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An Exponent-Based Propagation Path Loss Model for Wireless System Networks at Vehicular Speed

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ABSTRACT: *This work investigated and developed an exponent-based path loss model on the level of signal loss experienced on the Airtel Third Generation network within the Port-Harcourt city of Rivers State, Nigeria at vehicular speed. This was deduced by carrying out a drive test within the area, using Transmission Evaluation and monitoring system installed mobile phone, laptop, and Global Positioning System. From the data collected, a path loss model that best describe the signal loss within the area was developed via a path loss exponent for the Airtel Port-Harcourt Third Generation network. It is recommended that Airtel Communication Company should replace their directional Base Transceiver Station Antennas with a bi-sector high gain antenna that will ensure wider and Omni-directional signal coverage within the area.*

Keywords – *exponent, model, network, path loss, signal, wireless system*

I. INTRODUCTION

The era of modern wireless communication begun in the 1980's and is divided into generations. First Generation (1G) wireless communication systems could only transmit voice calls and a limited size of data, and had no roaming capability. The Second Generation (2G) systems came on board when the roaming capability was integrated into wireless communication. 2G has a high data carrying capacity compared to 1G. The emergence of cellular systems marked the beginning of the Third Generation (3G) systems which is also called International Mobile Telecommunication – 2000 (IMT-2000). 3G systems offer better voice quality, global roaming, as well as high data rate service. The Fourth Generation (4G) system is now being developed as an Internet Protocol (IP) based wireless mobile network which offers broadband data communication that is capable of transmitting voice, video, and data.

The challenges of 1G and 2G technologies were resolved when Airtel Communication Company deployed its 3G network in the city of Port-Harcourt, Rivers State, Nigeria. The 3G network carries the promise of ubiquitous broadband wireless access enabling real-time and multimedia applications [1]. Though the capacity of this network created a new ground for public surveillance, however, this technology is not without its peculiar challenges. At vehicular speed, its data rate does decrease sharply with speed for mobile applications thereby resulting to service degradation while traversing the streets in Port-Harcourt city. This challenge/drawback is traced to be as a result of multipath propagation, Doppler spread, among other factors.

This research intends to carry out a thorough investigation on the level of signal loss experienced on the Airtel 3G networks within the Port-Harcourt city by carrying out a drive test within the area. The research is expected to deduce a path loss exponent for the Airtel Port-Harcourt 3G network; compute the standard deviation that exists between the measured path losses and the predicted path losses; develop a path loss model that best describe the signal loss; compare the proposed model with the Okumura-Hata standard model, and then offer solution on how to minimize the service degradation in the Airtel 3G networks in Port-Harcourt city.

This study will be limited to the use of drive test to determine the signal loss in the AIRTEL Port-Harcourt 3G network. It will employ the use of Transmission Evaluation and Monitoring System (TEMS) software, Actix software, including the MatLab software in carrying out the analysis.

II. RELATED WORKS

2.1 Hata model

The Hata path loss prediction model is preferred since it is convenient for frequency range of 150-15000 MHz and for distance range of 1km - 20km. it demands that the base station antenna height be 30m and above while the receiving station antenna height will be 3m and above. Hata prediction model also gives room for correction factors addition.[2]

Hata model is a set of equation which is acquired from taken measurements and extrapolations acquired from curves that are developed by Okumura. [3]

The three categories of Hata prediction models, according to [4], are as enlisted below:

- Open or rural Hata pathloss,
- Suburban Hata pathloss and
- Urban Hata pathloss.

