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Analysis of Different Path Loss Propagation Models Based on 4G Walk Test Data

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Abstract

The study of path loss propagation is of high importance in telecommunication, for optimizing the efficiency of wireless communication networks. In this paper, four path loss propagation models; free space path loss (FSPL) model, Okumura model, Okumura-Hata model, and COST 231-Hata model were compared. The models were compared using measurement data from Choba, Port Harcourt, Nigeria. The data is gotten from a 4G walk test using two mobile applications. The first mobile application Network, Signal Info (version 5.68.07), was used to acquire the received signal strength in and the distance between the BTS antenna and the mobile antenna. While the second mobile application, G-NetTrack Lite (version 14.8), was used to map out the track path followed during the test. Choba, the study area, is a coastal suburban area with map coordinates 4.8941° N, 6.9263° E. The measured distance range was from 0.09 km to 0.45 km, and a path loss range of 69dB to 81dB. While the BTS and mobile antenna heights were 32 m and 1m respectively, with a carrier frequency of 800MHz. BTS transmission power of 23 dBm was assumed, based on 3GPP eNodeB recommendations. A graph comparison of the studied models showed that Okumura-Hata model and COST 231-Hata model had the closest predictions to the measured path loss. The need for better path loss models for 4G and 5G propagations was observed.

Keywords: Path Loss, FSPL, Okumura Model, Okumura-Hata Model, COST 231-Hata Model.

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Introduction

Communication has always been a very important part of life. The advantages of faster and further communication have been well known for ages, and different techniques such as the use of loud sounds, fire on hills and lighthouse have been applied in the past to achieve this. With the developments in science and technology, faster and further methods were invented, such as telegraph and telephone. We are currently living in the information age, in which we strive for instant global communication. This has been made possible through advancements in telecommunication; broadband technologies, satellite communications, and the internet.

But just as those loud sounds will get faint with distance and that bright fire on hills or lighthouse will be barely seen at a distance, all communication strategies are faced with attenuation. This reduction in signal strength over distance is more pronounced in wireless communication. This is because of the even radiation of transmitted signal in all directions of space, making a point receiver to receive just a fraction of the transmitted signal strength. Wireless communications are also more efficient at higher frequencies, but this increase in frequency leads to more atmospheric attenuation (Siles A., Riera M., & Garcia-del-Pino P., 2015). Also, wireless communications are susceptible to physical obstructions such as buildings, tress, etc. These unavoidable losses in communicated signal strength with distance can only be studied and managed properly. The minimum signal strength required at the receivers end for effective communication is used to determine the required signal strength at the transmitter, after accounting for the attenuations. These attenuations on the propagated signal are accounted for through path loss studies.

With the steady increase in the amount of data needed to be communicated wirelessly, there is a need for better telecommunication networks, especially in a developing nation as Nigeria. And the growth in the telecommunication industry can be easily linked to the growth of the nation (NCC Press Statment, 2021). Therefore it is important to analyze the propagation paths of communication signals, their losses, and optimal setups for better telecommunication networks. The use of appropriate path loss propagation models will lead to easier and better network coverage analysis, efficient use of energy, and the overall growth in the nation’s economy.

Literature Review

Path loss is defined as the ratio of the transmitted power of an antenna to the received power. This is usually expressed in decibels (dB). It includes all possible elements of loss that can affect the propagated wave between the transmitter and the receiver (Saunders & Aragon-Zavala, 2007). These elements of loss include attenuations caused by free space propagation, absorption, reflection, refraction, diffraction, and scattering (Anusha, Nithya, & Rao, 2017) (Sylvain, 2004).

Path loss propagation calculations are very important, especially for wireless communication systems. They play a key role in determining the strength of transmitted signal at any point, both outdoors and indoors. Path loss can be calculated for different terrain profiles such as urban, sub-urban, and rural (Anusha, Nithya, & Rao, 2017).

There are different ways of calculating path loss. There are the Statistical methods, the Deterministic methods, and the Empirical methods (Rakesh, Maheswari & Srivatsa, 2014). Statistical methods make use of probability analysis in predicting path loss. It is the least accurate method. Deterministic methods make use of electromagnetic propagation equations, calculating for reflection, refraction, diffraction, scattering, etc. It is the most accurate method, but it is very impractical to use in most cases. It requires a lot of calculation and computational effort, and even requires a detailed 3-dimensional map of every study area. Empirical methods are the most used methods. In this method defined equations are formed from the results of several measurements (Anusha, Nithya, & Rao, 2017). These defined equations can be used to calculate the path loss other similar location, making Empirical methods the most practical.

