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.
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.

\[ L = 10^n \log_{10}(d) + C \]  

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                |

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.
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 x 8 = 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 (m²)        | 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      | 1376                        | 1376                  | -79.8065             | -85.1871             |
| April      | 1376                        | 1376                  | -85.9333             | -90.1333             |
| May        | 1376                        | 1376                  | -83.0774             | -87.0774             |
| June       | 1376                        | 1376                  | -82.1333             | -87.1333             |
| July       | 1376                        | 1376                  | -82.9697             | -87.7677             |
| August     | 1376                        | 1376                  | -77.1032             | -82.3032             |
| September  | 1376                        | 1376                  | -77.3333             | -82.3333             |
| October    | 1376                        | 1376                  | -76.4129             | -81.8129             |
| November   | 1376                        | 1376                  | -78.7333             | -84.3333             |
| December   | 1376                        | 1376                  | -81.1097             | -87.1333             |
| Mean       | 1376                        | 1376                  | -80.6187             | -85.7023             |

2.1 Preliminary Results

For buildings B1 and B2, twenty measurements 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    | -95.1929     |             |
| February| 1570                         | 1576                                   | -89.1929      | -95.1929    | -95.1929     |             |
| March  | 1570                         | 1576                                   | -83.3971      | -89.1871    | -95.1929     |             |
| April  | 1570                         | 1576                                   | -89.3333      | -96.1333    | -96.1333     |             |
| May    | 1570                         | 1576                                   | -87.6774      | -94.0774    | -94.0774     |             |
| June   | 1570                         | 1576                                   | -86.7333      | -92.1333    | -92.1333     |             |
| July   | 1570                         | 1576                                   | -83.3871      | -89.9677    | -94.0774     |             |
| August | 1570                         | 1576                                   | -82.3032      | -88.3032    | -88.3032     |             |
| September| 1570                        | 1576                                   | -81.3333      | -86.9677    | -88.3032     |             |
| October| 1370                        | 1576                                   | -78.2129      | -84.0129    | -84.0129     |             |
| November| 1570                        | 1576                                   | -76.5333      | -82.1333    | -82.1333     |             |
| December| 1570                        | 1576                                   | -81.1032      | -87.1032    | -87.1032     |             |
| Mean   | 1570                         | 1576                                   | -83.5461      | -89.6164    | -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    | -75.2194     |             |
| February| 906                          | 912                                    | -67.9714      | -74.9714    | -74.9714     |             |
| March  | 906                          | 912                                    | -67.0701      | -75.9067    | -75.9067     |             |
| April  | 906                          | 912                                    | -69.9067      | -77.0516    | -77.0516     |             |
| May    | 906                          | 912                                    | -71.9871      | -78.4871    | -78.4871     |             |
| June   | 906                          | 912                                    | -73.9133      | -79.1933    | -79.1933     |             |
| July   | 906                          | 912                                    | -74.3032      | -80.303     | -80.303      |             |
| August | 906                          | 912                                    | -77.9355      | -84.9355    | -84.9355     |             |
| September| 906                         | 912                                    | -72.8933      | -78.8933    | -78.8933     |             |
| October| 906                          | 912                                    | -71.0516      | -77.0516    | -77.0516     |             |
| November| 906                         | 912                                    | -68.8800      | -74.88      | -74.88       |             |
| December| 906                         | 912                                    | -67.0581      | -75.0581    | -75.0581     |             |
| Mean   | 906                          | 912                                    | -71.0518      | -77.6326    | -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    | -88.3806     |             |
| February| 1450                         | 1455                                   | -79.2214      | -85.4571    | -85.4571     |             |
| March  | 1450                         | 1455                                   | -80.2710      | -86.4839    | -86.4839     |             |
| April  | 1450                         | 1455                                   | -83.2000      | -88.6000    | -88.6000     |             |
| May    | 1450                         | 1455                                   | -85.2710      | -92.8774    | -92.8774     |             |
| June   | 1450                         | 1455                                   | -87.2000      | -94.0000    | -94.0000     |             |
| July   | 1450                         | 1455                                   | -87.2710      | -94.0700    | -94.0700     |             |
| August | 1450                         | 1455                                   | -89.2700      | -96.6700    | -96.6700     |             |
| September| 1450                        | 1455                                   | -85.8000      | -92.0000    | -92.0000     |             |
| October| 1450                         | 1455                                   | -84.0710      | -90.2710    | -90.2710     |             |
| November| 1450                        | 1455                                   | -83.0000      | -88.0000    | -88.0000     |             |
| December| 1450                        | 1455                                   | -79.6710      | -86.0700    | -86.0700     |             |
| Mean   | 1450                         | 1455                                   | -83.8668      | -90.2400    | -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<sub>o</sub> | Inside, d<sub>i</sub> | Outside, P<sub>o</sub> | Inside, P<sub>i</sub> |
| 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                           | -98.1355                   | -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                   | -94.393                    |
| 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<sub>o</sub> | Inside, d<sub>i</sub> | Outside, P<sub>o</sub> | Inside, P<sub>i</sub> |
| 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<sub>o</sub> | Inside, d<sub>i</sub> | Outside, P<sub>o</sub> | Inside, P<sub>i</sub> |
| 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.

