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Determination of an Outdoor Path Loss Model and Signal Penetration Level in Some Selected Modern Residential and Office Apartments in Ogbomosho, Oyo State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author VOAA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors FIA and SIU managed the analyses of the study and final technical corrections. Author AII managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This article involves the site specific determination of an outdoor path loss model and Signal penetration level in some selected modern residential and office apartments in Ogbomosho, Oyo State. Measurements of signal strength and its associated location parameters referenced globally were carried out. Propagation path loss characteristics of Ogbomosho were investigated using three different locations with distinctively different yet modern building materials. Consequently, received signal strength (RSS) was measured at a distance d in meters, from appropriate base stations for various environments investigated. The data were analyzed to determine the propagation path loss exponent, signal penetration level and path loss characteristics. From calculations, the average building penetration losses were, 5.93dBm, 6.40dBm and 6.1dBm

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outside the hollow blocks B1, solid blocks B2 and hollow blocks mixed with pre cast asbestos B3, buildings respectively with a corresponding path loss exponent values of, 3.77, 3.80 and 3.63. Models were developed and validated, and used to predict the received power inside specific buildings. Moreover, the propagation models developed for the different building types can be used to predict the respective signal level within the building types, once the transmitter – receiver distance is known. The readings obtained from the developed models were compared with both the measured values and values computed using some existing models with satisfactory results obtained.

Keywords: Path loss; received signal strength indicator; base station.

1. INTRODUCTION

Path loss or path attenuation is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. Path loss is a major component in the analysis and design of the link budget of a telecommunication system.

The term is commonly used in wireless communications and signal propagation. Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss and absorption. Path loss is also influenced by terrain, contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of the antennas [1-2,3-5].

Path loss normally includes propagation losses caused by the natural expansion of the radio wave front in free space (which usually takes the shape of an ever-increasing sphere), absorption losses (sometimes called penetration losses), when the signal passes through media not transparent to electromagnetic waves, diffraction losses when part of the radio wave front is obstructed by an opaque obstacle, and losses caused by other phenomena [6-9,10].

The signal radiated by a transmitter may also travel along many different paths to a receiver simultaneously; this effect is called multipath. Multipath waves combine at the receiver antenna, resulting in a received signal that may vary widely, depending on the distribution of the intensity and relative propagation time of the waves and bandwidth of the transmitted signal. The total power of interfering waves in a Rayleigh fading scenario varies quickly as a function of space (which is known as a small-scale fading). Small-scale fading refers to the rapid changes in radio signal amplitude in a short period of time or travel distance.

1.1 Path Loss Experiment

In wireless communication studies, path loss is represented by the path loss exponent, whose value is normally in the range of 2 to 4, where 2 is for propagation in free space, 4 is for relatively lossy environments and for the case of full specula reflection from the earth surface referred to as the flat earth model. In some environments, the path loss exponent can reach values in the range of 4 to 6. On the other hand, a tunnel may act as a waveguide, resulting in a path loss exponent less than 2.

Path loss is usually expressed in dB. In its simplest form, the path loss can be calculated using the formula.

$$L = 10\, n \log_{10}(d) + C \qquad (1)$$

Where *L* is the path loss in decibels, *n* is the path loss exponent, *d* is the distance between the transmitter and the receiver, usually measured in meters, and *C* is a constant which account for system losses.

The value of C usually varies and is normally dependent on the type of modeling under consideration. A list of typical path loss exponents obtained in various mobile environments is shown in Table 1.

1.2 Study Area

The study area is the suburban area of Ogbomoso of Edo State, Nigeria. The investigated buildings shall be solid block and hollow block bungalows as well as a building with hollow block along with pre-cast asbestos materials used for partitioning of the rooms/offices. These are the prevalent type of

Table 1. Path loss exponents for different environments, [9,11-20]

Environment	Path Loss Exponent, n
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Fig. 1. Map showing the Town of Ogbomosho

buildings in Ogbomosho Town. The scope of this work shall cover the determination of GSM signal strength level outside and inside the selected buildings considering networks available in the location of the selected buildings.

2. METHODS

The study was performed using the following equipments; 2 Samsung S6 android phones, Network Signal Info Pro (Kabiit Software), Standalone Inverter, A pair of AIRTEL, GLO and MTN sim cards and a 100 Meters Measuring Tape. The Network Signal Info Pro' was installed in the 2 Samsung S6 Android phones, It consists of Global Positioning System (GPS) application capable of giving the geographical position of the mobile phone and a scale capable of giving accurate numerical value of the received signal strength indication in dBm. A 1.1 kVA power inverter enables the mobile phones to be recharged when necessary. Below is a diagram showing a description of the measurement set-up.

Measurements of the sites were made up of the following; Building B1 (6 bedroom bungalow-hollow blocks building), Building B2 (10 bedroom bungalow-solid blocks building) and Building B3 (14 – room office block, hollow blocks building with pre – cast asbestos partitioning). Table 2 gives a list of the houses used for the study and a brief description of construction and layout. The site and construction information for each of the buildings, that may have effect on the propagation of waves were carefully taken into consideration.

Three of the existing GSM operators, ETISALAT, GLO and MTN referred to in this work as Operator E, Operator G and Operator M respectively, were used for the investigation. Measurements were carried out within a period of twenty two months. Measurements were taken at evenly spaced pre – determined points along the side walls of each of the site outside. The inside measurements were taken at pre – determined points after dividing the buildings into cells with all doors and windows closed, which represents worst case indoor conditions. All measurements were taken in active mode.

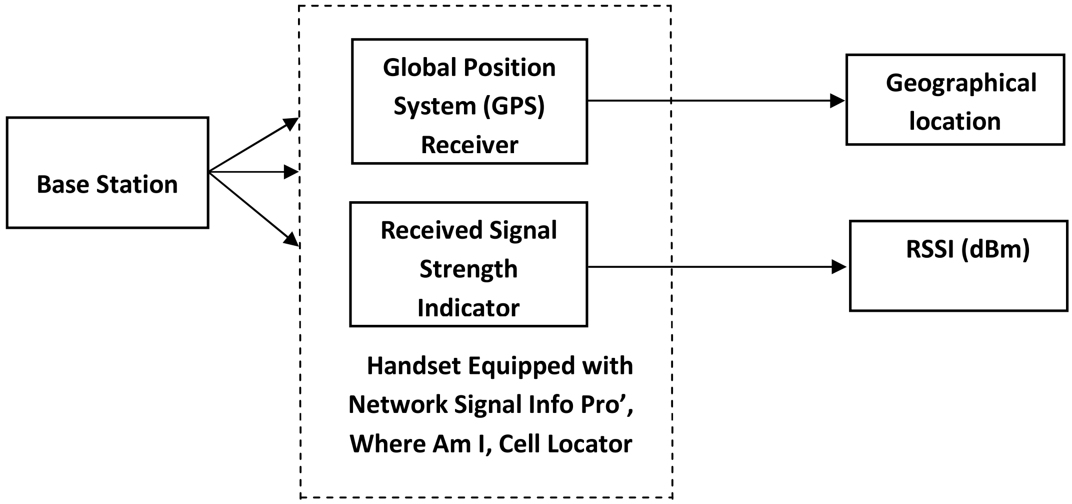

Fig. 2. Illustration of the measurement set-up

Table 1. Measurement site description

Building type	B1	B2	B3
External Paint Type	Text Coat	Text Coat	Emulsion
Building Dimension (m)	22 x 12 x 3.1	23.2 x 10 x 4.04	27.1 x 7.8 x 4.095
Wall Thickness	0.0254 x8 = 0.2032	0.1778	0.2794
Partitioning Materials	Hollow Block	Solid Block	Pre Cast Asbestos
Partitioning Thickness(m)	0.00254 x 9= 0.2032	0.1778	0.1016
Roofing Type	Corrugated Sheet	Corrugated Sheet	Aluminum
Average Room Size (m^2)	4.2672	3.048	3.048
Window Type	Aluminum/Louvers	Aluminum/Louvers	Louvers
Number of Doors / room	2	2	1
Door Material	Hard Wood	Hard Wood	Steel

Table 3. Monthly average measured signal level of operator E for building B1

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	1370	1376	-79.8194	-85.0194
February	1370	1376	-82.9929	-88.1929
March	1370	1376	-79.8065	-85.1871
April	1370	1376	-85.9333	-90.1333
May	1370	1376	-83.0774	-87.0774
June	1370	1376	-82.1333	-87.1333
July	1370	1376	-82.9697	-87.7677
August	1370	1376	-77.1032	-82.3032
September	1370	1376	-77.3333	-82.3333
October	1370	1376	-76.4129	-81.8129
November	1370	1376	-78.7333	-84.3333
December	1370	1376	-81.1097	-87.1333
Mean	1370	1376	-80.6187	-85.7023

2.1 Preliminary Results

For buildings B1 and B2, twenty measurements inside and outside each of the selected buildings were made, with a total of twenty samples each day for each building, totaling forty samples daily. For building B3, twelve measurements inside and outside the building were made, with a total of twelve samples each day for the building. Below are tables with the average values of the measured signal levels from January to December 2015 for the buildings under investigation.