Empirical methods have different models of equations which are used for different study area parameters such as the type of cell, the terrain type, the base transceiver station (BTS) antenna height and the MNO carrier frequency. Examples of these models include;

Free space path loss (FSPL)

Okumura model

Okumura-Hata model.

COST 231-Hata model etc. (Saunders & Aragon-Zavala, 2007).

Free Space Path Loss (FSPL) Model

FSPL model is used when there are no obstructions between the transmitter and receiver. That is, there is a direct line of sight between the transmitter and the receiver antennas. The path loss in this model is only dependent on the distance between the transmitter and receiver, and the operating frequency. Equation 1 shows a path loss formula for free space, which is calculated in decibels (Klozar & Prokopec, 2011).

$$L_{FS} = 32.44 + 20\log(f) + 20\log(d) \quad (1)$$

Where: LFS is the FSPL in decibels (dB).

f is the operating frequency in megahertz (MHz).

d is the distance in kilometers (km).

Figure 1 presents an example graph of the FSPL for different frequencies at different distances (Wisptools).

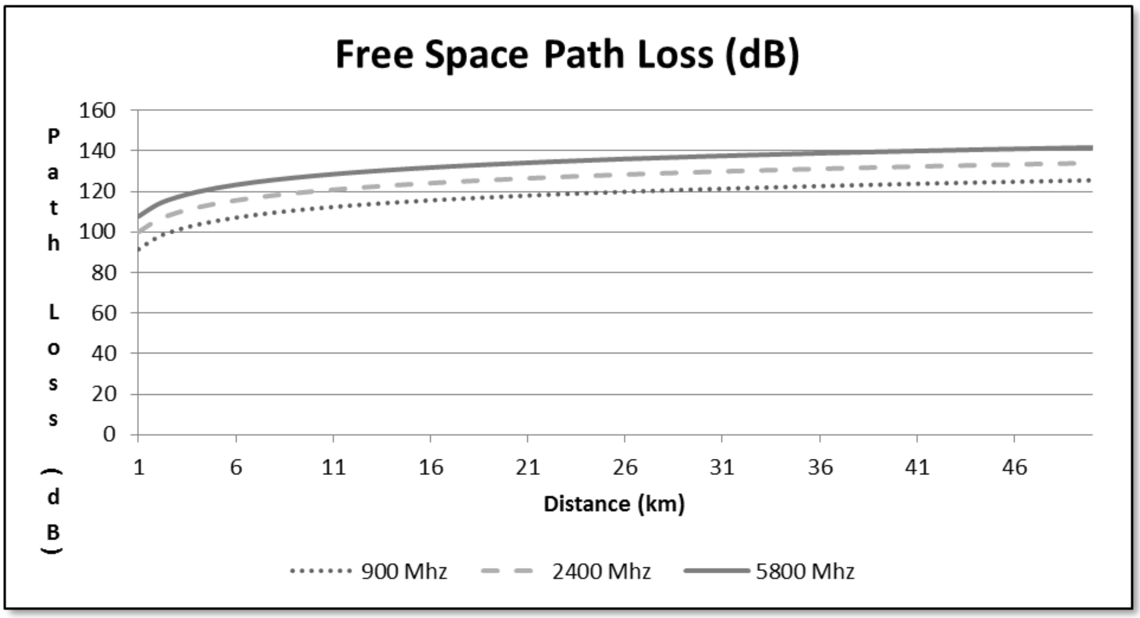

Figure 1. Graph of FSPL for Different Frequencies at Different Distances.

