Building Penetration Loss for GSM Signals into Selected Building Structures in Jigawa State, Nigeria

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Abstract

Global system for mobile communication (GSM) became the most active industry in our country Nigeria, since its inception in 2004. The number of service providers keeps on increasing, but the quality of services (QoS), provided is still low. This research work, studied by way of extensive measurements, the received signal strength inside buildings constructed using different types of building materials for both the structure and the roof. This is with a view to finding a signal attenuation margin that will improve the indoor propagation model. The degree of attenuation on the received signal may be used to provide a margin in GSM radio link planning so as to compensate for such loss. The measurements were conducted in selected areas in Jigawa metropolis where these types of buildings are common. Four geographical locations were used as case study within Jigawa metropolis namely, Dutse, Kazaure, Hadejia, Gumel and Ringim. Signals radiated from four GSM service providers (namely, MTN, ETISALAT, Glo and Airtel) were used as basis for the measurements. Spectrum analyzer mounted on a trolley and controlled by a PC was used for this work; measurements on straight routes in corridors, rooms and the balcony were performed with equidistant measurements points. Several measurements campaigns with different location at 230 and 1500MHz were undertaken. Based on the results obtained, we conclude that, among the combination of building materials studied in this research mud building/rusty zinc accounted for higher signal losses while sandcrete building/good zinc roof accounted for lower signal losses for all the network providers considered in this study.

Keywords: *GSM Network, Signal Loss, Building Materials, Spectrum Analyzer, Wheel Meter.*

I. Introduction

With the advent of microcellular, radio networks employed in third and four generation (3G & 4G) mobile communication systems, there is an increased interest in propagation models that are able to provide location specific predictions of channel parameters such as local mean power, and delay spread [1]. Propagation research for mobile communications in urban microcells has hitherto been focused mainly on the modeling of reflection and diffraction from exterior walls and corners of buildings. These buildings are usually treated as opaque at frequencies used for terrestrial mobile communications. Radio propagation inside buildings is governed by propagation mechanisms such as reflection, diffraction, and scattering from various objects. The field distribution inside a building is therefore dependent on specific features of the building and its internal structure (e.g.Indoor layout, construction materials) [2, 3]. There are several factors that affect radio wave propagation which result in the degradation of signals. These factors include multipath fading effect, non line-of-sight, path loss, and absorption by building materials used in construction [3, 4]. Although many researches have been conducted on the factors that cause the degradation of (GSM) signal strength in outdoor environments, only few works have been done in indoor environment. However there is need to study the signal strength of (GSM) indoor environment considering, mud (laterite) buildings coupled with rusted zinc roof which form the basis of this investigation. The frequency bands used for this research work are GSM 900MHz and 1800MHz for selected service providers in Jigawa where the study was conducted.

Radio waves propagation in indoor environment is affected by those propagation mechanisms which lead to multipath fading effect that result to the arrival of radio waves signal from transmitting antenna to the receiving antenna at different time, phases in high-rise buildings in urban environment. Propagation research can be done in both indoor and outdoor environments. Indoor and outdoor radio channels differ largely in terms of the transmitter-receiver separation distance covered (which is usually much smaller for indoor environments, and the variability of the environment is usually greater for indoor environments). Propagation in indoor environments have somewhat, more complex multipath structure than in outdoor environments which is largely due to the nature of the building structures used, the room layouts and the type of materials used in the construction of the building [2, 3, 4]. In outdoor environment, propagation is affected by obstacles within surroundings such as trees, buildings, and moving cars among others. While indoor environment propagation on the other hand is affected by interior walls, metallic objects such as whiteboards, bookcases, standing air conditioners and items of furniture. Since transmission and reception of signals can be from outdoor to indoor environment, there is need to quantify the various contribution by these factors on the signal strength. Quantifying the above mentioned effect is important so that the signal strength may be estimated at the receiving end. A block diagram of the measurement setup is shown in Fig.1.1