Table 2. Monthly average measured signal level of operator G for building B1

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	1570	1576	-82.2194	-91.0194
February	1570	1576	-89.1929	-95.1929
March	1570	1576	-83.3971	-89.1871
April	1570	1576	-89.3333	-96.1333
May	1570	1576	-87.6774	-94.0774
June	1570	1576	-86.7333	-92.1333
July	1570	1576	-83.3871	-89.9677
August	1570	1576	-82.3032	-88.3032
September	1570	1576	-81.3333	-86.1333
October	1370	1576	-78.2129	-84.0129
November	1570	1576	-76.5333	-82.1333
December	1570	1576	-81.1032	-87.1032
Mean	1570	1576	-83.5461	-89.6164

Table 3. Monthly average measured signal level of operator M for building B1

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	906	912	-69.2194	-75.2194
February	906	912	-67.9714	-74.9714
March	906	912	-67.0701	-74.9714
April	906	912	-69.9067	-75.9067
May	906	912	-71.9871	-78.4871
June	906	912	-73.9133	-78.9133
July	906	912	-743032	-80.303
August	906	912	-77.9355	-84.9355
September	906	912	-72.8933	-78.8933
October	906	912	-71.0516	-77.0516
November	906	912	-68.8800	-76.88
December	906	912	-67.0581	-75.0581
Mean	906	912	-71.0518	-77.6326

Table 4. Monthly average measured signal level of operator E for building B2

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	1450	1455	-82.1548	-88.3806
February	1450	1455	-79.2214	-85.4571
March	1450	1455	-80.2710	-86.4839
April	1450	1455	-83.2000	-88.6000
May	1450	1455	-85.2710	-92.8774
June	1450	1455	-87.2000	-94.0000
July	1450	1455	-87.2710	-94.0700
August	1450	1455	-89.2700	-96.6700
September	1450	1455	-85.8000	-92.0000
October	1450	1455	-84.0710	-90.2710
November	1450	1455	-83.0000	-88.0000
December	1450	1455	-79.6710	-86.0700
Mean	1450	1455	-83.8668	-90.2400

Table 5. Monthly average measured signal level of operator G for building B2

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	2510	2515	-86.0194	-93.0258
February	2510	2515	-84.7857	-91.5857
March	2510	2515	-87.1355	-93.3419
April	2510	2515	-89.9933	-96.393
May	2510	2515	-91.5907	-97.91
June	2510	2515	-93.9333	-100.333
July	2510	2515	-98.135	-103.135
August	2510	2515	-96.142	-101.135
September	2510	2515	-92.5933	-98.993
October	2510	2515	-90.9355	-97.335
November	2510	2515	-87.9933	-94.3933
December	2510	2515	-86.5806	-92.9806
Mean	2510	2515	-90.4865	-96.7134

Table 6. Monthly average measured signal level of operator M for building B2

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	805	810	-67.8194	-76.6645
February	805	810	-65.9714	-73.9929
March	805	810	-66.0710	-74.7226
April	805	810	-68.7067	-78.6400
May	805	810	-70.7871	-78.1871
June	805	810	-72.5133	-79.7333
July	805	810	-72.1032	-80.9677
August	805	810	-75.9355	-83.7097
September	805	810	-72.4533	-78.4933
October	805	810	-69.2516	-75.8710
November	805	810	-67.0800	-60.2800
December	805	810	-65.0810	-71.8581
Mean	805	810	-69.4811	-76.0934

Table 7. Monthly average measured signal level of operator E for building B3

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	472.5	476.4	-59.5000	-65.4700
February	472.5	476.4	-55.1960	-61.4820
March	472.5	476.4	-55.4247	-60.5590
April	472.5	476.4	-56.8167	-62.7440
May	472.5	476.4	-57.3925	-64.2258
June	472.5	476.4	-59.0778	-65.4111
July	472.5	476.4	-61.3925	-67.0591
August	472.5	476.4	-64.7258	-71.0591
September	472.5	476.4	-65.0890	-70.0778
October	472.5	476.4	-60.2688	-66.6602
November	472.5	476.4	-57.9111	-64.0778
December	472.5	476.4	-56.3925	-62.7258
Mean	472.5	476.4	-59.0990	-65.1293

Table 8. Monthly average measured signal level of operator G for building B3

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	1720.5	1724.4	-81.914	-88.1058
February	1720.5	1724.4	-80.8571	-87.1955
March	1720.5	1724.4	-83.4033	-89.3746
April	1720.5	1724.4	-85.7444	-91.4588
May	1720.5	1724.4	-85.1559	-91.7886
June	1720.5	1724.4	-87.7444	-93.9578
July	1720.5	1724.4	-89.457	-96.2886
August	1720.5	1724.4	-90.6344	-97.746
September	1720.5	1724.4	-86.4611	-92.9578
October	1720.5	1724.4	-83.4839	-90.3746
November	1720.5	1724.4	-83.5222	-88.4578
December	1720.5	1724.4	-81.129	-86.6972
Mean	1720.5	1724.4	-84.9589	-91.2003

Table 9. Monthly average measured signal level of operator M for building B3

Month	Average Measured Distance (m)		Average Measured Monthly Signals (dBm)	
	Outside, d_o	Inside, d_i	Outside, P_o	Inside, P_i
January	1452.5	1456.4	-79.8849	-85.8011
February	1452.5	1456.4	-77.2386	-83.8658
March	1452.5	1456.4	-76.0338	-82.8763
April	1452.5	1456.4	-78.1282	-84.6167
May	1452.5	1456.4	-80.0515	-86.7097
June	1452.5	1456.4	-82.8116	-88.8667
July	1452.5	1456.4	-83.8795	-90.828
August	1452.5	1456.4	-86.6107	-93.1613
September	1452.5	1456.4	-82.7782	-87.5333
October	1452.5	1456.4	-80.944	-86.2097
November	1452.5	1456.4	-81.3626	-85.45
December	1452.5	1456.4	-75.8204	-82.043
Mean	1452.5	1456.4	-80.462	-86.4968

2.1.1 Computation of path loss exponent for measured values

Path loss exponent for all locations were determined from the measured signal levels using the Log – Distant Path Loss Model Equation, (Rapparport, 2003) shown below.

$$PL(dBm) = PL(d_0) + 10nlog\frac{d}{d_0} \quad (2)$$

The reference path loss, $PL(d_0)$ is given as

$$PL(d_0) = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \quad (3)$$

For operator A, the operating frequency= 2412 MHz, the wavelength is then calculated from

$$\lambda = \frac{v}{f} \quad (4)$$

for v = 3 X 10^{-8} m/s, the wavelength is

$$\lambda = \frac{3 X 10^8}{2412 X 10^6} = 0.1244m$$

For outdoor propagation, the reference distance d_0 of 10 m or 100 m is recommended. (Omorogiuwa and Edeko, 2009). In this work, 10 m was chosen. It therefore follows that,

$$PL(d_0) = -10\log\left[\frac{0.1244^2}{(4\pi)^2 10^2}\right] = -60.008$$

dB = 0.06008 dBm.

Hence, equation (3.6) becomes,

$$PL(dBm) = 0.6008 + 10nlog\frac{d}{d_0} \quad (5)$$

The path loss exponent, n, may then be computed as

$$n = \frac{PL - 0.06008}{10\ log\frac{d}{d_0}} \quad (6)$$

The mean average measured signal outside buildings, B1, B2 and B3 are – 80.6187 dBm, 83.8668 and 59.099 dBm respectively.