Okumura Model

This empirical model is based on extensive drive test measurements made in Japan at several frequencies, ranging from 150MHz to 1920MHz. It is developed for macro-cells with cells diameters of 1km to 100km. The height of the BTS antenna is between 30m to 100m. This model considers some propagation parameters such as the type of environment, and the irregularities in the terrain. Equation 2 below shows the Okumura model formula for path loss calculation (Obot, Simeon & Afolayan, 2011).

$$L_{50} = L_{FS} + A_{mu} - G_{h_b} - G_{h_m} - G_{AREA} \quad (2)$$

Where: L50 is the the 50th percentile, the median value of path loss in decibels (dB)

LFS is the FSPL in decibels (dB), as shown in Equation 1

Amu is the median attenuation relative to free space in decibels (dB)

Ghb is the BTS antenna height gain factor in decibels (dB)

Ghm is the mobile antenna height gain factor in decibels (dB)

GAREA is the correction factor based on the type of environment, in decibels (dB)

Ghb and Ghm are calculated, based on the height of the BTS antenna (hb) and mobile antenna height (hm), using the following formulae (Anusha, Nithya, & Rao, 2017);

$$G_{h_b} = 20\,log(^{h_b}/_{200}) \qquad ; 1000m > h_b > 30m \quad (3)$$

$$G_{h_b} = 10\,\log(^{h_b}/_{200}) \qquad ; h_b < 30m \quad (4)$$

$$G_{h_m} = 20\,log(^{h_m}/_3) \qquad ; 10m > h_m > 3m \tag{5}$$

$$G_{h_m} = 10\,log(^{h_m}/_3) \qquad ; h_m < 3m \tag{6}$$

The values for Amu and GAREA are gotten from the plots in Figure 2. The median attenuation (Amu) plot shown is for a quasi-smooth urban area, and it is dependent on the operating frequency and the distance between the antennas. The correction factor (GAREA) depends on the operating frequency and the type of terrain being studied (Obot, Simeon & Afolayan, 2011).

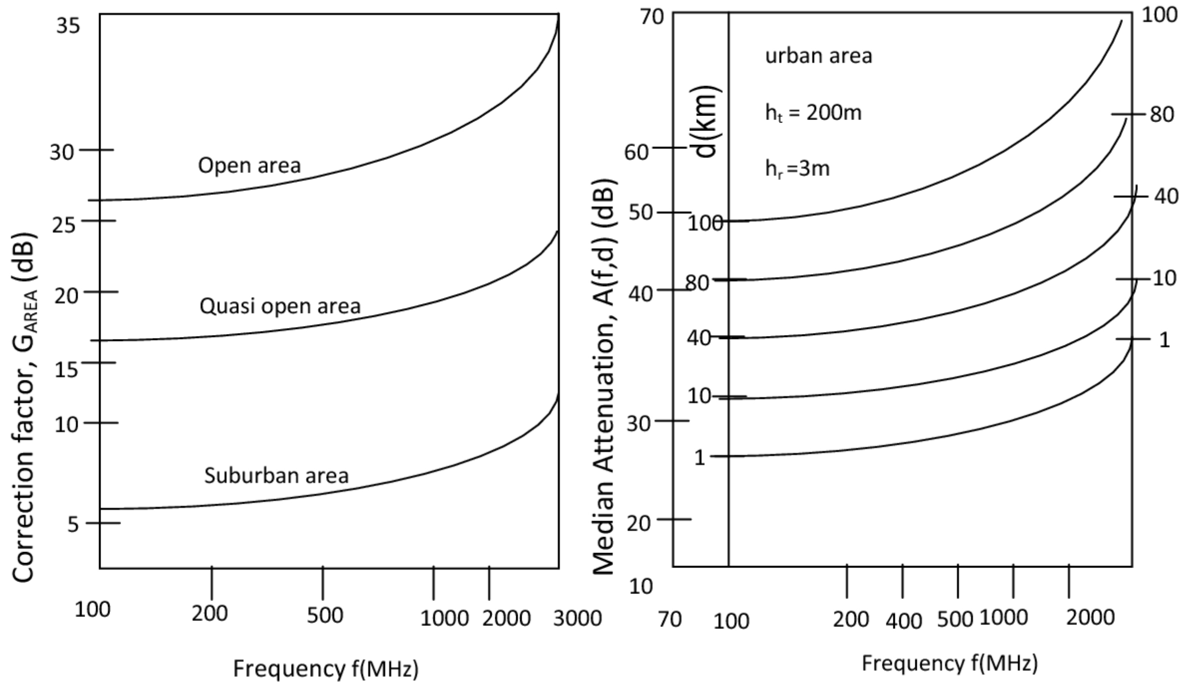

Figure 2. The Correction Factor G_{AREA} and Median Attenuation A_{mu} for Different Terrains.