\[
PL(dBm) = PL(d_0) + 10\log \frac{d}{d_0} \tag{2}
\]

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

\[
PL(d_0) = -10 \log \left[ \frac{\lambda^2}{(4\pi)^2 \frac{1}{d_0}} \right] \tag{3}
\]

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

\[
\lambda = \frac{\nu}{f} \tag{4}
\]

for \(\nu = 3 \times 10^8 \text{ m/s}, the wavelength is\n
\[
\lambda = \frac{3 \times 10^8}{2412 \times 10^6} = 0.1244 \text{ m}
\]

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,

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

Hence, equation (3.6) becomes,

\[
PL(dBm) = 0.06008 + 10\log \frac{d}{d_0} \tag{5}
\]

The path loss exponent, \(n\), may then be computed as
The path loss exponent, \( n \), may then be computed as

\[
  n = \frac{PL - 0.06008}{10 \log \frac{d}{d_0}}
\]

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.

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

\[
  \lambda = \frac{3 \times 10^8}{2412 \times 10^6} = 0.1244 m
\]

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

Mean PL\(_{d_0}\) for B1 = -80.6187 dBm.

Average distance \( d = 1370 \) m, hence,

\[
  n = \frac{80.6187 - 0.06008}{10 \log \frac{1370}{10}} = \frac{80.5586}{21.367} = 3.770.
\]

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.

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

\[
  \lambda = \frac{3 \times 10^8}{2437 \times 10^6} = 0.123 m
\]

The path loss exponent, \( n \), may then be computed as

\[
  n = \frac{PL - 0.06021}{10 \log \frac{d}{d_0}}
\]

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

Mean PL\(_{d_0}\) for B1 = -71.0158 dBm.

Average distance \( d = 906 \) m, hence,

\[
  n = \frac{71.0158 - 0.06021}{10 \log \frac{906}{10}} = \frac{70.9559}{19.559} = 3.6255.
\]
Table 11. Path Loss exponent outside Buildings B1, B2 and B3 with Operator G signals

| Building type | d(m) | PL₀ (dBm) | d₀ | PL(d₀) (dBm) | d/d₀ | 10log (d/d₀) (dBm) | PL-PL(d₀) (dBm) | 10log (d/d₀) |
|---------------|------|-----------|----|--------------|------|-------------------|----------------|---------------|
| 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) | PL₀ (dBm) | d₀ | PL(d₀) (dBm) | d/d₀ | 10log (d/d₀) (dBm) | PL-PL(d₀) (dBm) | 10log (d/d₀) |
|---------------|------|-----------|----|--------------|------|-------------------|----------------|---------------|
| 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     | 172.1| 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).

\[ ABL(dBm) = PL_0(dBm) - PL_I(dBm) \]  \( (17) \)

where ABL = Average Building Loss.