Mean PL_0 for B1 = – 80.6187 dBm.

Average distance d =1370 m, hence,

$$n = \frac{80.6187-0.06008}{10\ log\frac{1370}{10}} = \frac{80.5586}{10\ log137} = \frac{80.5586}{21.367} = 3.770. \quad (7)$$

The path loss exponents for all other locations were subsequently computed from equation (17), with the aid of Microsoft Excel. The flowchart for the program is as shown in Appendix 1, 2, 3.

Similarly, for operator G, the operating frequency is 2412 MHz. the wavelength was calculated from equation 3.8 as:-

$$\lambda = \frac{3\ X\ 10^8}{2412\ X\ 10^6} = 0.1244m \quad (8)$$

It therefore follows that,

$$PL(d_0) = -10\ log\left[\frac{0.1244^2}{(4\pi)^2 10^2}\right] = -60.008\ dB = 0.06008\ dBm.$$

Hence, equation 3.6 becomes,

$$PL(dBm) = 0.6008 + 10nlog\frac{d}{d_0} \quad (9)$$

The path loss exponent, n, may then be computed as

$$n = \frac{PL-0.06008}{10\ log\frac{d}{d_0}} \quad (10)$$

The mean average measured signal outside buildings, B1, B2 and B3 are – 83.5461 dBm, 94.4865 and 87.9589 dBm respectively.

Mean PL_0 fornB1 = – 83.5461 dBm.

Average distance d =1570 m, hence,

$$n = \frac{83.5461-0.06008}{10\ log\frac{15\ 70}{10}} = \frac{83.486}{10\ log157} = \frac{83.486}{21.96} = 3.802. \quad (11)$$

The path loss exponents for all other locations were subsequently computed from equation (18), with the aid of Microsoft Excel. The flowchart for the program is as shown in Appendix 1.

Finally, for operator M, the operating frequency is 2437 MHz. the wavelength was calculated from equation 3.8 as:-

$$\lambda = \frac{3\ X\ 10^8}{2437\ X\ 10^6} = 0.123m \quad (12)$$

It therefore follows that,

$$PL(d_0) = -10\ log\left[\frac{0.123^2}{(4\pi)^2 10^2}\right] = -60.21\ dB = 0.06021\ dBm. \quad (13)$$

Hence, equation 3.6 becomes,

$$PL(dBm) = 0.06021 + 10nlog\frac{d}{d_0} \quad (14)$$

The path loss exponent, n, may then be computed as

$$n = \frac{PL-0.06021}{10\ log\frac{d}{d_0}} \quad (15)$$

The mean average measured signal outside buildings, B1, B2 and B3 are – 71.0158 dBm, 69.4811 and 84.4615 dBm respectively.

Mean PL_0 fornB1 = – 71.0158 dBm.

Average distance d = 906 m, hence,

$$n = \frac{71.0158-0.06021}{10\ log\frac{9\ 06}{10}} = \frac{70.9559}{10\ log90.6} = \frac{70.95559}{19.571} = 3.6255. \quad (16)$$

The path loss exponents for all other locations were subsequently computed from equation (16), with the aid of Microsoft Excel.

Table 10. Path Loss exponent outside Buildings B1, B2 and B3 with Operator A signals

Building type	d(m)	PL_0 (dBm)	d_0 m	$PL(d_0)$ (dBm)	d/d_0	10log (d/d_0) (dBm)	PL- $PL(d_0)$ (dBm)	n=$\frac{PL-PL(d_0)}{10log\left(\frac{d}{d_0}\right)}$
B1	1370	80.619	10	0.06008	137	21.367	80.559	3.770
B2	1450	83.867	10	0.06008	145	21.613	83.807	3.864
B3	472.5	59.099	10	0.06008	47.3	16.749	59.039	3.524

Table 11. Path Loss exponent outside Buildings B1, B2 and B3 with Operator G signals

Building type	d(m)	PL_0 (dBm)	d_0 m	$PL(d_0)$ (dBm)	d/ d_0	10log (d/d_0) (dBm)	PL- $PL(d_0)$ (dBm)	$n=\frac{PL-PL(d_0)}{10log\left(\frac{d}{d_0}\right)}$
B1	1570	83.546	10	0.06008	157	21.959	83.486	3.802
B2	2510	90.487	10	0.06008	251	23.997	90.426	3.768
B3	1720.5	84.959	10	0.06008	172.1	22.357	84.899	3.797

Table 12. Path Loss exponent outside Buildings B1, B2 and B3 with Operator M signals

Building Type	d(m)	PL_0 (dBm)	d_0 m	$PL(d_0)$ (dBm)	d/ d_0	10log (d/d_0) (dBm)	PL- $PL(d_0)$ (dBm)	$n=\frac{PL-PL(d_0)}{10log\left(\frac{d}{d_0}\right)}$
B1	906	71.016	10	0.0602	157	19.571	70.956	3.626
B2	805	69.481	10	0.0602	251	19.058	69.421	3.643
B3	1452.5	80.462	10	0.0602	172	21.621	80.402	3.719

Table 13. Average value of Path Loss exponent outside Buildings B1, B2 and B3

Building type	Path loss exponent			Average path loss exponent
	Operator E	Operator G	Operator M	
B1	3.770	3.802	3.626	3.733
B2	3.877	3.768	3.643	3.763
B3	3.521	3.795	3.719	3.678
Mean				3.725

2.1.2 Computation of penetration loss for the building walls

The average penetration loss of the outer walls of the investigated buildings was computed using equation below, (Caluyo and Cruz, 2011; Plets et al., 2008).

ABL(dBm) = Mean Average Outside Path Loss Level (dBm) minus Mean Average Inside Path Loss Level (dBm), represented mathematically as:-

$$ABL(dBm) = PL_O\,(dBm) - PL_I\,(dBm) \qquad (17)$$

where ABL = Average Building Loss.

The average path loss levels in B1 using operator A Sim (Etisalat) are as given in Table 16, where PL_O = - 80.619 dBm and PL_I = - 85.72 dBm. The penetration loss of other two buildings, B1 and B2 were also calculated with equation (20), using Microsoft Excel. The results are as presented in Tables 16 to 18.

The average values of penetration loss for the three buildings are as detailed in Table 19.

Table 16. Penetration Loss in Buildings B1, B2, B3 with operator A Sim (Airtel)

Building type	Average Measured Path Loss Levels (dBm)		Average Penetration Loss (dBm)
	Outside, PL_O	Inside, PL_I	ABL = PL_O - PL_I
B1	80.619	85.72	5.101
B2	83.867	90.24	6.373
B3	59.099	65.129	6.03

Table 14. Penetration Loss in Buildings B1, B2, B3 with operator G Sim (GLO)

Building type	Average Measured Path Loss Levels (dBm)		Average Penetration Loss (dBm)
	Outside, PL_O	Inside, PL_I	ABL = PL_O - PL_I
B1	83.546	89.616	6.07
B2	90.487	96.713	6.226
B3	84.959	91.2	6.241

Table 15. Penetration Loss in Buildings B1, B2, B3 with operator M Sim (MTN)

Building type	Average Measured Path Loss Levels (dBm)		Average Penetration Loss (dBm)
	Outside, PL_O	Inside, PL_I	ABL = PL_O - PL_I
B1	71.016	77.632	6.616
B2	69.481	76.093	6.612
B3	80.462	86.497	6.035

Table 16. Mean of the Average values of Penetration Loss in Buildings B1, B2, B3

Building type	Average Penetration Loss			Mean of the Average Penetration Loss
	Operator E	Operator G	Operator M	
B1	5.101	6.07	6.616	5.929
B2	6.373	6.226	6.612	6.404
B3	6.03	6.241	6.035	6.102

2.1.3 Theoretical computation of path loss outside the different buildings

Equation (13) was used to compute the theoretical path loss values at different outdoor distances. The path loss exponent, n for shadowed urban cellular radio is used, which varies between 3 and 4, (Rappaport, 2003), and it gives the average value of n as

$$n = \frac{1}{2}\sum n \ = \ \frac{3+5}{2} \ = \ 4 \tag{18}$$

Hence, the theoretical path loss may be written as:-

$$PL_T = PL(d_0) \ + \ 10(4)log\frac{d}{d_0} \tag{19}$$

With d_o = 10 m,
$PL(d_0)$ = 0.06021

Equation 3.23 becomes,

$$PL_T = 0.06021 + \ 10(4)log\frac{d}{d_0} \tag{20}$$

The theoretical path loss values at various distances were computed using equation (21) with the aid of Microsoft Excel.