2.1.1 Rural Hata path loss

$$PL = PLUrban - 4.78(\log_{10}(f)^2) + 18.33\log_{10}(f) - 40.98 \qquad (2.1)$$

Where;

For the above three categories, the correction factor for the Mobile station antenna is given thus:

$$a(hm) = 1.11\log_{10}(f) - 0.7)h_m - (1.56\log_{10}(f) - 0.8)dB \qquad (2.2)$$

f is the frequency (MHz)

h_m is the height of the mobile antenna in meters

h_b is the height of the base station antenna in meters

2.1.2 Urban Hata path loss

$$PL = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(hb) + (44.9 - 6.55\log_{10}(hb))\log_{10}(d) + s\text{-}a(hm) \qquad (2.3)$$

2.1.3 Surban Hata path loss

$$PL = PLUrban - 2((\log_{10}f/28))\,2 - 5.4 \qquad (2.4)$$

III. DERIVATION OF THE PROPOSED MODEL

The apparatus that were used to carry out the drive test in the course of this research work include the following:

i. Laptop with an installed Transmission Evaluation and Monitoring System (TEMS) software
ii. Global positioning System (GPS)
iii. Mobile Phone with an installed TEMS software
iv. Power supply from external battery source
v. Car for mobility

The interconnections made among these materials are represented in Fig. 3.1

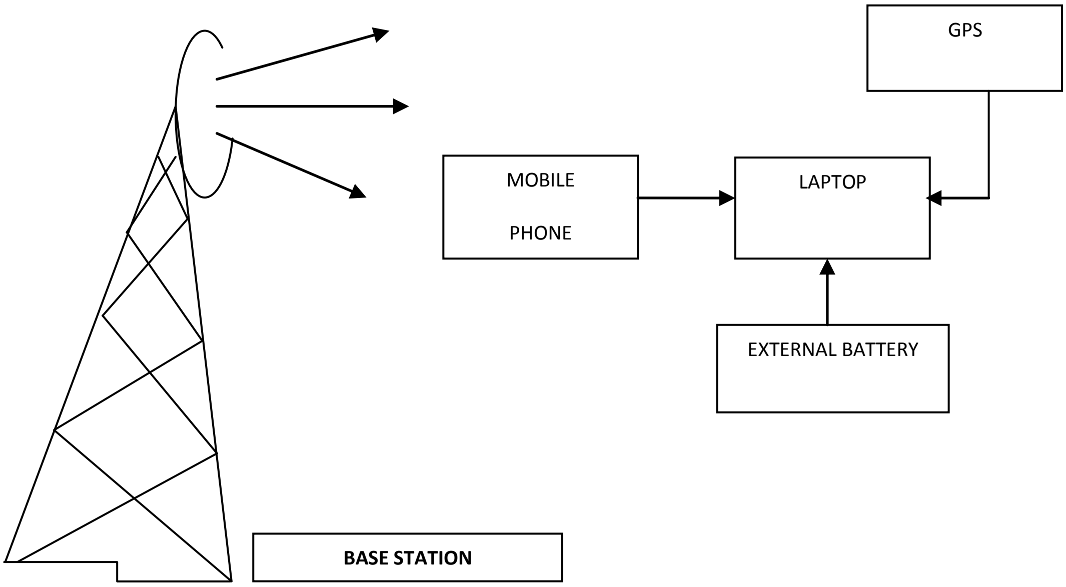

Figure 3.1: Block diagram showing the interconnections of materials used for the Drive test.

The above block diagram simplifies the essential connections made with required materials before the drive test was commenced. The service was provided by the Airtel 3G networks operating at a frequency range of 10,712MHz and 10,737MHz. The transmitter power is at the range of 20W and 30W, and was mounted on steel tower of about 30m above ground level.

An Airtel SIM card was inserted into the mobile phone installed with TEMS software, and the mobile phone is then connected to the Laptop mentioned above through a USB cord. The GPS is connected to the laptop through another USB cord and then placed firmly on top of the car. An external battery source provided an extra power source to the laptop in order to ensure continuous and constant power supply throughout the drive test.