The average path loss levels in B1 using operator A Sim (Etisalat) are as given in Table 16, where PL₀ = - 80.619 dBm and PL₁ = - 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, PL₀                             | Inside, PL₁                   | ABL = PL₀ - PL₁               |
| 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, PL₀                             | Inside, PL₁                   | ABL = PL₀ - PL₁               |
| 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                           |
| B2            | 6.373      | 6.226      | 6.612                           |
| B3            | 6.036      | 6.241      | 6.035                           |

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

$$ n = \frac{1}{2} \sum_{i=1}^{5} n = \frac{3+5}{2} = 4 $$

Hence, the theoretical path loss may be written as:

$$ PL_T = PL(d_o) + 10(4)\log\frac{d}{d_o} $$

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

Equation 3.23 becomes,

$$ PL_T = 0.06021 + 10(4)\log\frac{d}{d_o} $$

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) | $d_o$ (m) | $PL(d_o)$ | $d/d_o$ | $40\log(d/d_o)$ | $PL_T = PL(d_o) + 40\log(d/d_o)$ |
|---------------|---------|-----------|-----------|---------|-----------------|----------------------------------|
| 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) | $d_o$ (m) | $PL(d_o)$ | $d/d_o$ | $40\log(d/d_o)$ | $PL_T = PL(d_o) + 40\log(d/d_o)$ |
|---------------|---------|-----------|-----------|---------|-----------------|----------------------------------|
| 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) | $d_o$ (m) | $PL(d_o)$ | $d/d_o$ | $40\log(d/d_o)$ | $PL_T = PL(d_o) + 40\log(d/d_o)$ |
|---------------|---------|-----------|-----------|---------|-----------------|----------------------------------|
| 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\textsubscript{O} < PL\textsubscript{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:

\[
PL = 10 \log \left( \frac{d}{d_e} \right) + 10 \log \left( \frac{d}{d_0} \right) + V \tag{21}
\]

Where

- \(PL\) = Path Loss in Ogbomosho, hence \(PL = PL\textsubscript{O}\).
- \(d_e\) = reference distance = 10m
- \(P_L(d_e)\) = Path Loss at reference distance = 0.062.
- \(n = 3.5\).
- \(d = \) distance in meters (m).
- \(PL(d_Bm) = \) model or signal generated reception level for outdoor environment.

\[
V = PL\textsubscript{O} - PL(d_e) - 10 n \log \left( \frac{d}{d_0} \right) \tag{22}
\]

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\textsubscript{O} | Theoretical PL\textsubscript{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\textsubscript{O} | Theoretical PL\textsubscript{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\textsubscript{O} | Theoretical PL\textsubscript{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.,

\[ V = v \cdot d \cdot \log(d) \]

Or,

\[ v = \frac{V}{d \cdot \log(d)} \]

(23)

(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)

\[ PL_v = PL(d) + 10n \log_{10} \frac{d}{d_0} + v \cdot d \cdot \log(d) \]  

(25)

Where

- \( PL_v = \) Outdoor Path loss
- \( d_0 = \) reference distance =10m
- \( PL(d_0) = \) Path 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(d₀) dBm | \( \frac{d}{d_0} \) (m) | 35log(\( \frac{d}{d_0} \)) (dBm) | PL₀ (dBm) | V = PL₀ - (0.06 02 + 35log(\( \frac{d}{d_0} \))) (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(d₀) dBm | \( \frac{d}{d_0} \) (m) | 35log(\( \frac{d}{d_0} \)) (dBm) | PL₀ (dBm) | V = PL₀ - (0.06 02 + 35log(\( \frac{d}{d_0} \))) (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(d₀) dBm | \( \frac{d}{d_0} \) (m) | 35log(\( \frac{d}{d_0} \)) (dBm) | PL₀ (dBm) | V = PL₀ - (0.06 02 + 35log(\( \frac{d}{d_0} \))) (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 = \( \frac{V}{e^{logd}} \) |
|---------------|------|--------|---------|------------------|
| 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) | $e^{\log d}$ | $v = \frac{V}{e^{\log d}}$ (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) | $e^{\log d}$ | $v = \frac{V}{e^{\log d}}$ (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 $d$ | $PL(d)$ (dBm) | $\log d$ | $v$ | $ve^{\log d}$ | $PL_0$ (dBm) |
|---------------|---------|---------|---------------|----------|----|---------------|--------------|
| B1            | 1370    | 3.137   | 74.785        | 3.137    | 5.78 | 80.6252       |
| B2            | 1450    | 3.162   | 75.648        | 3.162    | 8.17 | 83.8782       |
| B3            | 472.5   | 2.674   | 58.604        | 2.674    | 1.38 | 60.0442       |