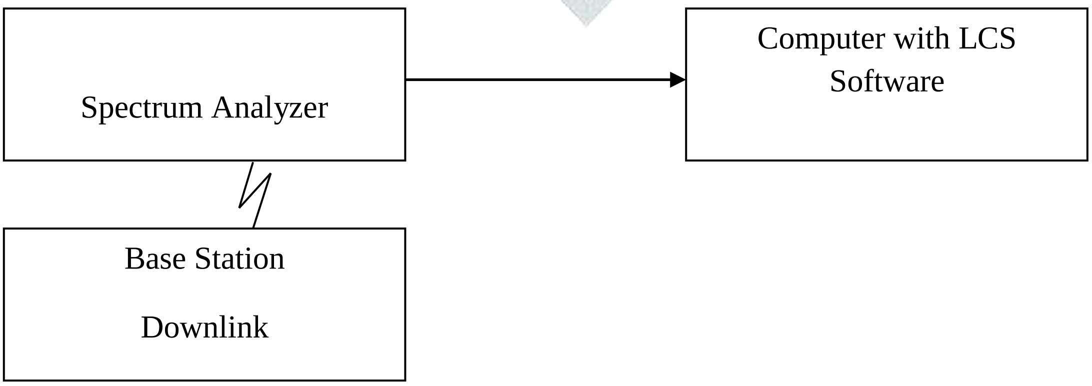

Figure 1: Block diagram of the Measurement Setup

II. Multipath Fading and Signal Transmission Mechanisms

In wireless communication channel, the transmitted signal generally propagates to the receiver antenna through many different paths. Multipath propagation is due to the multiple reflections caused by reflectors and scatterers in the environment. Possible reflectors and scatterers may include mountains, hills and trees in rural environments, building and vehicles in built-up urban environments or walls and floors in indoor environments [5]. The receiver antenna will therefore receive multiple versions of the transmitted signal. Since different versions of the signal propagate through different paths, they will in general have different attenuation, phase shifts, time delays and angles of arrival. Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. Multipath in radio channel creates small-scale fading effects which degrade signal strength. Which may includes: Rapid changes in signal strength over a small distance, Random frequency modulation due to varying Doppler shift on different multipath signals, Time dispersion (echoes) caused by multipath delays among others. Transmitted signal usually suffers from path loss when it arrives at the receiver, after traversing a path of several wavelengths [4, 6]. It is defined as,

$$Pl(dB) = 10 \log_{10} (p_t / P_r) \qquad 2.0$$

Where, P_t and P_r are the transmitter and receiver power respectively.

III. Signal Absorption by Buildings

Another source of poor radio performance can be signal absorption by building materials. An extensive study of electromagnetic signals attenuation in construction materials at the different frequencies has been conducted [7]. The results have shown that majority of building materials are relatively transparent to electromagnetic signals for the application, using RF to survey through walls. In general signal attenuation from absorption increases with increasing frequency. Modern construction methods and materials for large commercial building have changed quite substantially and can be a source of poor radio performance. Curtain-wall, construction for large high-rise buildings means that the walls are “hung” from the structures (typical steel). These walls are generally glass, frequently reflective to radio signals. The glass material used in the windows is RF friendly, but the windows usually contain tinting embedded in the glass which significantly shield and reflect radio signals. Building height contributes several factors that degrade signal in structures. Propagation through more building materials (floors walls etc) which increases the absorption, reflection and refraction of the radio signals through these materials [7]. In this work, we shall review some existing measurements conducted.

IV. Measurement of Building Penetration Loss and Propagation Model for Radio Transmission into Building

Different researches were conducted on the determination of G.S.M Signal Penetration level and signal path losses. D. M. Rose, and k. Thomas [8] conducted a research to determine the Outdoor-to-indoor propagation – Accurate Measuring and Modelling of Indoor Environments at 900 and 1800 MHz, which investigated the interference and attenuation of signals penetrating into building. Attenuations by walls, windows and doors were studied to determine the level of signals losses and data rate. For indoor measurements, it was evident that the signal strength was lower than that of outdoor environment. Building materials have obvious effects on the signal strength; as attenuation was observed to be due to path loss exponents [8, 9]. Similar study described novel method of path loss modelling for radio communication channels in container port area. Multi-variate empirical was presented, based on multidimensional regression analysis of real path loss measurements from the container terminal environment. Parameters, which affect the value of propagation path loss in port area, were chosen as independent variables in error function. The parameters are frequency f; propagation path length d; path type qualification: line of sight or non line of sight condition; difference between transmitter antennas heights above terrain level are average height of container stack. Ryszard J.et.al [9]. Another study by J. Klein et al [4], suggested that proper modelling (indoor and outdoor Channel modelling) of penetration loss is one of the basic approaches of predicting signal attenuation by building structures and to enhance the effective way of data transmission into building structures over a wireless mobile network.