This drive test was carried out in three sites in port-Harcourt city which altogether is about 1500m in distance. On the start of each phase, the laptop is initiated to commence readings on the site by the click of the cursor on the 'Record' button which is located at the start tab button. At this point, the radio Propagation Simulator (TEMS Phone) initiates and terminates short calls (about 15 seconds each), the GPS points coordinates (latitude and longitudes) of the environment, while the laptop records the Received Signal Strength (RSS) and displays the log video on the screen. The Average Received Signal Level along the measured routes are represented in Table 3.1

Table 3.1: Average Received Signal Level along the measured routes

Distance(km)	Average RSL (dBm)
0.10	-59
0.20	-67
0.30	-75
0.40	-71
0.50	-70
0.60	-70
0.70	-72
0.80	-85
0.90	-72
1.00	-76
1.10	-86
1.20	-71
1.30	-84
1.40	-83
1.50	-84

Table 3.1 stands for the Average Received Signal Level at various distances. From the table, the closest distance at which the signals were received is 100m. In other to calculate the average power received at this closest distance (100m), the conventional formular in (3.1) is used as shown below:

$$\text{Power Received, } P_r \ (RSS_{av}) \text{ in dBm} = 10\log P_r = -59\text{dBm} \tag{3.1}$$

$P_r = 10^{-5.9} = 1.26X10^{-6}\text{dB}$

The Transmitter power P_t is 30w. Thus:

$P_t = 30w = 14.77\text{dB}$

Using (3.2) below, the measured path loss across the Port-Harcourt city could easily be obtained thus:

$$P_m(d0) = 10\log\left(\frac{P_t}{P_r}\right) \tag{3.2}$$

Where;

P_m is the measured path loss

P_t is the transmitter power

P_r is the received signal strength [5]

Hence;

at d1 ,

$$P_m(d1) = 10\log\left(\frac{14.77}{1.26X10^{-6}}\right) \quad = 70\text{dB}$$

at d2,

$P_r = 10^{-6.7} = 2.0 \times 10^{-7}\text{dB}$

$$P_m(d2) = 10\log\left(\frac{14.77}{2.0 \times 10^{-7}}\right) \quad = 79\text{dB}$$

at d3,

$Pr = 10^{-7.5} = 3.16 \times 10^{-8}\text{dB}$

$$P_m(d3) = 10\log\left(\frac{14.77}{3.16 \times 10^{-8}}\right) \quad = 87\text{dB}$$

at d4,

$Pr = 10^{-7.1} = 7.9 \times 10^{-8}\text{dB}$

$$P_m(d4) = 10\log\left(\frac{14.77}{7.9 \times 10^{-8}}\right) \quad = 83\text{dB}$$

at d5,

$Pr = 10^{-7} = 1.0 \times 10^{-7}\text{dB}$

$$P_m(d5) = 10\log\left(\frac{14.77}{1.0 \times 10^{-7}}\right) = 82.\text{dB}$$

at d6,

$$Pr = 10^{-7} = 1.0 \times 10^{-7}\text{dB}$$

$$P_m(d6) = 10\log\left(\frac{14.77}{1.0 \times 10^{-7}}\right) = 82\text{dB}$$

at d7,

$$Pr = 10^{-7.2} = 6.31 \times 10^{-8}\text{dB}$$

$$P_m(d7) = 10\log\left(\frac{14.77}{6.31 \times 10^{-8}}\right) = 84\text{dB}$$

at d8,

$$Pr = 10^{-8.5} = 3.16 \times 10^{-9}\text{dB}$$

$$P_m(d8) = 10\log\left(\frac{14.77}{3.16 \times 10^{-9}}\right) = 97\text{dB}$$

at d9,

$$Pr = 10^{-7.2} = 6.31 \times 10^{-8}\text{dB}$$

$$P_m(d9) = 10\log\left(\frac{14.77}{6.31 \times 10^{-8}}\right) = 84\text{dB}$$

at d10

$$Pr = 10^{-7.6} = 2.51 \times 10^{-8}\text{dB}$$

$$P_m(d10) = 10\log\left(\frac{14.77}{2.51 \times 10^{-8}}\right) = 88\text{dB}$$