Okumura-Hata Model

This model is based on Okumura's report, improved for better computational use. The model is suitable of ultra-high frequencies (UHF) and very high frequencies (VHF) land mobile radio services. Its applicable frequency range is 100MHz–1500MHz, a distance range of 1km–20km, BTS antenna heights of 30 m - 200 m, and mobile antenna heights of 1m-10m (Hata, 1980). This model is divided into three types, based on the terrain type, they are;

Open area: which accounts for open spaces, no tall trees or buildings in the propagation path, 300m-400m cleared land, like farmlands and open fields.

Suburban area: they include villages or highways, scattered with trees and houses with some obstacles, but not very congested.

Urban area: these are built up cities or large town, containing large buildings, close houses, and thick tall trees (Saunders & Aragon-Zavala, 2007).

The Okumura-Hata models for the median path loss for the different terrains are shown in Equations 7, 8 and 9 (Sylvain, 2004).

For Urban areas:
$L_{OH} = A + B \log R - E$ (7)
For Suburban areas:
$L_{OH} = A + B \log R - C$ (8)
For Open areas:
$L_{OH} = A + B \log R - D$ (9)
Where;
$A = 69.55 + 26.16\log f - 13.82\log h_b$ (10)
$B = 44.9 - 6.55\log h_b$ (11)
$C = 2(\log({}^{f}/_{28}))^2 + 5.4$ (12)
$D = 4.78\ (\log f)^2 + 18.33\log f + 40.94$ (13)
R is the link distance in kilometers (km).

f is the operating frequency in megahertz (MHz).

hb is the BTS antenna height in meters (m).

For Urban area calculations, "E" has different formulas which are dependent on the type of city and the operating transmission frequency.

For large cities, and f ≥ 300MHz: $E = 3.2\ (\log(11.7554h_m))^2 - 4.97$ (14)
For large cities, and f < 300MHz: $E = 8.29\ (\log(1.54h_m))^2 - 1.1$ (15)
For medium to small cities: $E = (1.1\log f - 0.7)h_m - (1.56\log f - 0.8)$ (16)
hm is the mobile antenna height in meters (m).

COST 231-Hata Model

This model was devised as an extension of the Okumura-Hata model. It is used for a frequency range of 500MHz - 2000MHz (Abhayawardhana et al., 2005). It focuses on the Okumura-Hata model for medium and small cities. The path loss "LC" in decibels (dB) according to COST 231-Hata model formula is shown in Equation 17 (Saunders & Aragon-Zavala, 2007).

$L_C = F + B\log R - E + G$
(17)

Where;

$f = 46.3 + 33.9\log f - 13.82\log h_b$ (18)

hb is the BTS antenna height in meters (m).

B & R terms are the same as defined in Okumura-Hata model above.

E as defined in Equation 16 (for medium to small cities).

For medium-sized cities and suburban areas: $G = 0dB$ (19)

For metropolitan areas: $G = 3dB$ (20)

Methodology

A geographical analysis of the study area is reviewed to determine the most suitable path loss model for calculations. The data acquisition method is also analyzed.

Study Area

The study area is Choba, a suburban area in Port Harcourt, Rivers State, a coastal state in Nigeria. It is a busy commercial area, and very populated, mainly because of the presence of a federal university – the University of Port Harcourt (Uniport) in the area. Typical of coastal states, there are vegetation and tall trees around, but there are not many trees in the developed area. The area also lacks high rising buildings, most less than four stories. The map of Choba, as shown in Figure 3, has the coordinate 4.8941° N, 6.9263° E (Google, n.d.).