Table 17. Computation of Path Loss outside the Buildings Using Operator E Sim

Building type	d (m)	d_0 (m)	$PL(d_0)$ dBm	d/d_0	$40log(d/d_0)$ dBm	$PL_T = PL(d_0) + 40log(d/d_0)$ DBm
B1	1370	10	0.0602	137	85.469	85.529
B2	1450	10	0.0602	145	86.455	86.515
B3	472.5	10	0.0602	47. 3	66.976	67.036

Table 18. Computation of Path Loss outside the Buildings Using Operator G Sim

Building type	d (m)	d_0 (m)	$PL(d_0)$ dBm	d/d_0	$40log(d/d_0)$ dBm	$PL_T = PL(d_0) + 40log(d/d_0)$ dBm
B1	1570	10	0.0602	157	87.836	87.896
B2	2510	10	0.0602	251	95.987	96.047
B3	1720.5	10	0.0602	172	89.421	89.481

Table 19. Computation of Path Loss outside the Buildings Using Operator M Sim

Building type	d (m)	d_0 (m)	$PL(d_0)$ dBm	d/d_0	$40log(d/d_0)$ dBm	$PL_T = PL(d_0) + 40log(d/d_0)$ dBm
B1	906	10	0.0602	90.6	78.285	78. 345
B2	805	10	0.0602	80.5	76.232	76.292
B3	1452.5	10	0.0602	145.3	86.491	86.551

2.1.4 Comparison between measured and theoretical path loss outside the buildings

The mean of the average path loss values obtained from measurement and theoretical computation are as presented in Tables 20 to 22. The percentage difference between the measured and theoretical path loss outside the buildings were also computed as indicated.

2.1.5 Development of model equation for path loss in Ogbomosho

A careful study of Tables 30, 31 and 32 which represents the comparison for operators E, G and M Sims, indicated that for Building types B1, B2 and B3, the measured path loss values are lower than the theoretically computed values at all locations. It therefore becomes necessary to develop a model which will be consequently be used to determine expected signal levels at required locations. The model will be developed to satisfy the condition, $PL_O < PL_I$,

In this work the path loss exponent for all locations lies between 3.5 and 4, the mean value of the entire path loss exponent is as computed in Table 15, with a value of 3.5 adopted for the model.

Recall that the measured path loss in Ekpoma may be expressed as:-

$$PL_o = PL(d_o) + 10\,n\,log\frac{d}{d_o} + V \quad (21)$$

Where

PL = Path Loss in Ogbomosho, hence PL = PL_o.
PL_o = Measured Signal Level outside the building.
d_o = reference distance = 10m
$PL(d_o)$ = Path Loss at reference distance = 0.062.
n = 3.5.
d = distance in meters (m).
PL(dBm) = model or signal generated reception level for outdoor environment.

$$V = PL_o - PL(d_o) + 10\,n\,log\frac{d}{d_o}$$

$$V = PL_o - \{0.0602 + 10\,(3.5)\,log\frac{d}{10}\} \quad (22)$$

Values of V were computed from equation (23) for the different buildings as shown in Tables 33 to 35.

Table 23. Comparison between Measured and Theoretical Path Loss outside the Buildings Using Operator E Sim

Building type	d(m)	Path Loss (dBm)		Percentage Difference
		Measured PL_O	Theoretical PL_O	
B1	1370	80.619	85.529	5.74
B2	1450	83.867	86.515	3.06
B3	472.5	59.099	67.036	11.84

Table 24. Comparison between Measured and Theoretical Path Loss outside the Buildings Using Operator G Sim

Building Type	d(m)	Path Loss (dBm)		Percentage Difference
		Measured PL_O	Theoretical PL_O	
B1	1570	83.546	87.896	4.95
B2	2510	90.847	96.047	5.41
B3	1720.5	84.959	89.481	5.05

Table 25. Comparison between Measured and Theoretical Path Loss outside the Buildings Using Operator M Sim

Building type	d(m)	Path Loss (dBm)		Percentage Difference
		Measured PL_O	Theoretical PL_O	
B1	906	71.016	78. 345	9.36
B2	805	69.481	76.292	8.93
B3	1452.5	80.462	86.551	7.04

2.1.6 Calculation of V (modeled loss constant) for each of the locations for the Study period

Plotting the graph of Tables 33 to 35 indicates that V should be of the form ve^{logd}. i.e.,

$$V = ve^{logd} \tag{23}$$

Or,

$$v = \frac{V}{e^{logd}} \tag{24}$$

where v = coefficient of an exponential function. The values of v at locations being considered were computed from equation (3.28), and the results are as presented in Tables 36 to 38.

Hence, the path loss outside the buildings B1, B2, B3 in Ekpoma may be expressed as equation (25)

$$PL_O = PL(d_O) + 10n\log\frac{d}{d_O} + ve^{logd} \tag{25}$$

Where

PL_O = Outdoor Path loss
d_O = reference distance =10m
$PL(d_O)$ =Pqth loss at reference distance= 0.0602 dBm
d = distance in meter (m)
n = 3.5
v = a positive number
$0.095 \leq v \leq 0.346$

2.1.7 Computation of path loss outside the various buildings using Generated model

The values of the path loss outside the buildings B1, B2, B3 computed from the generated model are shown in Tables 39 to 40.

Table 26. Calculation of V for Buildings B1, B2, B3 with Operator A Sim

Building type	D (m)	PL(d_O) dBm	$(\frac{d}{10})$ (m)	35log$(\frac{d}{10})$ (dBm)	PL_O (dBm)	V = PL_o- $\{0.0602 + 35log\frac{d}{10}\}$ (dBm)
B1	1370	0.0602	137	74.78	80.62	5.78
B2	1450	0.0602	145	75.65	83.87	8.16
B3	472.5	0.0602	47.25	58.61	59.10	0.429

Table 27. Calculation of V for Buildings B1, B2, B3 with Operator G Sim

Building type	d (m)	PL(d_O) dBm	$(\frac{d}{10})$ (m)	35log$(\frac{d}{10})$ (dBm)	PL_O (dBm)	V = PL_o- $\{0.0602 + 35log\frac{d}{10}\}$ (dBm)
B1	1570	0.0602	157	76.86	83.546	6.63
B2	2510	0.0602	251	83.99	90.847	6.80
B3	1720.5	0.0602	172.1	78.25	84.959	6.65

Table 28. Calculation of V for Buildings B1, B2, B3 with Operator M Sim

Building type	d (m)	PL(d_O) dBm	$(\frac{d}{10})$ (m)	35log$(\frac{d}{10})$ (dBm)	PL_O (dBm)	V = PL_o- $\{0.0602 + 35log\frac{d}{10}\}$ (dBm)
B1	906	0.0602	90.6	68.50	71.016	2.45
B2	805	0.0602	80.5	66.70	69.481	2.72
B3	1452.5	0.0602	145.25	75.67	80.462	4.73

Table 29. Calculation of v for Buildings B1, B2, B3 with Operator E Sim

Building type	d (m)	V (dBm)	e^{logd}	$v = \frac{V}{e^{logd}}$ (dBm)
B1	1370	5.78	23.03	0.251
B2	1450	8.16	23.60	0.346
B3	472.5	0.429	14.50	0.095

Table 30. Calculation of v for Buildings B1, B2, B3 with Operator G Sim

Building type	d (m)	V (dBm)	e^{logd}	$v = \frac{V}{e^{logd}}$ (dBm)
B1	1570	6.63	24.43	0.271
B2	2510	6.80	29.95	0.227
B3	1720.5	6.65	25.42	0.262

Table 31. Calculation of v for Buildings B1, B2, B3 with Operator M Sim

Building type	d (m)	V (dBm)	e^{logd}	$v = \frac{V}{e^{logd}}$ (dBm)
B1	906	2.45	19.24	0.127
B2	805	2.72	18.28	0.149
B3	1452.5	4.73	23.62	0.200