at d11,

$$Pr = 10^{-8.6} = 2.51 \times 10^{-9}\text{dB}$$

$$P_m(d11) = 10\log\left(\frac{14.77}{2.51 \times 10^{-9}}\right) = 98\text{dB}$$

at d12,

$$Pr = 10^{-7.1} = 7.90 \times 10^{-8}\text{dB}$$

$$Lp(d12) = 10\log\left(\frac{14.77}{7.90 \times 10^{-8}}\right) = 83\text{dB}$$

at d13

$$Pr = 10^{-8.4} = 3.98 \times 10^{-9}\text{dB}$$

$$P_m(d13) = 10\log\left(\frac{14.77}{3.98\times10^{-9}}\right) = 96dB$$

at d14

$$Pr = 10^{-8.3} = 5.01\times10^{-9}\,dB$$

$$P_m(d14) = 10\log\left(\frac{14.77}{5.01\times10^{-9}}\right) = 95dB$$

at d15

$$Pr = 10^{-8.4} = 3.98\times10^{-9}dB$$

$$P_m(d15) = 10\log\left(\frac{14.77}{3.98\times10^{-9}}\right) = 96dB$$

Table 3.2: Average Received Signal Levels and the measured path losses

Distance(km)	Average RSL (dBm)	Measured Path losses, Pm (dB)
0.10	-64	70
0.20	-67	79
0.30	-75	87
0.40	-71	83
0.50	-70	82
0.60	-70	82
0.70	-72	84
0.80	-85	97
0.90	-72	84
1.00	-76	88
1.10	-86	98
1.20	-71	83
1.30	-84	96
1.40	-83	95
1.50	-84	96

In order to generate the proposed model for the Airtel 3G network for the port-Harcourt city, (3.3) is a veritable tool. The model demands the computation of the path loss exponent and the standard deviation as shown:

$$Lp = Lp(d0) + 10np\log\left(\frac{di}{do}\right) + X\delta \qquad (3.3)$$

Where;

$Lp =$ is the proposed path loss

$Lp(do)$ is the path loss at close-in distance, do

$np = \text{path loss exponent}$ [6]

It is very vital to determine the predicted path losses along the routes concern. The values of the measured path losses and predicted path losses are essential for computing the path loss exponent along the routes under consideration. The predicted path losses are computed using (3.4):

$$Lp(di) = Lp(d0) + 10np\log\left(\frac{di}{do}\right) \qquad (3.4)$$

Where;

$Lp(di)$ is the predicted path loss at di

for i=1, 2, 3, ...

$Lp(do)$ is the path loss at close-in distance, do

$np = \text{path loss exponent}$ [6]

From Table 3.2,

Lp(d0)= 70dB (at close- in distance (do) of 0.10km).

Generating the predicted path losses at various distances;