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

| Building Type | $d$ (m) | Log $d$ | $PL(d)$ (dBm) | $\log d$ | $v$ | $ve^{\log d}$ | $PL_0$ (dBm) |
|---------------|---------|---------|---------------|----------|----|---------------|--------------|
| B1            | 1570    | 3.196   | 76.857        | 3.196    | 6.62 | 83.5372       |
| B2            | 2510    | 3.400   | 83.989        | 3.400    | 6.80 | 90.8492       |
| B3            | 1720.5  | 3.236   | 78.244        | 3.236    | 6.66 | 84.9642       |
Table 34. Path loss Outside the Buildings using generated model for operator M

| Building Type | d(m) | Log d | PL(d0) (dBm) | log(v) | e-5log(d) | v | e-log(d) | PL₀ = \{0.06 \cdot 0.02 + 351og(d)\} + v log(d) |
|---------------|------|-------|--------------|--------|-----------|---|---------|-----------------------------------------------|
| B1            | 906  | 2.957 | 0.0602       | 90.6   | 68.500    | 19.24 | 0.127   | 71.0002                                       |
| B2            | 805  | 2.906 | 0.0602       | 80.5   | 66.703    | 18.284| 0.149   | 69.4832                                       |
| B3            | 1452.5 | 3.162 | 0.0602      | 145.3  | 75.679    | 23.618| 0.200   | 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          | 80.625             | 0.0031             |
| B2            | 1450 | 83.867          | 83.878             | 0.0056             |
| B3            | 472.5 | 59.099         | 60.044             | 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          | 83.537             | 0.0044             |
| B2            | 2510 | 90.847          | 90.849             | 0.0011             |
| B3            | 1720.5 | 84.959       | 84.964             | 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](image-url)
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](image-url)
### Table 38. Path loss outside building B1, from the generated models for Etisalat, Glo, MTN and log distance n=4