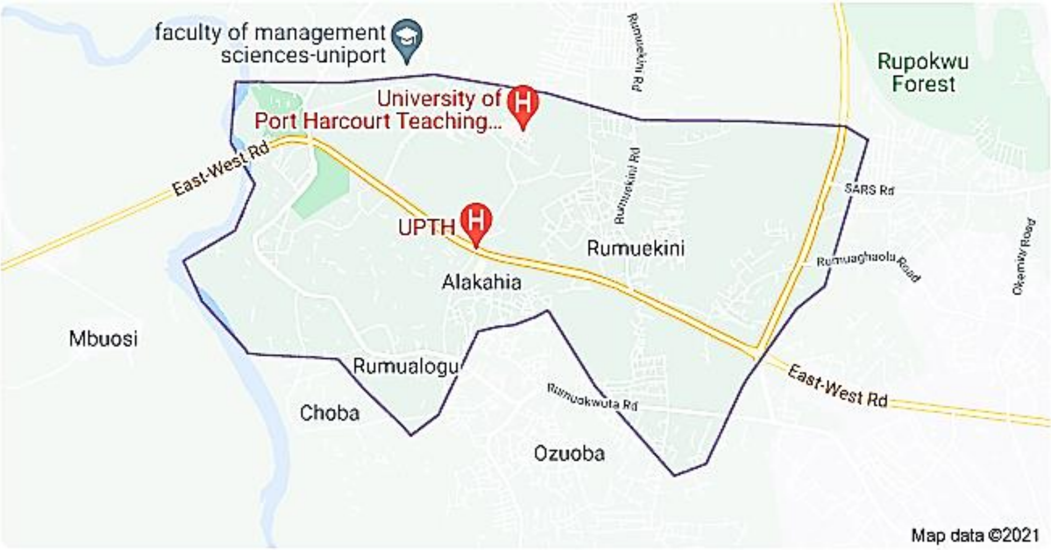

Figure 3. Map Showing the Study Area – Choba, Port Harcourt.

Data Acquisition Method

A walk test within the University of Port Harcourt was carried out on the evening of 9th October 2021, around 5pm. The atmosphere was cloudy as it was about to rain. The test was carried out using two Android mobile applications; Network Signal Info and G-NetTrack Lite, using a Samsung J4 Android phone.

Network Signal Info is a mobile app which provides detailed information of the currently used network, showing the signal strength, location of the BTS and the distance between the mobile device and the BTS (KAIBITS Software GmbH, 2021). Through this app, the map location of the BTS connected to, with the eNodeB identifier and Cell ID numbers were known. It also showed the distance between the mobile phone and the BTS, as well as the signal strength simultaneously.

G-NetTrack Lite is the second mobile app used during this project. It is a net monitor and drive test application used for 5G/4G/3G/2G radio network (GyokovSolutions, 2021). This app was used to trace out the map path taken doing the test as shown in Figure 4.

Other details such as the BTS antenna height was gotten from the mobile network operator (MNO) used, using the eNodeB identifier and Cell ID numbers. The mobile antenna height was obtained through measurement. The referenced MNO is a 4G/LTE network, and its operating frequency is 800MHz (NCC Frequency Allocation, 2020).

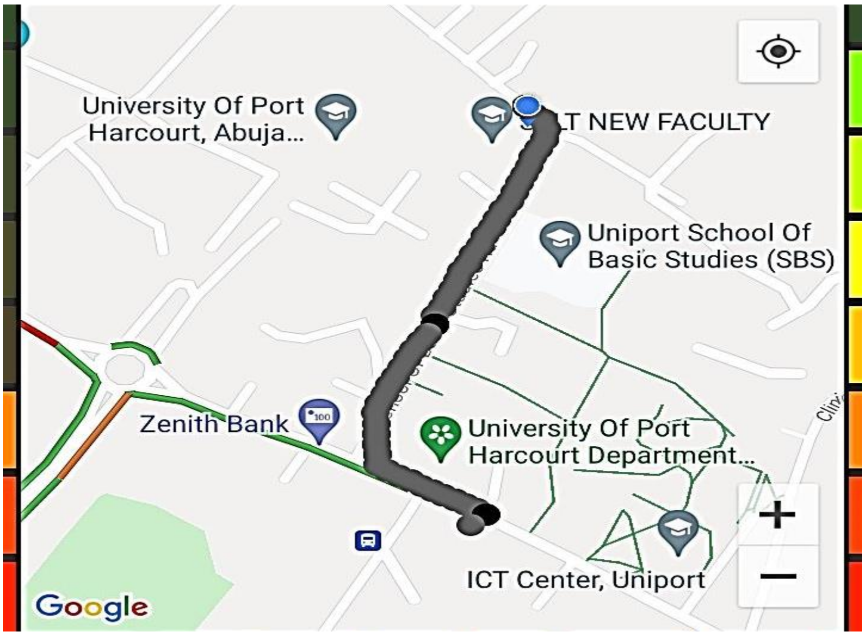

Figure 4. Map of Path Taken During the Walk Test.