$\text{at } d1 = 0.10\text{km} = do$

$$Lp(d1) = 70 + 10nplog\left(\frac{0.10}{0.10}\right) = 70$$

$\text{at } d2 = 0.20\text{km}$

$$Lp(d2) = 70 + 10nplog\left(\frac{0.20}{0.10}\right) = 70 + 3.0np$$

$\text{at } d3 = 0.30\text{km}$

$$Lp(d3) = 70 + 10nplog\left(\frac{0.30}{0.10}\right) = 70 + 4.8np$$

$\text{at } d4 = 0.40\text{km}$

$$Lp(d4) = 70 + 10nplog\left(\frac{0.40}{0.10}\right) = 70 + 6.0np$$

$\text{at } d5 = 0.50\text{km}$

$$Lp(d5) = 70 + 10nplog\left(\frac{0.50}{0.10}\right) = 70 + 7.0np$$

$\text{at } d6 = 0.60\text{km}$

$$Lp(d6) = 70 + 10nplog\left(\frac{0.60}{0.10}\right) = 70 + 7.8np$$

$\text{at } d7 = 0.70\text{km}$

$$Lp(d7) = 70 + 10nplog\left(\frac{0.70}{0.10}\right) = 70 + 8.5np$$

$\text{at } d8 = 0.80\text{km}$

$$Lp(d8) = 70 + 10nplog\left(\frac{0.80}{0.10}\right) = 70 + 9.0np$$

$\text{at } d9 = 0.90\text{km}$

$$Lp(d9) = 70 + 10nplog\left(\frac{0.90}{0.10}\right) = 70 + 9.5np$$

at d10 = 1.0km

$$Lp(d10) = 70 + 10np\log\left(\frac{1.0}{0.10}\right) = 70 + 10.0np$$

at d11 = 1.10km

$$Lp(d11) = 70 + 10np\log\left(\frac{1.10}{0.10}\right) = 70 + 10.4np$$

at d12 = 1.20km

$$Lp(d12) = 70 + 10np\log\left(\frac{1.20}{0.10}\right) = 70 + 10.8np$$

at d13 = 1.30km

$$Lp(d13) = 70 + 10np\log\left(\frac{1.30}{0.10}\right) = 70 + 11.1np$$

at d14 = 1.40km

$$Lp(d14) = 70 + 10np\log\left(\frac{1.40}{0.10}\right) = 70 + 11.5np$$

at d15 = 1.15km

$$Lp(15) = 70 + 10np\log\left(\frac{1.50}{0.10}\right) = 70 + 11.8np$$

Table 3.3: Average Received Signal Levels, the measured path losses and predicted Path Losses

Distance (km)	Average RSL (dBm)	Measured Path loss, Pm (dB)	Predicted Path loss Lp (dB)
0.10	-64	70	70
0.20	-67	79	70+3.0np
0.30	-75	87	70+4.8np
0.40	-71	83	70+6.0np
0.50	-70	82	70+7.0np
0.60	-70	82	70+7.8np
0.70	-72	84	70+8.5np
0.80	-85	97	70+9.0np
0.90	-72	84	70+9.5np
1.00	-76	88	70+10.0np
1.10	-86	98	70+10.4np
1.20	-71	83	70+10.8np
1.30	-84	96	70+11.1np
1.40	-83	95	70+11.5np
1.50	-84	96	70+11.8np

Predicted path losses have been computed as represented in Table 3.3. The path loss exponent which shows the relationship between the signal loss in the Airtel 3G Network can now be calculated using (3.4) below:

$$\text{path loss exponent}, np = \sum_{i=1}^{k}\left[P_m(d_i) - L_p(d_0)\right]^2 \qquad (3.4)$$

Substituting the values of Table 3.4 into (3.4) accordingly generates (3.5) below:

$$\text{Path loss exponent}, np = 1140.7(np)^2 - 4574np + 5202 \qquad (3.5)$$

Differentiating both sides with respect to np:

$$\frac{\partial(np)}{\partial np} = 2[1140.7np] - 4574 = 0$$

$$2281.84np = 4574$$

$$\text{path loss exponent, } np = 2.01$$

According to [3], the value for the standard deviation, δ can be obtained using (3.6) below:

$$\delta = \sqrt{\sum \frac{[(P_m) - (L_p)]^2}{N}} \quad (3.6)$$

$$\delta = \left[\frac{[(P_m) - (L_p)]^2}{N}\right]^{\frac{1}{2}}$$

Where;

δ = Standard deviation

P_m= measured path loss values

L_p= predicted path loss value

N=Number of data points =15

$$\delta = \left[\frac{(1140.7np)^2 - 4574np + 5202)}{15}\right]^{\frac{1}{2}}$$

$$\delta = [76.05(np)^2 - 305np + 346.8]^{\frac{1}{2}}$$

$$\delta = [2]^{\frac{1}{2}}$$

$$\delta = 1.49$$

$$\delta = 1.49dB$$

Hence, standard deviation δ is computed as being equal to 1.49dB, which approximated to $\delta = 1.5dB$.

