram of measurement set up

Fig 3.2: Netmonitor display of Enheren BTS during measurement

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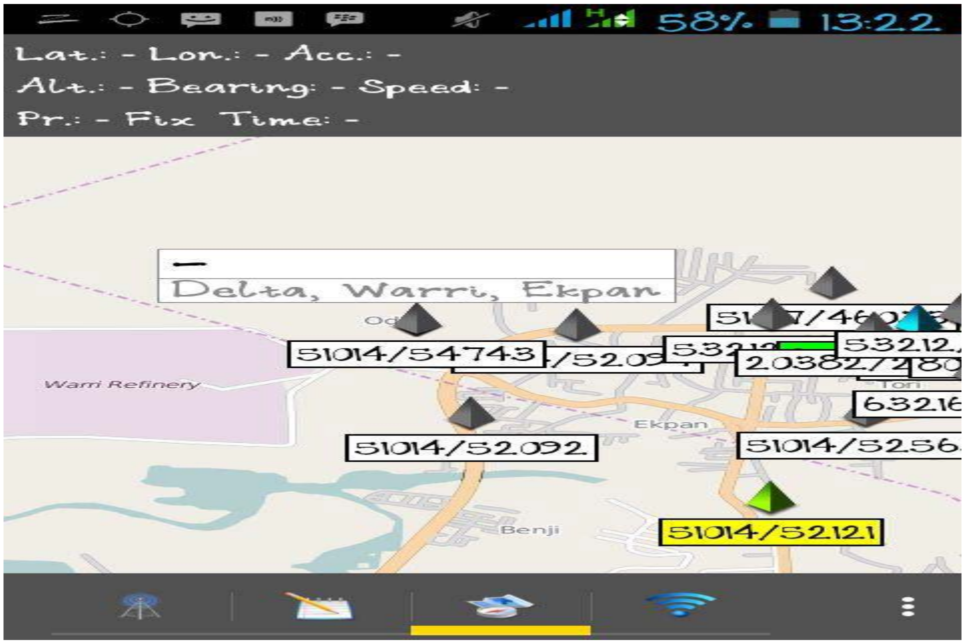

Fig 3.3: Netmonitor display of Refinery Road BTS during measurement

Fig 3.4: Netmonitor display of Okuokuku BTS during measurement

Fig.3.5: The clutter of propagation in Enheren (urban terrain)

Fig. 3.6: The clutter of propagation in Refinery road (suburban terrain)

3.5 Measurement of Pathloss

We obtained the propagation pathloss from the received signal level (RSL) as in the field using the expression given by [16] as shown in (26):

$P_L = P_t - P_r$ (in dBm) (26)

Where P_L = Pathloss, P_t = transmit power or EIRP, and P_r = received signal level

Table 3.1: Experimental Parameters (Link Budget)

Parameters	**Rating**
Frequency	900MHz
Power transmitted ($P_{BTS)}$	46dBm or 16dBfor all sites
Height of BTS Tower	25m terrain 1, 33m terrain 2 and 52m in terrain 3
Height of mobile station	1.5m in all cases
Connector loss (P_{con})	2dB for uplink and downlink
Duplexes loss (P_D)	4.5dB
Feeder loss (P_f)	1.5dB
Base station gain (G_{BTS})	18dBi Terrain 1, 17.5dBi Terrain 2 and Terrain 3
Mobile Station Gain (G_{ms})	7dBi
BS EIRP	62.5dBm, rural & suburban

BS EIRP	63dBm, urban

The effective isotropic radiation power (EIRP) as in [16]:

$EIRP = P_{BTS} - P_{con} - P_D - P_f + (G_{BTS} + G_{ms})$ (27)

$EIRP_{rural} = 32.5dB = 62.5dBm$ (same as suburban)

Since $P_{dbm} = 10\log_{10}P_{mW} = 10\log P_W + 30$

Similarly,

$EIRP_{urban} = 62.5dB$.

Other experimental data were obtained from the GSM network provider, MTN. Pathloss values from existing models where obtained from simulation using MATLAB and results shown in section 4.0.