V. Measurement set up

In this work investigation of radio transmission into building models for the propagation into buildings was developed. The operational frequencies of GSM service providers were used for this measurement. To measure the indoor, outdoor propagation loss characteristic at the frequencies of 900MHz and 1800MHz, measurements were performed with a spectrum analyzer as a receiver. Models for the propagation into building enable the calculation of the indoor field strength coverage based on the given outdoor coverage. In order to develop and to calibrate such models, several measurements of the building penetration loss with different transmitter location were undertaken and evaluated. Two types of buildings were used for the purpose of this measurement. The buildings are mud- building with both rusted and good zinc roofing and sandcrete building with both rusted and good zinc roofing. Measurements were carried out inside these buildings. Furniture, ceiling fans and set of TV are found in almost all households where the measurements were conducted. The spectrum analyzer was used for the selection of the downlink frequencies of GSM service providers; spectrum analyzer has PC software installed on the laptop served as graphical user interface to analyze the received power in dBm. The measurements were performed for both indoor and outdoor environments. For the indoor measurements were conducted in four different building types; the buildings that the measurements were conducted in; are mud building coupled with rusted zinc roof, mud building coupled with good zinc roof, sandcrete building coupled with rusted zinc roof and sandcrete building coupled with good zinc roof. While for the outdoor measurements, for each of the measurement conducted inside the building types mention above there was measurements being conducted outside the building.

To develop and calibrate propagation models which calculate the indoor field strengths at the outer walls of the specific building, measurements of the building penetration loss with different transmitter location have been carried out. The Spectrum analyzer mounted on a trolley and controlled by a PC was used for this work; measurements on straight routes in corridors, rooms and the balcony were performed with equidistant measurements points. When the far-field distance was determined and use as reference distance

d_o, then the wheel meter was use to measure the distance from reference distance close-in distance from transmitter and covered about approximately 900 meters.

Figure 2: Measurement Set Up Showing the Spectran Unit [10].

Field measurements work

Field measurements were performed within Jigawa metropolitan city. The measurements were conducted to investigate the variation of GSM signal received within the building types mentioned in this study. The measurements were performed for both indoor and outdoor situation and results were obtained. The frequencies bands used for this measurement are those of GSM service providers operating their business in Nigeria. The service operators are as follows: Airtel (955-960MHz), MTN (950-955MHz), Glo (945-950MHz) and Etisalat (890-895MHz) respectively [11].

Also five areas were selected where the measurements were conducted within Jigawa metropolitan city; these areas are Dutse, Kazaure, Hadejia, Gumel and Ringim. The measurements were conducted from 7:00am to 5:00pm for a period lasted for three weeks.

The study involves obtaining the mean received power distribution at specified building types. Data collection was done by taking measurements at both indoor and outdoor environments. Statistical approach was employed to analyzed signal strengths of the existing GSM signals, both outside (outdoor) and inside (indoor) of buildings, thus defining building attenuation as a ratio of the external fields to the fields inside, expressed in decibel-meter (dBm). The service providers and their frequencies are shown in Table 1. For this purpose, the 900MHz and 1800MHz frequency bands was considered for the service providers as shown in table 1:

Table 1: Showing the frequency bands of GSM service providers in Nigeria [11]

S/N	NETWORK PROVIDER	FREQUENCY BAND 900 MHz
1	Airtel	Downlink (955-960), Uplinnk (910-915)
2	MTN	Downlink (950-955), Uplinnk (705-910)
3	Glo	Downlink (9545-950), Uplinnk (900-905)
4	Etisalat	Downlink (890-895), Uplinnk (935-940)

The model development is based on the building types under consideration Viz, mud building coupled with rusted zinc roof, and sandcrete building coupled with good zinc roof. The model generated was totally statistical and the steps followed are outline.

- The average mean power received for the building type was computed.

- The path loss characteristics for the particular buildings type were computed.

The spectrum analyzer was set to record three maximum values of the signal for each sweep. Each measurement was recorded for five minutes per each scenario using the LCS software. The output file was then processed as follows: the average of the three maximum values was calculated, and considered as the value of the signal strength measured by the spectrum analyzer.