Results and Discussion

Here, the data from the walk test is tabulated. Using the data and known parameters such as the mobile height, BTS antenna height and distances, four path losses are calculated with the four models (FSPL, Okumura, Okumura-Hata and Cost 231-Hata models). These calculated path losses are graphically compared with the measured path loss using graphs.

Measured Data

The reference BTS antenna height measures 32 meters and the mobile antenna height is 1 meter. Table 1 shows the recorded distances between the BTS and mobile antennas in kilometers (km), and the signal strength at those distances in decibel millwatts (dBm).

Table 1. Measured Distances and Signal Strength

Distance (km)	Signal Strength (dBm)
0.090	-79
0.130	-83
0.170	-75
0.210	-76
0.250	-79
0.290	-81
0.330	-88
0.370	-80
0.410	-86
0.450	-84

Calculated Data

Using the four reviewed path loss propagation models (FSPL, Okumura, Okumura-Hata and Cost 231-Hata models), the known parameters are used to calculate the path losses based on each model. The path loss propagation of the measured signal strength is also calculated by assuming the BTS transmission power of 200mW (23dBm) as recommend (3GPP, 2016). Equation 21 shows the formula for calculating the path loss of measure signal strength in decibel (dB).

$$L_{dB} = 23 - MSS - 30 \tag{21}$$

Where MSS is the Measured Signal Strength in decibel millwatts (dBm).

Table 2 shows the measured and calculated path losses (in dB) at different distances (in km).

Table 2. Measured and Calculated Path Losses at Different Distances

Distance (km)	Measured PL	FSPL	Okumura	Okumura-Hata	COST 231-Hata
0.090	72	117.9733	143.6633	30.6756	40.7756
0.130	76	125.3278	151.0178	43.5607	53.6607
0.170	68	130.6931	156.3831	52.9606	63.0606
0.210	69	134.9193	160.6093	60.3649	70.4649
0.250	72	138.4063	164.0963	66.4742	76.5742
0.290	74	141.3747	167.0647	71.6749	81.7749
0.330	81	143.9590	169.6490	76.2025	86.3025
0.370	73	146.2472	171.9372	80.2114	90.3114
0.410	79	148.3003	173.9903	83.8084	93.9084
0.450	74	150.1621	175.8521	87.0703	97.1703

Figure 5 shows that the Okumura model calculation is done using Amu of 12dB (median attenuation at 800 MHz, 0.09 km – 0.5 km), and GAREA of 7 dB (for Suburban area at 800MHz). The Okumura-Hata model calculation is done using the Suburban formula. Further, a small Suburban city is also considered for the COST 231-Hata model calculation.

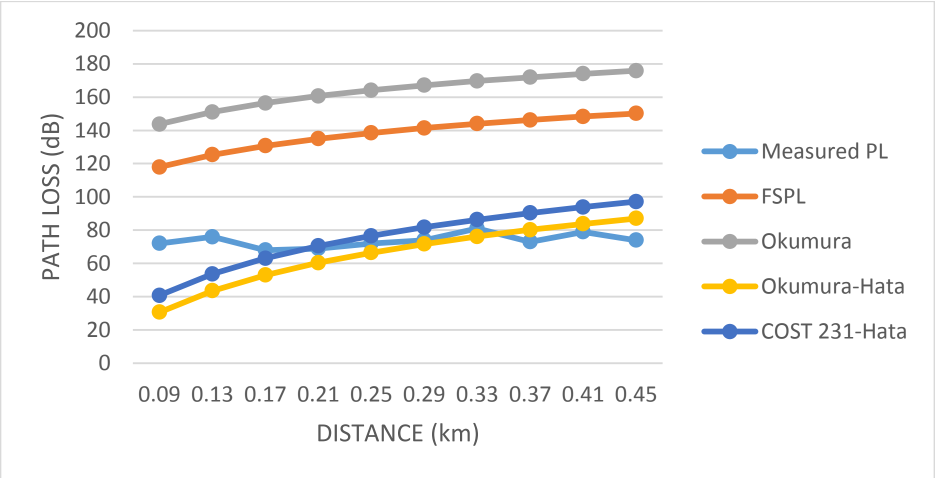

Figure 5. The measured and calculated path losses against various values of distance.