4.0 Result and discussion

The simulation results obtained from the experiment are shown in the following tables:

Table 4.1: Measured path-loss values for the 3 terrrains

Path length (km)	Measured Path loss Terrain1 (dB)	Measured path loss terrain 2 (dB)	Measured path loss terrain 3 (dB)
0.1	123.5	115.5	114.5
0.2	131.0	127.5	116.5
0.3	134.5	128.5	122.0
0.4	137.0	131.5	127.0
0.5	146.5	134.5	129.5
0.6	148.0	135.5	130.0
0.7	149.3	135.5	130.0
0.8	151.0	137.3	133.0
0.9	152.5	138.3	135.5
1.0	155.0	141.5	141.5

Table 4.2: Measured path-loss with the prediction models in terrain 1

Path length (km)	Measured path-loss (dB)	WIM Model (dB)	Hata model (dB)	CCIR Model (dB)	Free space (dB)
0.1	123.5	117.7945	78.5327	107.8815	71.5349

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0.2	131.0	129.2337	85.7021	118.6414	77.5555
0.3	134.5	135.9251	89.8960	124.9355	81.0773
0.4	137.0	140.6728	92.8716	129.4013	83.5761
0.5	146.5	144.3554	95.8716	132.8652	85.5143
0.6	148.0	147.3643	97.0654	135.6954	87.0979
0.7	149.3	149.9082	98.6598	138.0883	88.43.68
0.8	151.0	152.119	100.0410	140.1611	89.5966
0.9	152.5	154.0559	101.2593	141.9895	90.6179
1.0	155.0	155.7945	102.3490	143.6250	91.5349

Table 4.3: Measured path-loss with prediction themodels in terrain 2

Path length (km)	Measured path-loss (dB)	WIM Model (dB)	Hata model (dB)	CCIR Model (dB)	Free space (dB)
0.1	115.5	106.1108	66.5549	103.3518	71.5349
0.2	127.5	117.5499	73.1769	113.8739	77.5555
0.3	128.5	124.2414	77.0505	120.0289	81.0773
0.4	131.5	128.9891	79.7989	124.3960	83.5761
0.5	134.5	132.6717	81.9307	127.7834	85.5143
0.6	135.5	135.6805	83.6726	130.5510	87.0979
0.7	135.5	138.6805	85.1452	132.8911	88.4368
0.8	137.3	140.4282	86.4209	134.9181	89.5966
0.9	138.3	142.3720	87.5462	136.7061	90.6177
1.0	141.5	144.1108	88.5528	138.3055	91.5349

Table 4.4: Measured path-loss with prediction the models in terrain 3

Path length (km)	Measured path-loss (dB)	WIM Model (dB)	Hata model (dB)	CCIR Model (dB)	Free space (dB)

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0.1	114.5	100.6923	63.2490	99.4933	71.5349
0.2	116.5	112.1314	63.9743	109.62	77.5555
0.3	122.0	118.8229	72.3235	115.5532	81.0773
0.4	127.0	123.5705	74.6997	119.7582	83.5761
0.5	129.5	129.2531	76.5429	123.0207	85.5143
0.6	130.0	130.2620	78.0489	125.6360	87.0979
0.7	133.0	132.8060	79.3222	127.9394	88.4368
0.8	133.0	135.0097	80.4251	129.8914	89.5966
0.9	135.5	136.9535	81.3980	131.6132	90.6177
1.0	141.5	138.6923	82.2683	133.1534	91.5349