VI. Least-square line method

The least-square line method is used to obtain a line of best fit because the best-fit curve is the curve that has the minimal sum of the deviation s squared for a given set of data.

The least square line approximating the set of points (X1, Y1), (X2, Y2……………. Xi, Yi) has the equation below.

$$Y = a + bx \qquad \ldots\ldots 3.5$$

To approximate the set of data (x_1,y_1), (x_2,y_2), (x_3,y_3),…………,$(x_n y_n)$ where $n \geq 2$; such that the sum of squares of the distances to this straight line y= a + bx from the set of point is a minimum.

Where we have [13]

$$a = \frac{\left(\sum_{i=1}^{n} y_i\right)\left(\sum_{i=1}^{n} x^2{}_i\right) - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i x_i\right)}{n\left(\sum_{i=1}^{n} x^2{}_i\right) - \left(\sum_{i=1}^{n} x_i\right)^2} \qquad \ldots\ldots\ldots\ldots 3.6a$$

$$b = \frac{n\left(\sum_{i=1}^{n} y_i x_i\right) - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n\left(\sum_{i=1}^{n} x^2{}_i\right) - \left(\sum_{i=1}^{n} x_i\right)^2} \qquad \ldots\ldots\ldots\ldots 3.2b$$

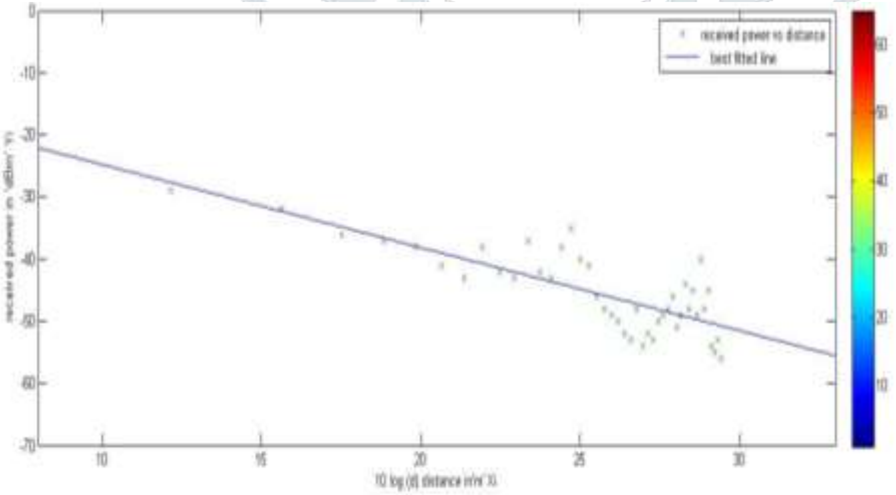

Figure 3: Scatter point's best fit for Airtel network at Dutse

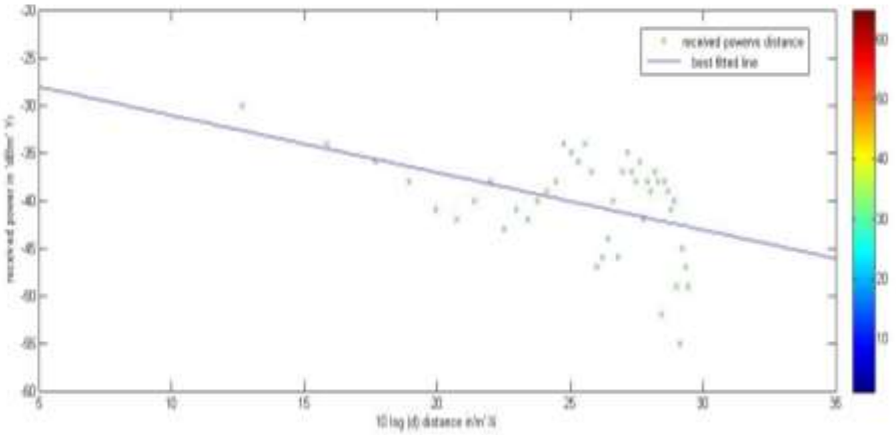

Figure 4: Scatter point's best fit for MTN network at Dutse