Table 32. Path loss Outside the Buildings using generated model for operator E

Building Type	d(m)	Log d	$PL(d_O)$ (dBm)	$\{\frac{d}{10}\}$(m)	$35log\{\frac{d}{10}\}$	$e^{log\ d}$	v	ve^{logd}	$PL_O = [0.0602+35log\{\frac{d}{10}\}+ ve^{logd}]$ (dBm)
B1	1370	3.137	0.0602	137	74.785	23.03	0.251	5.78	80.6252
B2	1450	3.162	0.0602	145	75.648	23.60	0.346	8.17	83.8782
B3	472.5	2.674	0.0602	47.25	58.604	14.50	0.095	1.38	60.0442

Table 33. Path loss Outside the Buildings using generated model for operator G

Building Type	d(m)	Log d	$PL(d_O)$ (dBm)	$\{\frac{d}{10}\}$	$35log\{\frac{d}{10}\}$	e^{logd}	v	$ve^{log\ d}$	$PL_O = \{0.0602 + 35log\{\frac{d}{10}\} + velog\ d\}$ (dBm)
B1	1570	3.196	0.0602	157	76.857	24.44	0.271	6.62	83.5372
B2	2510	3.400	0.0602	251	83.989	29.964	0.227	6.80	90.8492
B3	1720.5	3.236	0.0602	172	78.244	25.432	0.262	6.66	84.9642

Table 34. Path loss Outside the Buildings using generated model for operator M

Building Type	d(m)	Log d	$PL(d_O)$ (dBm)	$\log\left\{\frac{d}{10}\right\}$	$35\log\left\{\frac{d}{10}\right\}$	$e^{\log d}$	v	$ve^{\log d}$	$PL_O = \left\{0.0602 + 35\log\left\{\frac{d}{10}\right\} + ve\log d\right\}$ (dBm)
B1	906	2.957	0.0602	90.6	68.500	19.24	0.127	2.44	71.0002
B2	805	2.906	0.0602	80.5	66.703	18.284	0.149	2.72	69.4832
B3	1452.5	3.162	0.0602	145.3	75.679	23.618	0.200	4.72	80.4592

Table 35. Comparison between Path Loss Values outside the various buildings from measurement and generated model with operator A

Building type	d(m)	Path Loss (dBm)		Standard deviation
		Measured	Generated	
B1	1370	80.619	80.6252	0.0031
B2	1450	83.867	83.8782	0.0056
B3	472.5	59.099	60.0442	0.4726

Table 36. Comparison between Path Loss Values outside the various buildings from measurement and generated model with operator G

Building type	d(m)	Path Loss (dBm)		Standard deviation
		Measured	Generated	
B1	1570	83.546	83.5372	0.0044
B2	2510	90.847	90.8492	0.0011
B3	1720.5	84.959	84.9642	0.0026

Table 37. Comparison between Path Loss Values outside the various buildings from measurement and generated model with operator M

Building Type	d(m)	Path Loss (dBm)		Standard deviation
		Measured	Generated	
B1	906	71.016	71.0002	0.0079
B2	805	69.481	69.4832	0.0011
B3	1452.5	80.462	80.4592	0.0014

2.1.8 Comparison between Path Loss Values outside the various buildings from measurement and generated model

Values of path loss obtained from measurement and those obtained from the generated model are as shown in Tables 35 to 37.

3. RESULTS AND DISCUSSION

3.1 Path Loss Exponent

The average values of path loss exponent outside the buildings B1, B2 and B3 in Ogbomosho were summarized in Table 15. The least value of 3.521 was obtained outside building B3, where the building density of the area is relatively low while the highest value of 3.877 was obtained outside building B2, solid block building where the buildings were relatively clustered together, with no proper planning and layout. Also, the value of n for building B1 for operator G was 3.802, which is also high. This might be attributable to the effect of perimeter at the location.

Generally, the values of path loss exponent are in agreement with theoretical values of between 3 and 5, for such environments. These also agree with the value of 3.84 for suburban areas in Lees work (Adenike, 2010; Idim & Anyasi, 2014).

3.2 Building Penetration Loss

The building penetration losses for buildings B1, B2, B3 are compared in Fig. 3. Building B2, with hollow block structure has the lowest value of 5.1, while building B2 has the highest value of 6.6. these values attests to the fact that the type of construction materials affects GSM signal levels inside buildings (Caluyo, Cruz, 2011).

The penetration loss of 6.7 dBm obtained for the block wall under consideration is a bit lower than 8.33 dBm earlier reported by researchers in Ekpoma environ (Anyasi, Yesufu, Akpaida, Evbogbai and Erua). The difference may be attributable to the varying degree of quality of block used for the construction as well as the size of windows plus other differences in measurement conditions. Generally, the results are in agreement with earlier researchers opinion that, penetration loss decreases with increase in frequency.

Earlier researches were based on f = 1800 MHz, while the current research indicated that the frequency measured for GLO and AIRTEL is 2412 MHz, while that for MTN network is 2437 MHz.

It is also important to note that the value of penetration loss of a building depends on the point at which the signal is measured. In this work outside measurement were taken by the closest points to the wall, and the average taken Figs. 3, while the inside measurements.

The penetration loss of 6.7 dBm obtained for the block wall under consideration is a bit lower than 8.33 dBm earlier reported by researchers in Ekpoma environ (Anyasi, Yesufu, Akpaida, Evbogbai and Erua). The difference may be attributable to the varying degree of quality of block used for the construction as well as the size of windows plus other differences in measurement conditions. Generally, the results are in agreement with earlier researchers opinion that, penetration loss decreases with increase in frequency. Earlier researches were based on f = 1800 MHz, while the current research indicated that the frequency measured for GLO and ETISALAT is 2412 MHz, while that for MTN network is 2437 MHz

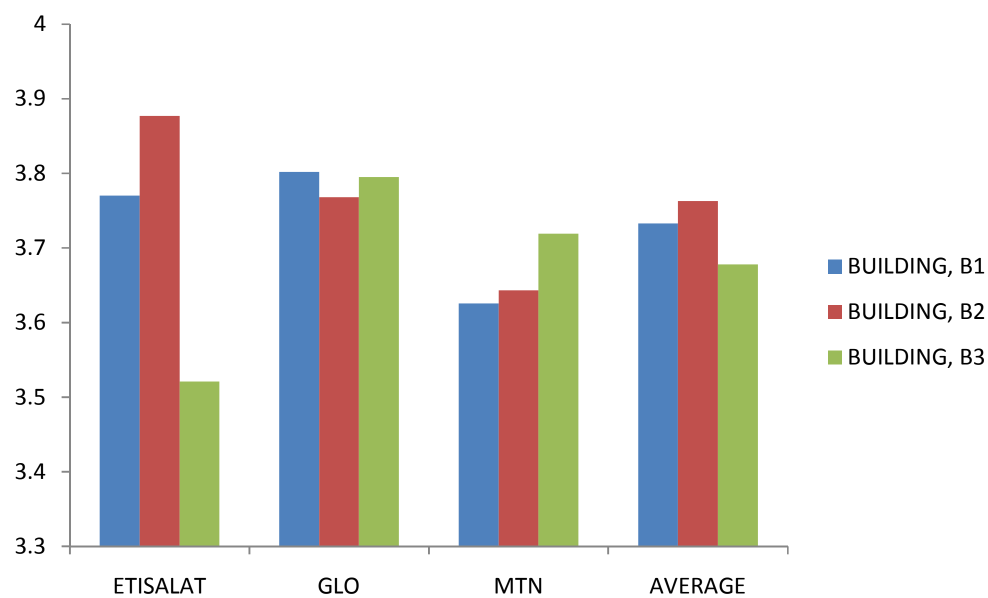

Fig. 3. Penetration loss of the three buildings under study

It is also important to note that the value of penetration loss of a building depends on the point at which the signal is measured. In this work outside measurement were taken by the closest points to the wall, and the average taken, while the inside measurements were taken at three different points along a straight line inside the building and the average taken.