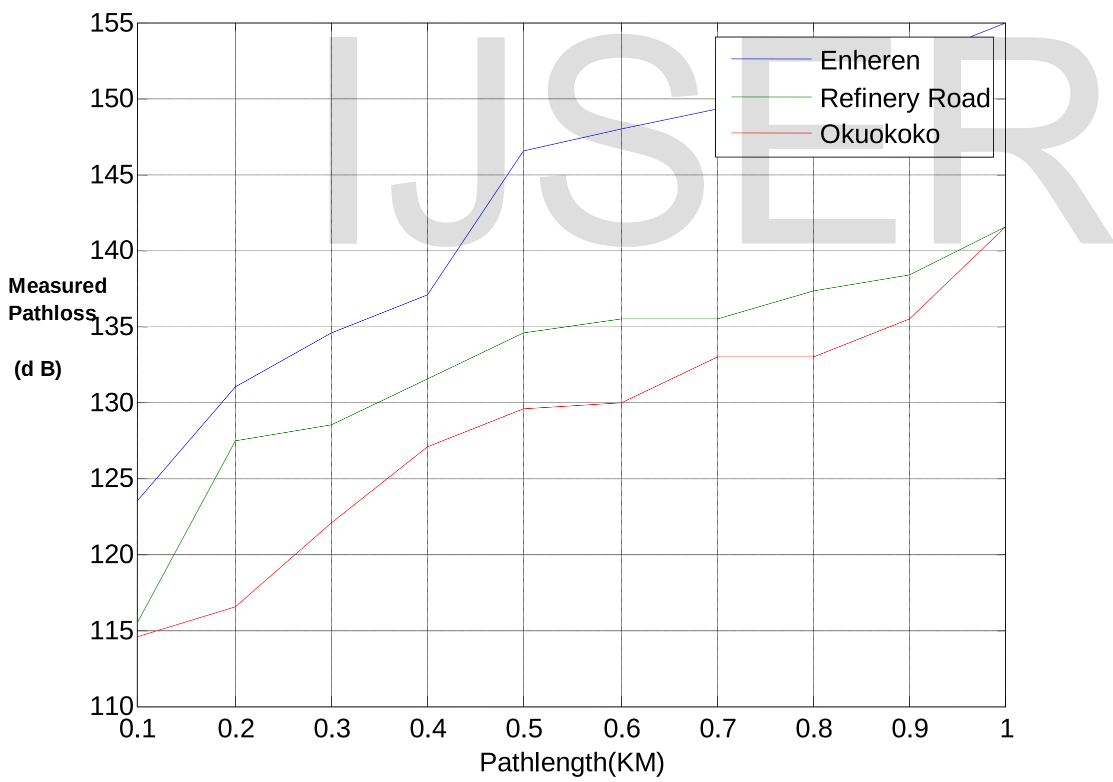

Fig. 4.2: Graph comparing measured path loss in the 3 terrains.