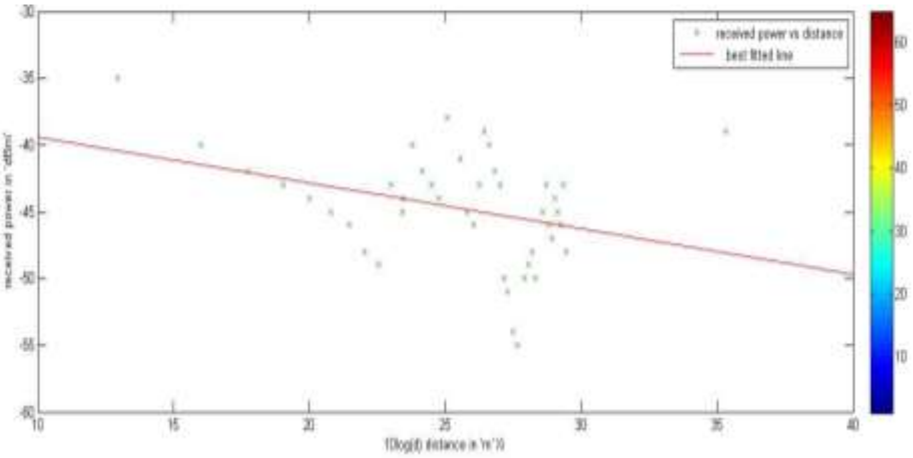

Figure 5: Scatter point's best fit for Airtel network at Kazaure

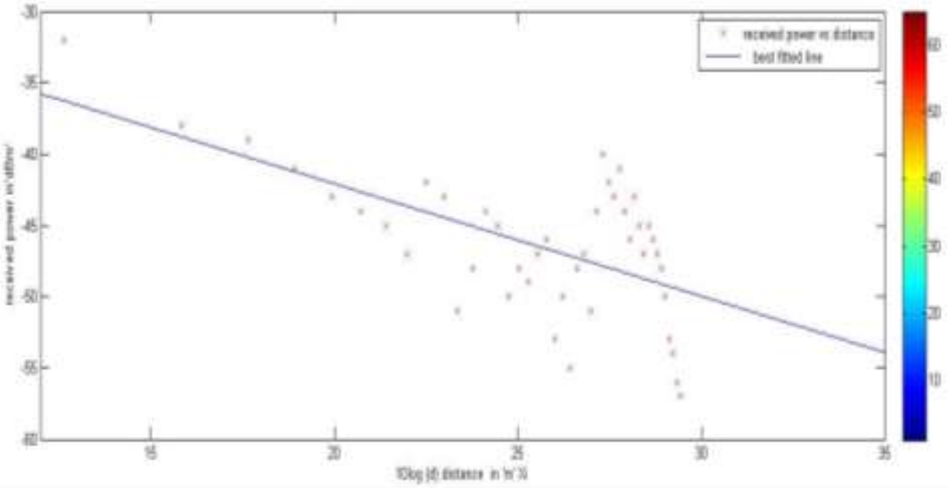

Figure 6: Scatter point's best fit for MTN network at Kazaure

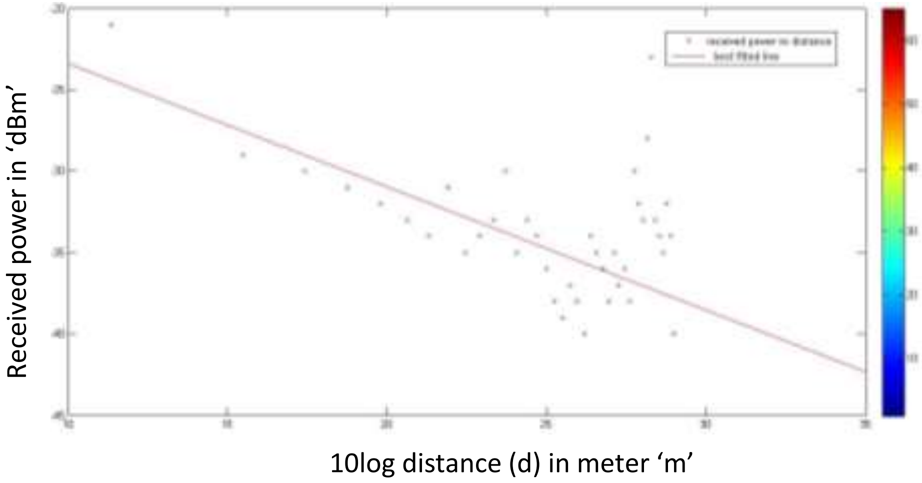

Figure 7: Scatter point best's fit for Airtel network at Hadejia

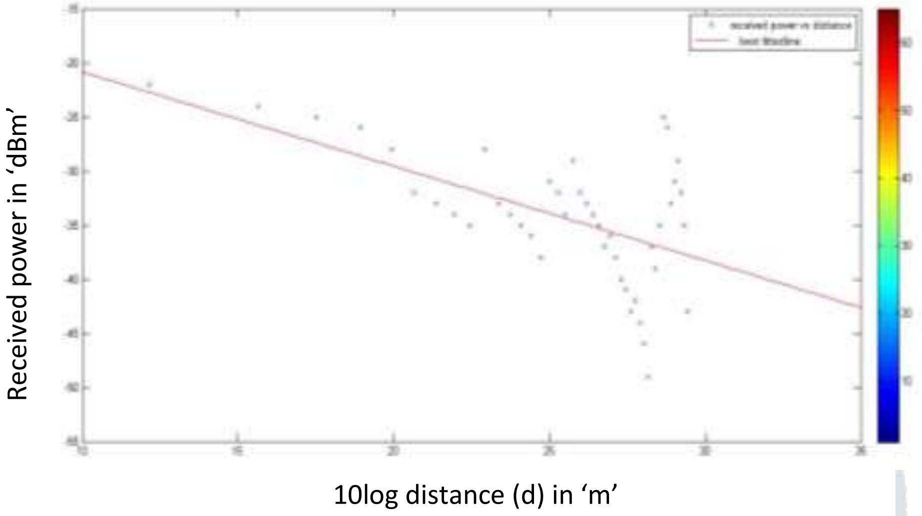

Figure 8: Scatter point's for best fit for MTN network at Hadejia

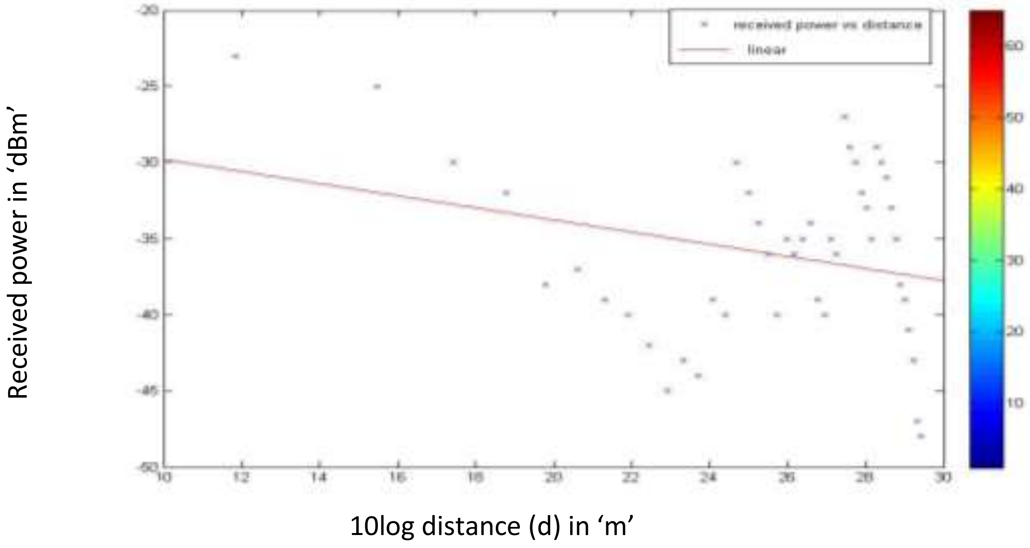

Figure 9: Scatter point of best fit line for Etisalat network Hadejia

Table 2: Summary of results obtained from statistical analysis for path loss exponent and standard deviation.