3.3 Generated Outdoor Path Loss Model

The generated outdoor path loss model, equation (36) assumes a constant value of 3.5 as the path loss exponent for all locations. Plots of path loss outside each of the three buildings obtained from the generated model are shown in Figs. 4 to 6.

Fig. 4 shows a loss of 42.02 dB/decade outside building B1 using Etisalat Sim, 42.65 dB/decade was recorded for Glo Sim, while 38.48 dB/decade was observed for the MTN Sim. The values for Etisalat nd GLO operators are 2.02dB/decade and 2.65 dB/decade higher respectively when compared with the 40 dB/decade obtained for similar distances using the theoretical log – distance path loss model. On the other hand the path loss recorded for the MTN operator is 1.52dB/decade lower than the theoretical log distance path loss model. This shows that for building B1, MTN operator recorded the strongest signal strength. From the graph of Fig. 4, at a distance of 1370 m outside the building B1, the path loss for Etisalat is 86.4dBm, similarly at a distance of 1570 m outside the building B1, the path loss for Glo is 90dBm while that for MTN at 906 m is 73dBm.

Outside building B2 path losses of 44.58dBm/decade, 41.58dBm/decade and 38.99dBm/decade are obtained in Fig. 5 for the Etisalat, Glo and the MTN Sims respectively. The path losses for operators E and G are 4.58dBm/decade and 1.58dBm/decade higher than the theoretical log – distance path loss model, while the path loss for operator M is 38.99dB/decade with a 1.01 dB/decade lower than the theoretical model.

Outside building B3, path losses of 36.87dB/m was recorded for operator A Sim, 42.47dB/decade path loss was recorded for operator G Sim while operator M Sim recorded a 40.62dB/decade path loss, as shown in Fig. 6. Similarly measurements taken at distances 472.5 m for operator E Sim, 1720.5 m for operator G Sim and 1452.5 m for operator M Sim outside building B3, give corresponding values of 60, 90 and 85 dBm/decades respectively. The above indicates that operator E Sim, is the one with the lowest and most consistent path loss in most of the measurements taken, hence the calculations.

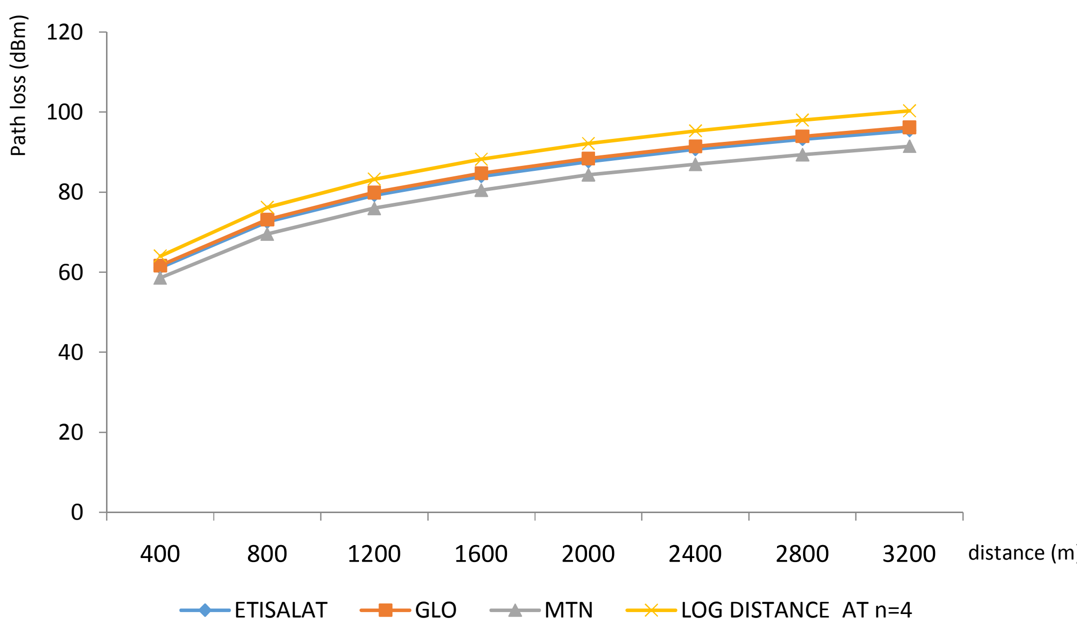

Fig. 4. Path loss outside building B1, from the generated models for Etisalat, Glo, MTN and log distance n=4

Table 38. Path loss outside building B1, from the generated models for Etisalat, Glo, MTN and log distance n=4

d (m)	Log $\left[\frac{d}{d_o}\right]$ dB	40Log$\left[\frac{d}{d_o}\right]$ Db	A_A = 37.7Log$\left[\frac{d}{d_o}\right]$ dB	Log [d] dB	Exp{Log [d]} dB	A_B = 0.251{Exp{Log [d]}} dB	Log distance @ n=4	L_{AIRTEL} = 0 .0602+ A_A + A_B dBm	G_A = 38Log$\left[\frac{d}{d_o}\right]$ dB	G_B = 0.271{Exp{Log [d]}} dB	L_{GLO} = 0 .0602+ G_A + G_B dBm	M_A = 36.3 Log$\left[\frac{d}{d_o}\right]$ dB	M_B = 0.127{Exp{Log [d]}} dB	L_{MTN} = 0 .0602+ G_A + G_B dBm
200	1.301	52.04	49.05	2.301	9.98	2.51	52.10	51.62	49.44	2.71	52.20	47.23	1.27	48.55
400	1.602	64.08	60.41	2.602	13.49	3.39	64.14	63.86	60.88	3.66	64.59	58.15	1.71	59.93
800	1.903	76.12	71.76	2.903	18.23	4.58	76.18	76.40	72.31	4.94	77.32	69.08	2.32	71.45
1200	2.080	83.2	78.44	3.080	21.76	5.46	83.26	83.96	79.04	5.90	85.0	75.50	2.76	78.33
1600	2.204	88.16	83.11	3.304	27.22	6.83	88.22	90.00	83.75	7.38	91.19	80.01	3.46	83.52
2000	2.301	92.04	86.77	3.301	27.14	6.81	92.10	93.64	87.44	7.36	94.85	83.53	3.45	87.03
2400	2.380	95.2	89.75	3.380	29.37	7.37	95.26	97.18	90.44	7.96	98.46	86.40	3.73	90.19
2800	2.450	97.89	92.26	3.45	31.5	7.91	97.95	100.17	92.99	8.54	101.59	88.83	4.00	92.89
3200	2.505	100.21	94.44	3.51	33.45	8.40	100.27	102.84	95.20	9.07	104.32	90.94	4.25	95.25

Table 39. Path loss outside building B2, from the generated models for Etisalat, Glo, MTN and log distance n=4

d (m)	Log $\left[\frac{d}{d_o}\right]$ dB	40Log$\left[\frac{d}{d_o}\right]$ dB	A_A = 38.64og$\left[\frac{d}{d_o}\right]$ dB	Log [d] dB	Exp{Log [d]} dB	A_B = 0.346{Exp{Log [d]}} dB	Log distance @ n=4	L_{AIRTEL} = 0 .0602+ A_A + A_B dBm	G_A = 37.68Log$\left[\frac{d}{d_o}\right]$ dB	G_B = 0.227{Exp{Log [d]}} dB	L_{GLO} = 0 .0602+ G_A + G_B dBm	M_A = 36.43 Log$\left[\frac{d}{d_o}\right]$ dB	M_B = 0.149{Exp{Log [d]}} dB	L_{MTN} = 0 .0602+ G_A + G_B dBm
200	1.301	52.04	50.27	2.301	9.98	3.45	52.10	53.78	49.02	2.27	51.35	47.40	1.49	48.94
400	1.602	64.08	61.90	2.602	13.49	4.67	64.14	66.63	60.36	3.06	63.49	58.36	2.01	60.43
800	1.903	76.12	73.53	2.903	18.23	6.31	76.18	79.90	71.71	4.14	75.90	69.33	2.72	72.10
1200	2.080	83.2	80.37	3.080	21.76	7.53	83.26	87.96	78.37	4.94	83.37	75.77	3.24	79.08
1600	2.204	88.16	85.16	3.304	27.22	9.42	88.22	94.64	83.05	6.18	89.29	80.29	4.06	84.41
2000	2.301	92.04	88.91	3.301	27.14	9.39	92.10	98.36	86.70	6.16	92.93	83.83	4.04	87.93
2400	2.380	95.2	91.96	3.380	29.37	10.16	95.26	102.19	89.68	6.67	96.41	86.70	4.38	91.14
2800	2.450	97.89	94.67	3.45	31.5	10.90	97.95	105.63	92.32	7.15	99.53	89.26	4.70	94.01
3200	2.505	100.21	96.79	3.51	33.45	11.57	100.27	108.43	94.39	7.59	102.04	91.26	4.98	96.30