Conclusion

The result and graph comparison of the four studied path loss propagation models (FSPL, Okumura, Okumura-Hata, and COST 231-Hata models) shows that Okumura-Hata model and COST 231-Hata model were the closest to the measured path loss data. This is an expected observation, because Okumura-Hata and COST 231-Hata models are model improvements of the FSPL and Okumura models.

Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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References

3rd Generation Partnership Project (3GPP). (2016). *Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); TDD Home eNodeB (HeNB) Radio Frequency (RF) Requirements Analysis.* Technical Report, 13(0).

Abhayawardhana, V. S., Wassell, I. J., Crosby, D., Sellars, M. P. & Brown, M. G. (2005). *Comparison of Empirical Propagation Path Loss Models for Fixed Wireless Access Systems*. IEEE 61st Vehicular Technology Conference, 2005, pp.73-77, 1, doi: 10.1109/VETECS.2005.1543252.

Anusha, V. S., Nithya, G. K. & Rao, S. N. (2017). *A Comprehensive Survey of Electromagnetic Propagation Models*. International Conference on Communication and Signal Processing (ICCSP), 2017, pp. 1457-1462, doi: 10.1109/ICCSP.2017.8286627.

Google. (n.d.). [Google map of Choba, Port Harcourt]. Retrieved October 6, 2021, from https://www.google.com/maps/place/Choba,+500102/@4.8843854,6.894629,13z/data=!3m1!4b1!4m5!3m4!1s0x1069d0718ffef741:0xb3d11af9c6caf824!8m2!3d4.8940975!4d6.9262805

GyokovSolutions. (2021). *G-NetTrack Lite* (14.8) [Mobile app]. Play Store https://play.google.com/store/apps/details?id=com.gyokovsolutions.gnettracklite&hl=en&gl=US

Hata, M. (1980). *Empirical Formula for Propagation Loss in Land Mobile Radio Services*. IEEE Transactions on Vehicular Technology, 29(3), pp. 317-325

KAIBITS Software GmbH. (2021). *Network Signal Info* (5.68.07) [Mobile app]. Play Store https://play.google.com/store/apps/details?id=de.android.telnet&hl=en&gl=US

Klozar, L. & Prokopec, J. (2011). *Propagation Path Loss Models for Mobile Communication*. Proceedings of 21st International Conference Radioelektronika 2011, pp. 1-4, doi: 10.1109/RADIOELEK.2011.5936478.

Nigerian Communications Commission (NCC). (2020). *Frequency Allocation: Frequency Assignment Tables*. https://www.ncc.gov.ng/technology/spectrum/frequency-allocation.

Nigerian Communications Commission (NCC). (2021). *Press Statement: Telecoms Sector, others Take Nigeria out of Recession as Sector Boosts GDP by 12.45%*. NCC Media Team: https://ncc.gov.ng/media-centre/news-headlines/960-press-statement-telecoms-sector-others-take-nigeria-out-of-recession-as-sector-boosts-gdp-by-12-45.

Obot, A., Simeon, O. & Afolayan, J. (2011). *Comparative Analysis of Path Loss Prediction Models for Urban Macrocellular Environments*. Nigerian Journal of Technology, 30(3), pp. 50-59.

Rakesh, N., Maheswari, B. U. & Srivatsa, S. K. (2014). *Performance Analysis of Propagation Models in Different Terrain Conditions for IEEE Standard 802.16e WIMAX*. International Conference on Communication and Signal Processing, 2014, pp. 142-146.

Saunders, R. S. & Aragon-Zavala, A. (2007). *Antennas and Propagation for Wireless Communication Systems* (2nd ed.). John Wiley & Sons, Ltd.

Siles, G. A., Riera, J. M. & Garcia-del-Pino, P. (2015). *Atmospheric Attenuation in Wireless Communication Systems at Millimeter and THz Frequencies [Wireless Corner]*. IEEE Antennas and Propagation Magazine, 57(1), 48–61.

Sylvain, R. (2004). *Path Loss Models*. Physical Layer Methods in Wireless Communication Systems.

Wisptools: Free E-Book Chapter 3, Section 2. *Chapter 3: Path Loss and Free-Space Path Loss (FSPL)*. (2021). Retrieved 28 September 2021, from http://wisptools.net/book.php?c=3&s=2

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