Locations	**Network Providers**	**Path loss exponent 'n"**	**Standard deviation 'σ' in dB**
Dutse	Airtel	6.8	3.70
Dutse	MTN	5.2	3.74
Kazaure	Airtel	6.8	3.98
Kazaure	MTN	6.7	3.86
Hadejia	Airtel	1.5	4.50
Hadejia	MTN	3.4	3.93
Hadejia	Etisalat	2.8	4.49

VII. Results and Discussion

The results to be discussed were obtained from measurements conducted in buildings (indoor) and outside buildings (outdoor) to compare the signal strength of received power inside building and outside the building for GSM signal strength. The measurements were conducted in five (5) different areas in Jigawa metropolitan city, to compare the signal strength inside building and outside building (i.e. sandcrete buildings/rusty and good zinc roof and mud buildings/rusty and good zinc roof). The measurements were conducted in four different building types, constructed with different building materials in five selected areas; Dutse, Kazaure, Hadejia, Gumel and Ringim respectively. The results are illustrated below:

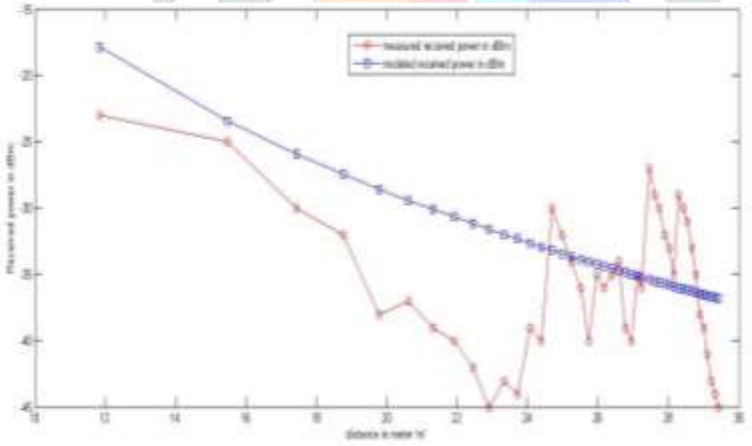

Figure 10: Graph of measured & modelled received power for Etisalat network Hadejia

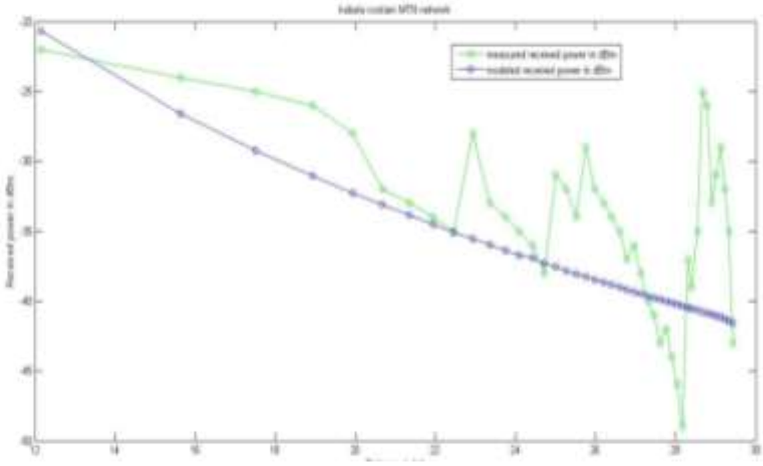

Figure 11: Graph of measured & modelled received power for MTN network at Hadejia

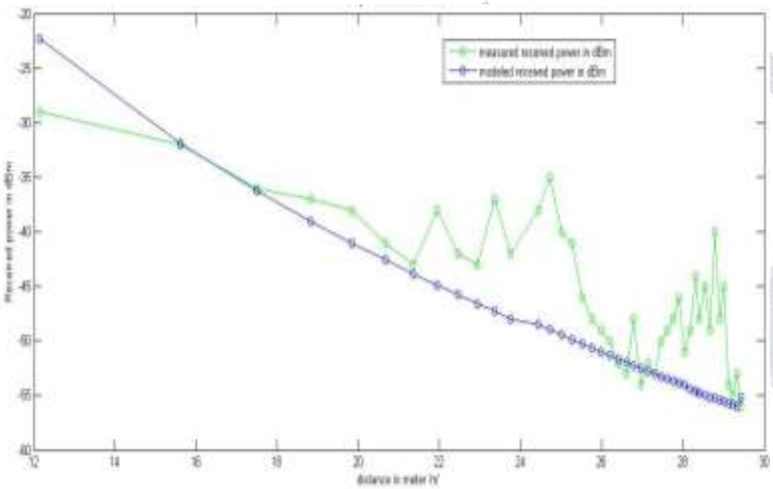

Figure 12: Graph of measured & modelled received power for Airtel network Kazaure