| d (m) | $L_{\log} \frac{|d|}{40}$ | $40 \log_{10} \frac{|d|}{40}$ | $A_A = 37.7 \log_{10} \frac{|d|}{40} + A_B$ dB | $A_B = 0.251 \{ \exp \{ L_{\log} \frac{|d|}{40} \} \}$ dB | $G_A = 38 \log_{10} \frac{|d|}{40}$ dB | $G_B = 0.271 \{ \exp \{ L_{\log} \frac{|d|}{40} \} \}$ dB | $L_{\log} \frac{|d|}{40} \mu A + G_A + G_B$ dBm | $M_A = 36.3 \log_{10} \frac{|d|}{40}$ dB | $M_B = 0.127 \{ \exp \{ L_{\log} \frac{|d|}{40} \} \}$ dB | $L_{\log} \frac{|d|}{40} \mu A + G_A + G_B$ dBm |
|------|--------------------------|--------------------------|---------------------------------|---------------------------------|--------------------------|---------------------------------|---------------------------------|--------------------------|---------------------------------|---------------------------------|
| 200  | 1.301                    | 52.04                    | 49.05                           | 9.98                            | 2.51                     | 52.10                           | 49.44                           | 2.71                     | 52.20                           | 47.23                           | 1.27                           | 48.55                           |
| 400  | 1.602                    | 64.08                    | 60.41                           | 13.49                           | 3.39                     | 64.14                           | 63.86                           | 3.66                     | 64.59                           | 58.15                           | 1.71                           | 59.93                           |
| 800  | 1.903                    | 76.12                    | 71.76                           | 18.23                           | 4.58                     | 76.18                           | 76.40                           | 4.94                     | 77.32                           | 69.08                           | 2.32                           | 71.45                           |
| 1200 | 2.080                    | 83.2                     | 78.44                           | 21.76                           | 5.46                     | 83.26                           | 83.96                           | 5.90                     | 85.0                            | 75.50                           | 2.76                           | 78.33                           |
| 1600 | 2.204                    | 88.16                    | 83.11                           | 27.22                           | 6.83                     | 88.22                           | 90.00                           | 7.38                     | 91.19                           | 80.01                           | 3.46                           | 83.52                           |
| 2000 | 2.301                    | 92.04                    | 86.77                           | 27.14                           | 6.81                     | 92.10                           | 93.64                           | 7.36                     | 94.85                           | 83.53                           | 3.45                           | 87.03                           |
| 2400 | 2.380                    | 95.2                     | 89.75                           | 29.37                           | 7.37                     | 95.26                           | 97.18                           | 7.96                     | 98.46                           | 86.40                           | 3.73                           | 90.19                           |
| 2800 | 2.450                    | 97.89                    | 92.26                           | 31.5                             | 7.91                     | 97.95                           | 100.17                          | 8.54                     | 101.59                          | 88.83                           | 4.00                           | 92.89                           |
| 3200 | 2.505                    | 100.21                   | 94.44                           | 33.45                           | 8.40                     | 100.27                          | 102.84                          | 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 $|d|_4$ dB | 40Log $|d|_4$ dB | $A_A = 38.64 + 3.45$ dB | $A_B = 0.346 \cdot \exp(\text{Log }|d|_4)$ dB | Log distance @ n=4 | $L_{\text{AIRTEL}} = 0.0602 + A_A + A_B$ dBm | $G_A = 37.68 \cdot \log |d|_4 + 49.02$ dB | $L_{\text{GLO}} = 0.0602 + G_A + G_B$ dBm | $M_A = 36.43 \cdot \log |d|_4 + 51.35$ dB | $M_B = 0.149 \cdot \exp(\text{Log }|d|_4)$ dBm | $L_{\text{MTN}} = 0.0602 + G_A + G_B$ dBm |
|-------|----------------|----------------|----------------------|------------------------|------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| 200   | 1.301          | 52.04          | 50.27                | 2.301                  | 9.98             | 52.10                            | 53.78                            | 49.02                            | 2.27                             | 51.35                            | 47.40                            | 1.49                             |
| 400   | 1.602          | 64.08          | 61.90                | 2.602                  | 13.49            | 64.14                            | 66.63                            | 60.36                            | 3.06                             | 63.49                            | 58.36                            | 2.01                             |
| 800   | 1.903          | 76.12          | 73.53                | 2.903                  | 18.23            | 76.18                            | 79.90                            | 71.71                            | 4.14                             | 75.90                            | 69.33                            | 2.72                             |
| 1200  | 2.080          | 83.2           | 80.37                | 3.080                  | 21.76            | 83.26                            | 87.96                            | 78.37                            | 4.94                             | 83.37                            | 75.77                            | 3.24                             |
| 1600  | 2.204          | 88.16          | 85.16                | 3.304                  | 27.22            | 88.22                            | 94.64                            | 83.05                            | 6.18                             | 89.29                            | 80.29                            | 4.06                             |
| 2000  | 2.301          | 92.04          | 88.91                | 3.301                  | 27.14            | 92.10                            | 98.36                            | 92.36                            | 6.78                             | 90.43                            | 84.11                            | 3.64                             |
| 2400  | 2.380          | 95.2           | 91.96                | 3.380                  | 29.37            | 95.26                            | 102.19                           | 96.88                            | 9.46                             | 102.19                           | 91.41                            | 4.28                             |
| 2800  | 2.450          | 97.89          | 94.67                | 3.45                   | 31.5             | 97.95                            | 105.63                           | 92.32                            | 7.15                             | 99.53                            | 89.26                            | 4.70                             |
| 3200  | 2.505          | 100.21         | 96.79                | 3.51                   | 33.45            | 100.27                           | 108.43                           | 94.39                            | 7.59                             | 102.04                           | 91.26                            | 4.98                             |

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

| d (m) | Log [d] dB | 40Log [d] dB | Log [d] dB | Exp[Log [d]] dB | Log distance @ n=4 | \( A_A = 35.24 \) Log [d] dB | \( A_A = 0.095 \)Exp[Log [d]] dB | \( A_A = 0.0602 + A_A + A_B \) dBm | \( A_B = 0.262 \)Exp[Log [d]] dB | \( A_B = 0.262 \)Exp[Log [d]] dBm | \( M_A = 0.2 \)Exp[Log [d]] dBm | \( M_B = 0.2 \)Exp[Log [d]] dBm | \( L_{MTN} = 0.0602 + M_A + M_B \) 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                       |
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 the measurement outside the buildings B1, B2 and B3, respectively in Ekpoma fall 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 quality 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 chosen. 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 path 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. In 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 researchers 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 Signal.
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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