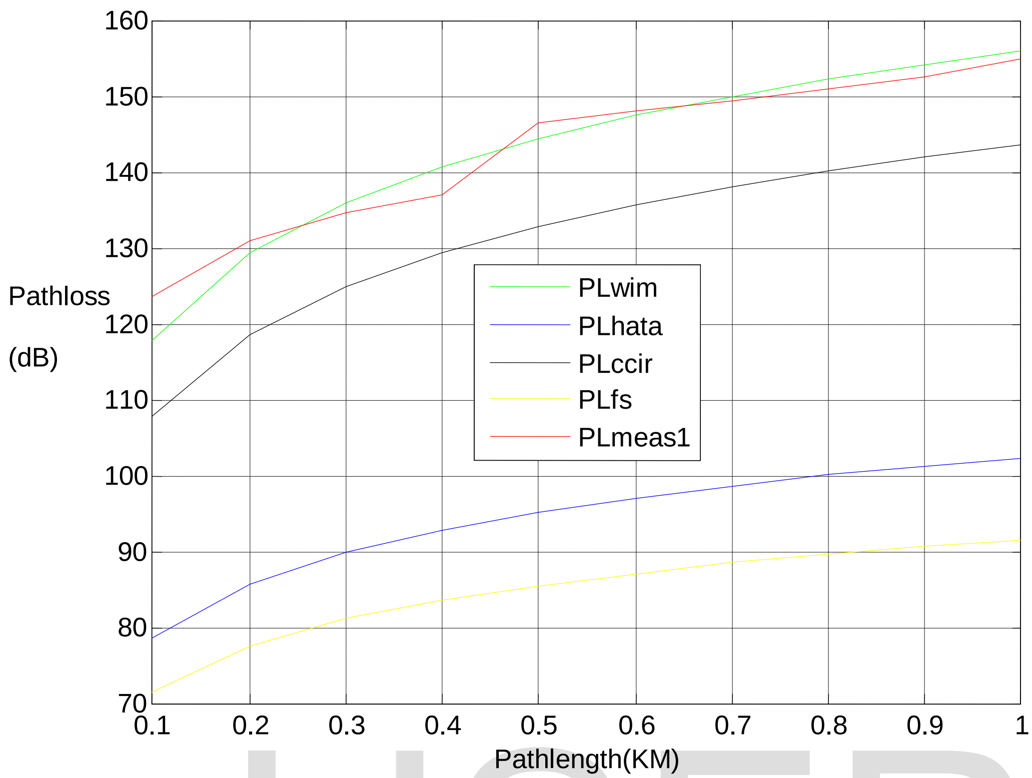

Fig.4.3:Comparing performance of path-loss models at Enheren

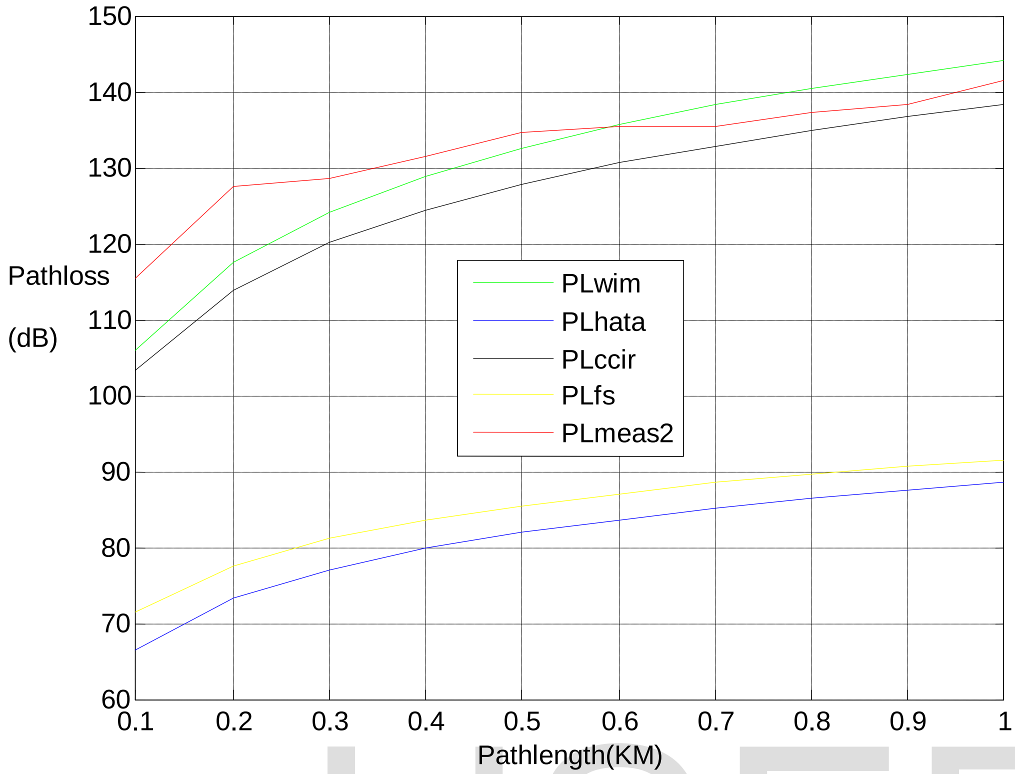

Fig 4.4: Comparing performance of Path-loss models at Refinery Road.