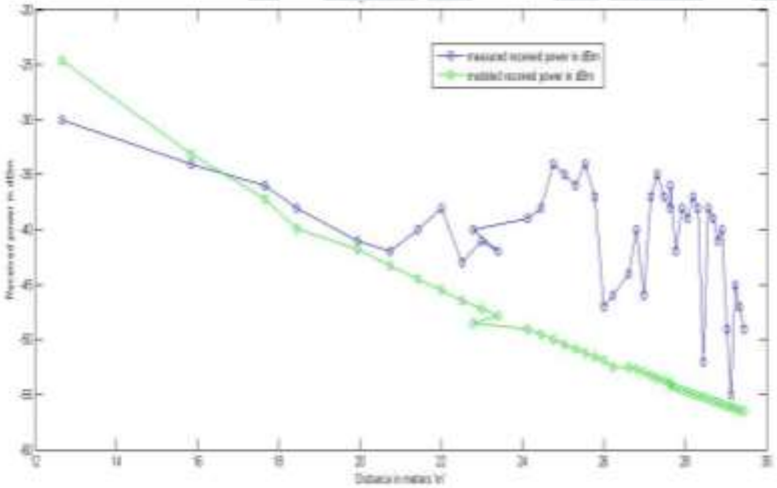

Figure 13: Graph of measured & modelled received power for MTN network Kazaure

Table 3: Comparison between signal strength variations in mud building with rusty zinc roof and other buildings types

Network provider	Sandcrete building with rusty zinc roof in dbm	Sandcrete building with good zinc roof in dbm	Mud building with rusty zinc roof in dbm	Mud building with good zinc roof in dbm
Dutse				
Airtel	-52.84	-47.03	-54.11	-52.99
Mtn	-45.25	-42.34	-48.07	-46.54
Glo	-47.98	-44.97	-53.41	-49.44
Etisalat	-47.67	-41.62	-69.23	-53.65
Kazaure				
Airtel	-47.23	-45.55	-58.34	-50.41
Mtn	-42.61	-41.47	-51.00	-48.92
Glo	-52.01	-50.05	-58.55	-57.69
Etisalat	-48.91	-43.02	-57.44	-54.21
Hadejia				
Airtel	-50.36	-40.62	-52.70	-51.53
Mtn	-49.42	-39.17	-53.72	-52.02
Glo	-47.39	-40.21	-55.89	-50.65
Etisalat	-46.47	-41.07	-69.47	-56.41
Gumel				
Airtel	-47.33	-40.72	-54.37	-50.04
Mtn	-47.57	-37.87	-56.10	-52.42
Glo	-48.08	-39.21	-58.94	-51.33
Etisalat	-50.28	-40.89	-59.66	-54.33
Ringim				
Airtel	-51.57	-49.92	-55.26	-53.41
Mtn	-42.14	-40.57	-53.93	-44.33
Glo	-42.33	-39.44	-47.94	-45.04
Etisalat	-48.88	-47.85	-56.86	-52.52

VIII. Conclusion

In conclusion results obtained showed that among the various combination of building materials considered, mud building/rusty zinc roof accounted higher signal losses of -58.08dBm, followed by mud building/good zinc roof had an average signal losses of -53.63dBm, while sandcrete building/rusty zinc roof presents an average signal losses of -50.32dBm and sandcrete building/good zinc indicate lower signal losses of -45.37dBm. Also for each of the network and environment considered, path loss exponent and standard deviation were determined. Results obtained for each of the network and environment, indicate path loss exponent of between 1.5dB to 6.8dB, also standard deviation indicate value of between 3.70dB to 4.49dB for the network providers and environment considered. Log-normal shadowing model was used and results obtained indicate slight variation with measured results. Based on these results we conclude that among the combination of building materials studied in this research mud building/rusty zinc accounted for higher signal losses while sandcrete building/good zinc roof accounted for lower signal losses for all the network providers considered in this study.

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