Table 40. Path loss outside building B3, from the generated models for Etisalat, Glo, MTN and log distance n=4

d (m)	$\text{Log}\left[\frac{d}{d_o}\right]$ dB	$40\text{Log}\left[\frac{d}{d_o}\right]$ dB	$A_A = 35.24\ \text{Log}\left[\frac{d}{d_o}\right]$ dB	Log [d] dB	Exp{Log [d]} dB	A_B = 0.095{Exp{Log [d]}} dB	Log distance @ n=4	L_{AIRTEL} = 0 .0602+ A_A + A_B dBm	$G_A = 37.97\text{Log}\left[\frac{d}{d_o}\right]$ dB	G_B = 0.262{Exp{Log [d]}} dB	L_{GLO} = 0 .0602+ G_A + G_B dBm	$M_A = 37.19\ \text{Log}\left[\frac{d}{d_o}\right]$ dB	M_B = 0.2{Exp{Log [d]}} dB	L_{MTN} = 0 .0602+ M_A + M_B dBm
200	1.301	52.04	45.85	2.301	9.98	0.95	52.10	46.86	49.40	2.62	52.07	48.38	2.00	50.44
400	1.602	64.08	56.46	2.602	13.49	1.28	64.14	57.80	60.83	3.54	64.42	59.58	2.70	62.34
800	1.903	76.12	67.06	2.903	18.23	1.73	76.18	68.85	72.26	4.78	77.09	70.77	3.65	74.48
1200	2.080	83.2	73.30	3.080	21.76	2.07	83.26	75.43	78.98	5.70	84.74	77.36	4.35	81.77
1600	2.204	88.16	77.67	3.304	27.22	2.59	88.22	80.32	83.69	7.13	90.88	81.97	5.44	87.47
2000	2.301	92.04	81.09	3.301	27.14	2.58	92.10	83.73	87.37	7.11	94.54	85.58	5.43	91.06
2400	2.380	95.2	83.87	3.380	29.37	2.79	95.26	86.72	90.37	7.70	98.12	88.51	5.87	94.45
2800	2.450	97.89	86.34	3.45	31.5	2.99	97.95	89.39	93.03	8.25	101.34	91.12	6.30	97.48
3200	2.505	100.21	88.28	3.51	33.45	3.18	100.27	91.51	95.12	8.76	103.94	93.16	6.69	99.91

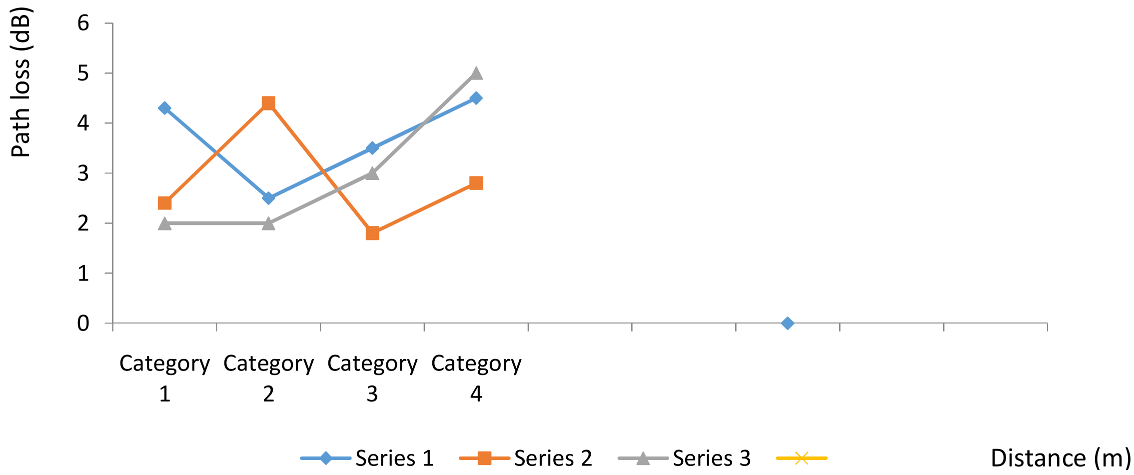

Fig. 5. Path loss outside building B2, from the generated models for Airtel, Glo, MTN and log distance n=4

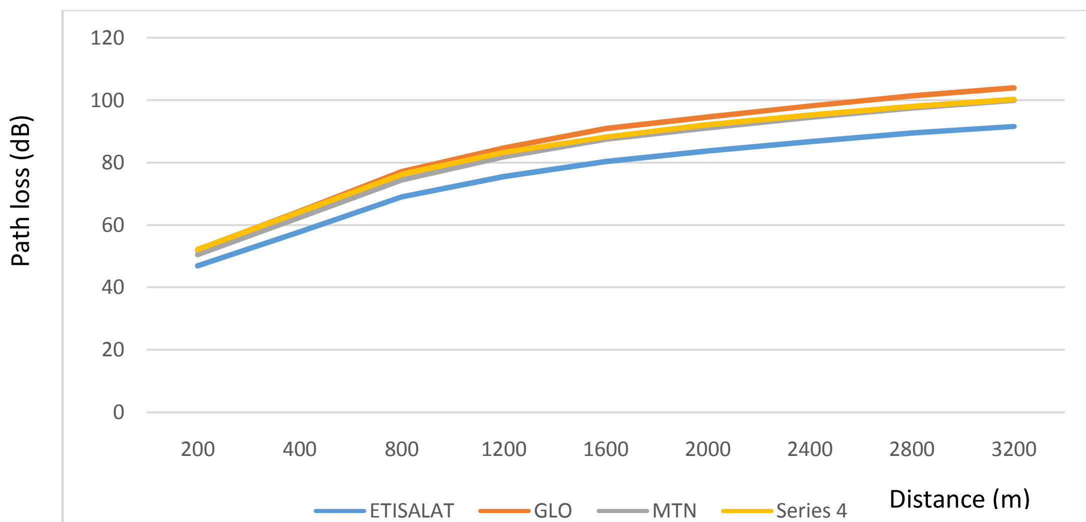

Fig. 6. Path loss outside building B3, from the generated models for Etisalat, Glo, MTN and log distance n=4

4. CONCLUSION

Path loss values at three locations have been measured using the signals of three out of the five existing GSM networks, namely AIRTEL, GLO and MTN NETWORKS, acronym Operator A Sim, Operator M Sim and Operator G Sim respectively. The values obtained were used to generate models that maybe used to calculate the path loss at locations similar to the studied buildings.

The ITU indoor path loss model was also to generate a model that was then compared with the log normal model earlier developed, comparison were made to validate the ITU indoor path loss model as a standard model to be employed for indoor calculations.

Previous literatures in the field of GSM and radio wave propagation were examined and the three propagation mechanisms were confirmed to be reflection, diffraction and scattering. From the investigation of the received signal strength as monitored for Operators A, G and M and the corresponding path loss exponent at the locations of Buildings B1, B2 and B3, the following conclusions were drawn.

1. The path loss of GSM signals increase with distance from the base station, which is in consonance with log-distance path loss models and other existing models.
2. The building penetration loss, ABL, accounts for the increase in attenuation of the received signal when the measurement device is moved from outdoor to indoor.
3. The penetration loss is a function of the building materials and the content of the building. The penetration loss of a crowded building, or buildings well-furnished will have a higher penetration loss than an empty building.
4. The average penetration loss of 5.929dBm, 6.404dBm and 6.102dBm were obtained for buildings B1, B2 and B3 respectively.
5. The path loss exponent values of 3.733, 3.763 and 3.678 obtained from he measurement outside the buildings B1, B2 and B3, respectively in Ekpoma fll within the theoretical range of 3 to 5 for suburban areas.
6. The ITU indoor path loss model was also validated.
7. The outdoor and indoor path loss equations are important as they will be useful to wireless operators for site – specific planning and deployment in areas similar to Ekpoma.
8. With the generated model equations, path loss at any distance of interest can be calculated, and the corresponding signal quqlity at every point can therefore be estimated.
9. This will aid the GSM providers to know where to locate the base stations and how far the signals from such stations will get to, which will in turn help to improve indoor signal quality.