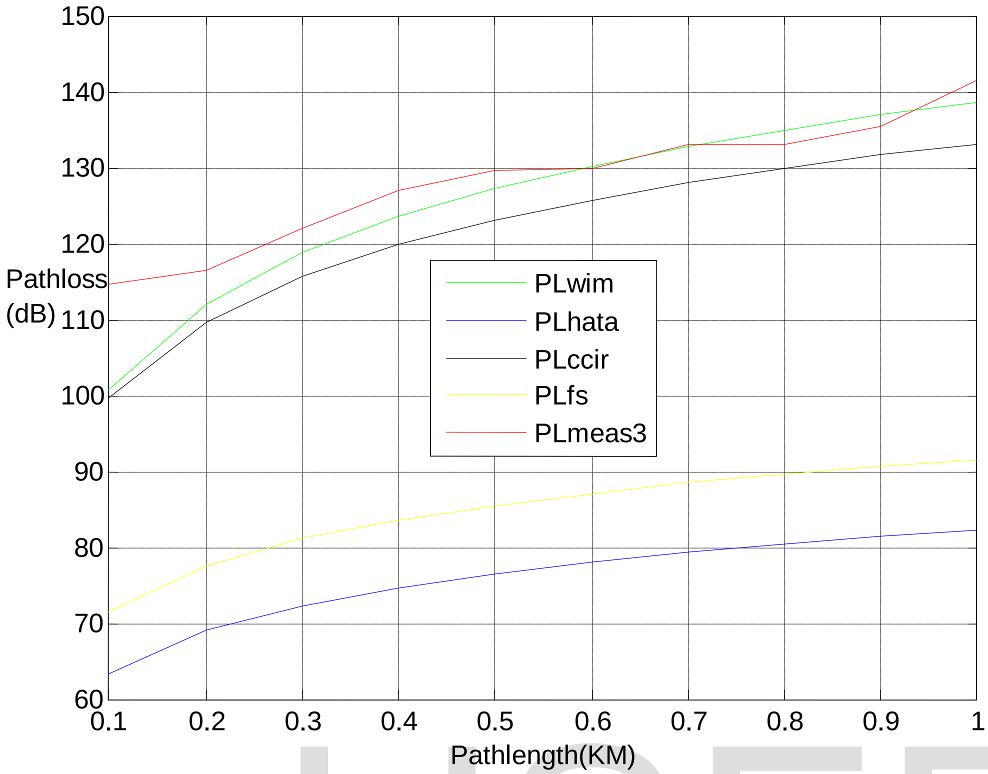

Fig 4.5: Comparing performance for path-loss models at Okuokuku

4.1 Discussion

Fig. 4.2 shows that signal pathloss is highest in Enheren-urban terrain followed by Refinery Road-suburban and then, Okuokuku-rural. Fig. 4.3 shows the plot of COST-231 Walfish Ikegami model indicated in the legend as PLwim, Okumura Hata model indicated as PLhata and CCIR model indicated as PLccir. It also indicated the Free Space model model as PLfs and the measured path loss as PLmeas1 in the legend. It can therefore be observed from the graph that the WIM model predicts pathloss in this terrain more accurately as its curve has a very close correlation with the field measured pathloss.

Refinery road is named Terrain 2 in this research and it represents a suburban environment. The performance of the existing path-loss models are depicted in Fig. 4.4 . COST-231 WIM model still gave the best performance as its curve conform more closely with that of the field measured path-loss within the path distance under consideration.

At Okuokuku (see Fig. 4.5) COST 231-Walfish Ikegami model gave the best path-loss prediction in this environment. The performance of the WIM model is followed closely by the CCIR model. The predictions offered by the Hata and free space model shows a clear departure from the actual path-loss obtained from the received signal strength. For Hata model offering the worst performance could be attributed to the fact that the model is designed mainly for urban environments, and path distance of the range 1km ≤d≤20km .

5.0 Conclusion

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The objective of this work is to obtain a suitable pathloss prediction model for the city of Warri in South South Nigeria. To this end a comparative analysis was conducted for various prediction models such as, WIMNLOS model, Hata, CCIR, and Free Space models. These models where then compared with the pathloss from field measured data. The result obtained from the measurements shows that signal pathloss is higher in the urban clutter with value of 138dBm at 900MHz and pathlength of 1000m compared to the rural clutter which is 125dBm at same propagation distance.

The summary of all the values obtained for the pathloss models are presented in tables shown in section 4 and the corresponding graphs were generated through MATLAB simulation. From the result obtained (see Figs. : 4.3, 4.4, 4.5, and 4.6) the COST-231 Walfish Ikegami model showed the best prediction for the three terrains followed by the CCIR model. When tested for correctness, COST-231 WIM model gave a mean square error and standard deviation of acceptable values for the three terrains considered. Hence the COST-231 WIM model should be the preferred pathloss prediction model for the city of Warri.

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