Substituting theses values for path loss, np (2.01) and standard deviation, δ (1.5dB) into (3.3); (3.7) is then obtained as shown below:

$$Lp = Lp(d_0) + 20.1 \log\left(\frac{d_i}{d_0}\right) + X\delta \quad (3.7)$$

In other words, the path loss model for the Airtel 3G network in Port-Harcourt city is written as:

$$Lp = 70 \text{ dB} + 10 * 2.01 \log\left(\frac{d_i}{d_0}\right) + 1.5 \text{ dB} \quad (3.8)$$

$$Lp = 71.5 \text{ dB} + 20.1 \log\left(\frac{d_i}{d_0}\right) \quad (3.9)$$

$$Lp = 71.5 \text{ dB} + 20.1 \log(D) \quad (3.10)$$

For,

$$D = \frac{d_i}{d_0}$$

IV. SIMULATION RESULTS & DISCUSSION

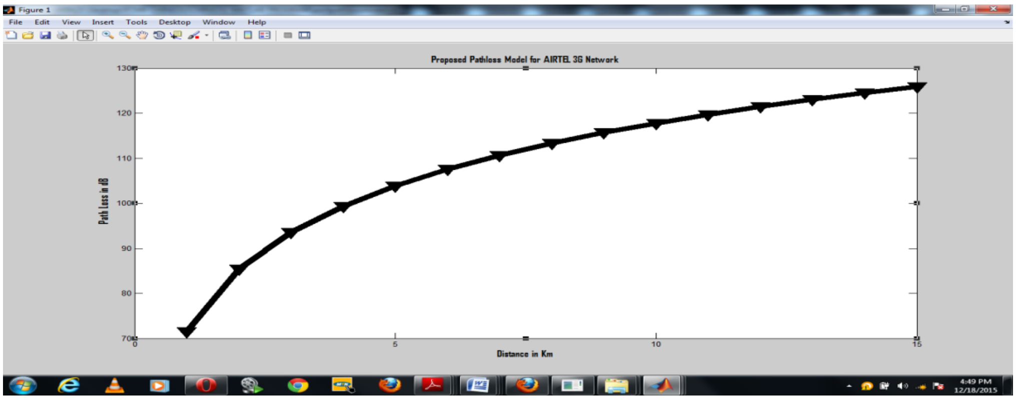

Figure 4.1: The MatLab plot of the Airtel 3G network Model for Port-Harcourt city

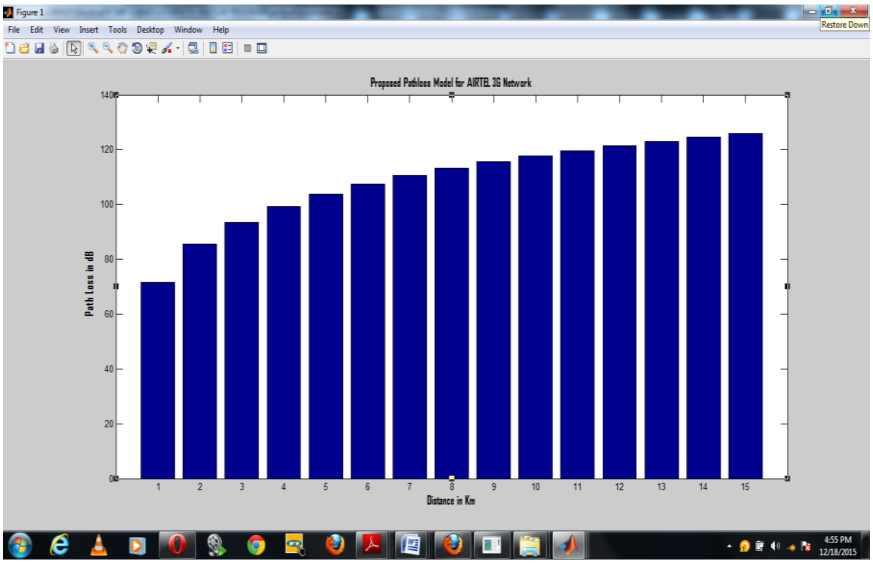

Figure 4.2: The MatLab Bar Plot of the Airtel 3G network Model for Port-Harcourt city