5. RECOMMENDATION

In this research work, three buildings at three arbitrary locations were chsen. The value of path loss exponent obtained is in consonance with research findings at similar locations as published by some other authors (Adenike, 2010; Isobona and Konyeha, 2013; Idim and Anyasi, 2014).

The generated model is dependent on the density of buildings. It is thus important to use the correct value of building cluster factor when using the generated model to calculate oath loss. In addition to the building clutter factor which also affects the indoor model, the correct value of the building penetration loss should be used when calculating path loss.

Models for indoor field strength prediction based on uniform theory of diffraction (UTD) and are encouraged. Detailed information of the building structure is necessary for the calculation of the indoor field strength. These models combine empirical elements with the theoretical electromagnetic approach of UTD. Bu including reflected and diffracted rays, the path loss prediction accuracy is significantly improved.

6. APPLICATION OF THE MODELS

The results obtained in this work is going to be very useful for GSM providers before future site-specific planning and installation of any base station in Ekpoma environs or other locations similar to the ones other review.

It will also be very useful to researches in the area of site-specific planning as a handy information, guide and a reference material.

Finally, it will go a long way in reducing outages if well applied, especially for subscribers who use their mobile devices within building premises

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX 1

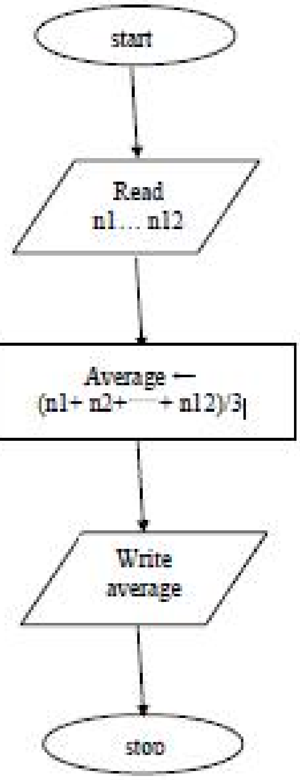

Figure A2: Flow Chart for computing the average values of Tables 3.2 -3.10.

APPENDIX 2

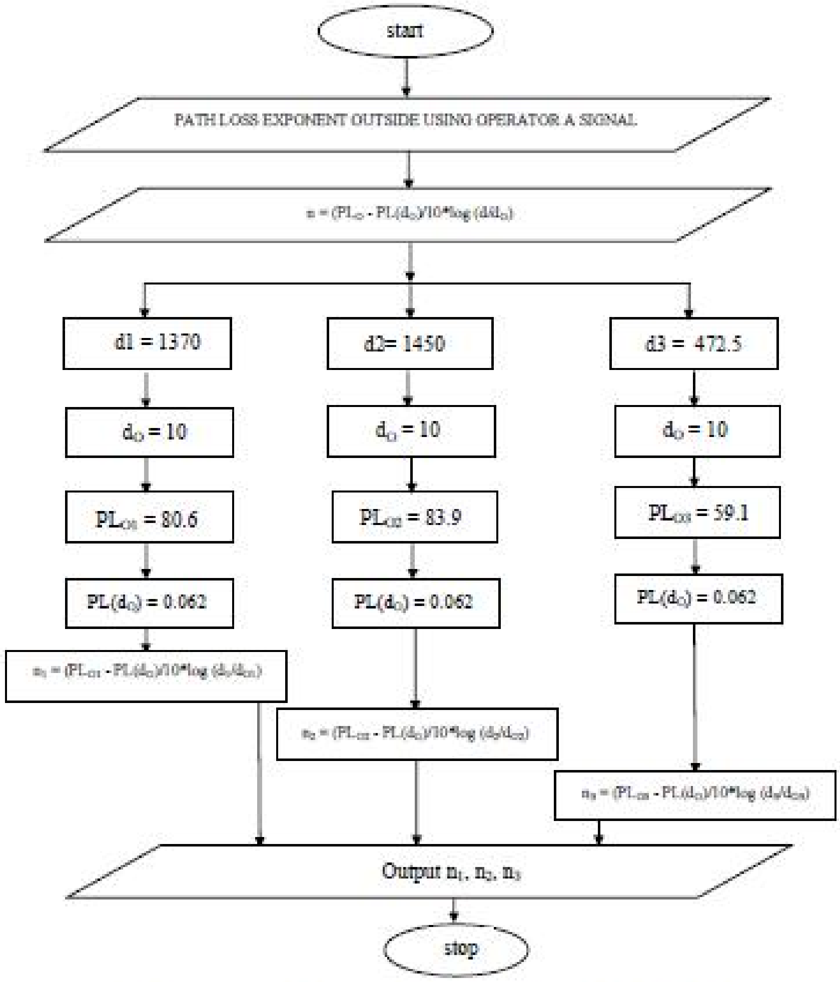

Figure A3: Flow Chart for Computing the Path Loss Exponent of Buildings B1, B2, B3 using Operator A Signals

APPENDIX 3

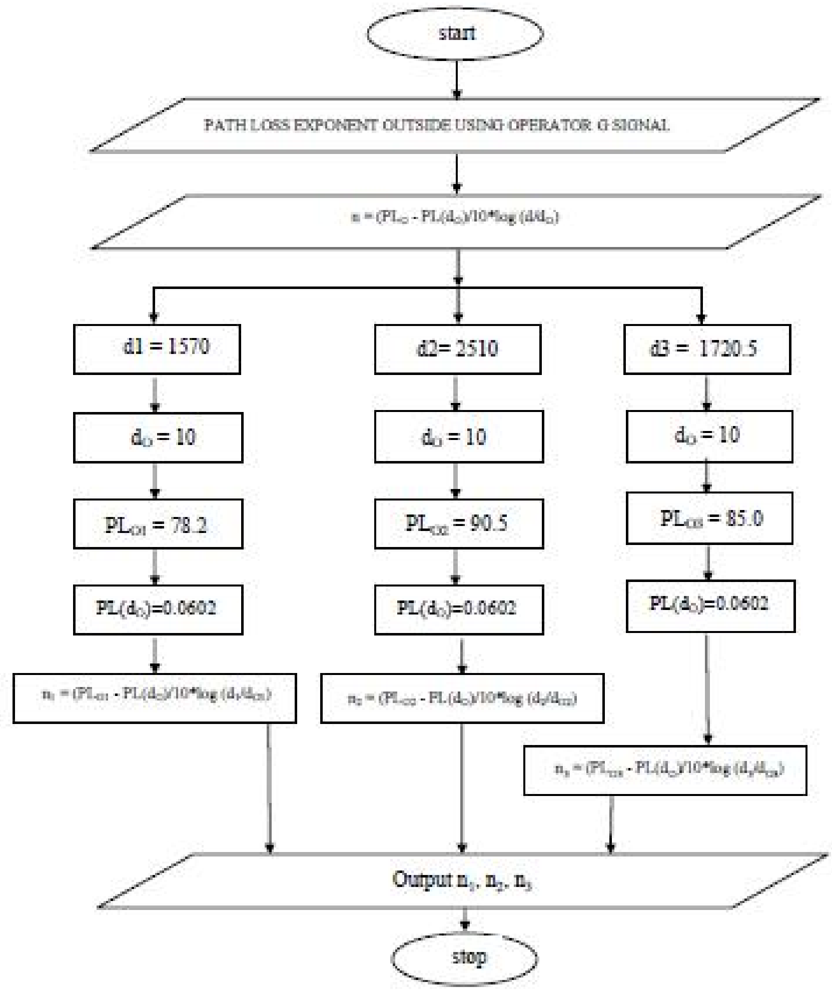

Figure A4: Flow Chart for Computing the Path Loss Exponent of Buildings B1, B2, B3 using Operator G Signals

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