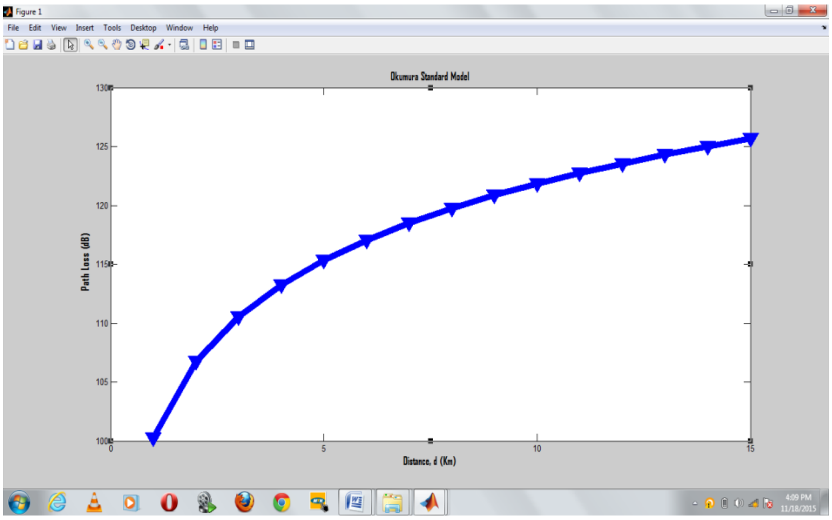

Figure 4.3: The MatLab plot of the Okumura-Hata Standard Model

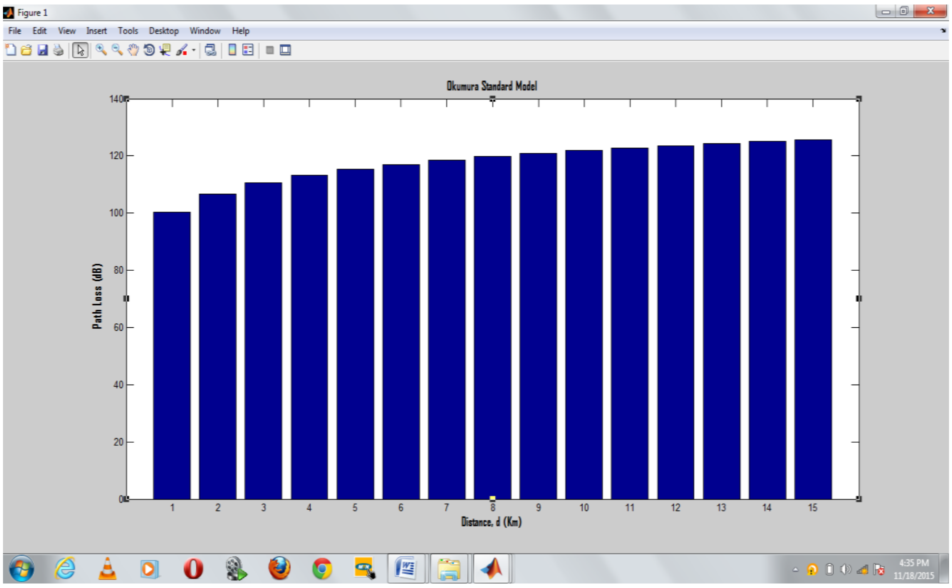

Figure 4.4: The MatLab Bar plot of the Okumura-Hata Standard Model

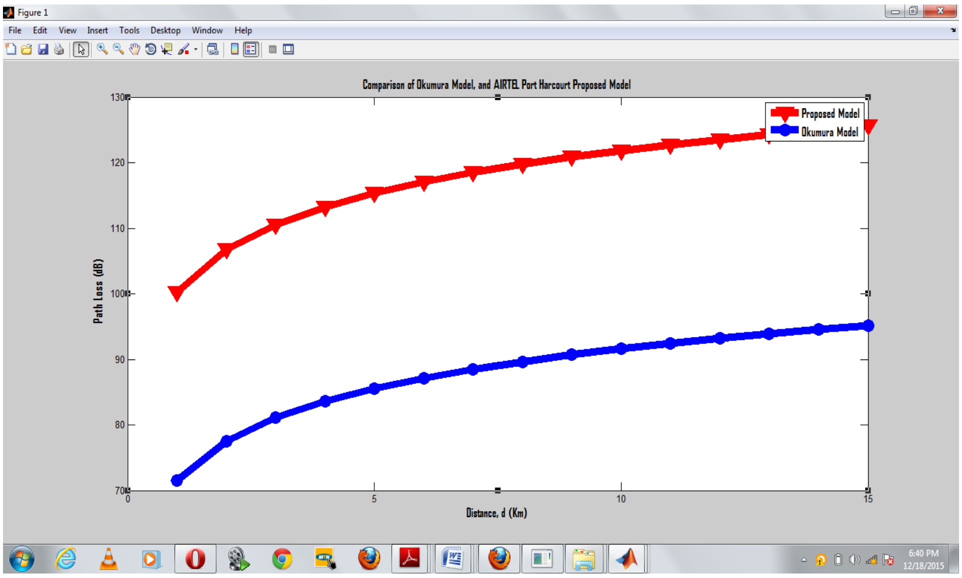

Figure 4.5: The MatLab plot of the Airtel 3G network Model for Port-Harcourt city compared with Okumura-Hata Model

4.1 Discussion

(3.10) is the Airtel 3G network Model for Port-Harcourt city. From the model, it clearly shows that the minimum signal loss experienced in the network at a close-in distance of 100m (0.1Km) is 71.5dB. At further increase of the distance, the signal loss is increased with the factor, $20.1 \log(D)$. The MatLab program of this model is plotted in Figs. 4.1 and 4.2. To ascertain the authenticity of this model, it was compared with a standard model called Okumura model, and then plotted in Figs. 4.3 and 4.4. Both models (the AIRTEL 3G network Model for Port-Harcourt city and Okumura-Hata Model) were compared in Fig. 4.5.

The Okumura-Hata model is employed since it is convenient for frequency range of 150-15000 MHz and for distance range of 1km - 20km. [2] It could be seen from the plot that both curves, though are spaced a bit from each other, are similar in the rate at which the signal loss varies with distance of separation of the receiver from the transmitter. In other words, Okumura model could well be deployed to determine this variation rate whereas the proposed model will best describe the path loss at each distance. In order to ensure proper signal coverage and accurate signal handover at a vehicular speed, it is recommended that Airtel Communication Company should replace their directional BTS Antennas with a bi-sector high gain antenna that will ensure wider and Omni-directional signal coverage.

V. CONCLUSION

In this work, a drive test was carried out at a vehicular speed within the Port-Harcourt city using Transmission Evaluation and Monitoring System (TEMS) software installed mobile phone, laptop, and Global Positioning System (GPS). From the data collected, an analysis was carried out. A path loss exponent for the Airtel Port-Harcourt 3G network was deduced; the standard deviation that exists between the measured path losses and the predicted path losses in the Airtel Port-Harcourt 3G network was computed; a path loss model that best describe the signal loss was developed; the proposed model with the Okumura-Hata standard model was compared; and solution on how to minimize the service degradation in the Airtel 3G network was offered.

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