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Assessment of Building Penetration Loss of Cellular Network Signals at 900 MHz Frequency Bands in Otuoke, Bayelsa State, Nigeria

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ABSTRACT

Indoor cellular network signal outages and poor reception occur in some indoor locations, as a result of building penetration loss; which accounts for increased attenuation of received signal strength of a cellular network signal when a mobile is moved from outdoor to indoor. Penetration loss is influenced by the type of building materials used in building construction and the building structure/orientation. In this study, the effect of building materials and structures on cellular network signal strength was investigated. A Sony Ericson mobile unit with TEMS software installed in it was used to collect data from two major cellular network service providers in Nigeria. The measurements were carried out outside and inside of four different of buildings types, namely; tiled building with concrete tiled roof, concrete building with corrugated galvanized roof, mud building with rusted corrugated roof and wooden building with rusted corrugated roof in order to ascertain the penetration loss in the selected buildings in Otuoke community of Bayelsa State, Nigeria. The results reviewed that the average penetration loss for the tilled, concrete, mud and the wooden buildings are 13.0 dBm, 10.8 dBm, 9.57 dBm and 8.72 dBm respectively. It was observed that the tiled building with concrete tiled roof has the highest penetration loss in all the months considered, followed by the concrete wall building with corrugated galvanized iron roof, while the wooden wall building with rusted corrugated roof was having the lowest penetration loss. Information from this research will assist cellular network service providers in planning and management of their cellular networks signals in suburban environments having similar building types and pattern. This study will also be helpful to researchers and builders in their selection of building materials especially if good cellular network signal reception is significant.

1.0 Introduction

The deregulation of the telecommunication industry in Nigeria gave birth to the Global System for Mobile Communication (GSM) in August, 2001, which brought great sigh of relief for the Nigeria citizens having been denied access to efficient telecommunication services for quite some time. Since then the telecommunication industry has witnessed phenomenal growth in terms of the number of subscribers [1, 2]. In March 2017, the total number of mobile cellular network subscribers was estimated to be 151,999,197 [3]. It is pertinent to mention that the despite the growth of the telecommunication industry in Nigeria with the springing up of different cellular network service providers such as MTN, Globalcom (Glo), Airtel and Etisalat/9mobile, cellular network is not without problems as it is not an uncommon sight to see a cellular mobile user at some location move from inside to outside of a building in order to have an uninterrupted communication [4].

The mechanism behind electromagnetic wave propagation are diverse but can generally be traced to reflection, diffraction and scattering. Most cellular radio systems operate where there is no line of sight between the mobile receiver and the transmitter and where the presence of tall buildings cause severe diffraction loss.

Due to multiple reflections from various obstacles, the electromagnetic waves propagates along different paths of varying lengths. The interaction between these waves causes multipath fading at a specific location and the strengths of the wave diminishes as the distance between the transmitter and receiver increases [2]. Generally speaking, the three basic mechanisms that attenuate the signal strength of any cellular network system and affect the overall performance of the cellular network signal inside a building are:

- Reflection,
- Diffraction and
- Scattering

Reflection arises when a propagating electromagnetic wave impinges upon an object which is very large in dimensions when compared to the wavelength of the propagating wave, for example; the earth surface, buildings, walls, etc. This mechanism often dominates radio propagation in indoor application. In outdoor propagation, this mechanism often loses its importance because it involves multiple transmissions that lessen the signal strength to negligible values. Diffraction can occur when the radio path between the transmitter (Tx) and the mobile receiver (Rx) are obstructed by a surface that has irregularities (edges).

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At high frequencies, diffraction, like reflection depends on the geometry of the object, as well as the phase, polarization, and amplitude of the incoming wave at the point of diffraction. Scattering occurs when the medium through which the wave propagates comprises objects with dimensions that are small compared to the wavelength and where the where the obstacles per volume number is large. Scattered waves are produced by rough/irregular surfaces, small objects or by other anomalies in the channel. The combine effects of reflection, diffraction and scattering causes multipath fading which occur when the transmitted signal arrives at the mobile receiver end in more than one paths. The multipath signal components combine at the receiver to form a distorted version of the transmitted waveform. The multipath components can be combined constructively or destructively depending on the phase variations of the components signals.

The destructive combination of the multipath components can results in a severely attenuated received signal [2].

In outdoor-to-indoor propagation building penetration losses can be seen as the additional losses that radio signal suffers as it propagates from outdoor to indoor environment. Propagation in indoor environments somewhat have more complicated multipath structure than that of the outdoor environments; which is largely due to the nature of the building structures, the room arrangement and the type of materials used in the construction of the building [5]. An important requirement for mobile radio systems is the provision of dependable services to the increasing number of users across outdoor to indoor interface. There are numerus factors that affect radio wave propagation which result in the degradation of signals, these factors include but not limited to the following:

- Multipath fading effect
- Height
- Transmission frequency
- building structure and internal layout
- Non-line-of- sight
- Path loss
- Building penetration loss
- Type of materials used in construction of the furniture in the building, among others.

These may be possible factors that cause variation in cellular network signal strength received in these buildings under study [6]. Physical surroundings can also possibly be among these factors that cause the variation; because within any building the signal strength may be affected, since radio frequency (RF) waves may travel into the building directly from transmitting antenna. Once inside a building, the field encounters a wide array of objects which shield, absorb or reflects the RF signal or cause losses to it. Penetration losses are generally higher in urban environment and it is a function of the building materials/structures [6]. Other factors that also lead to variation of cellular network signal strength are the dimension of the windows area, direct incident wave arrival and the absorption of moisture (water) by building materials [7]. In this research, cellular network signal strength of two cellular network service providers (MTN and Glo) in Nigeria that are transmitting at 900 MHz frequency band was monitored as the mobile is moved from outside to inside of four different buildings with different building structures and materials in Otuoke community of Bayelsa State, Nigeria, in order to ascertain their penetration loss.

The major driving force for this research work, is the need to establish average GSM building penetration losses for four building types that are predominant in the studied environment, the results of this research will aid GSM service providers in future specific-site planning in the studied environment.

This paper is structured as follows: Section 2 presents the experimental sites, materials and research method. Penetration loss calculation method is described in section 3. Result presentation and discussion are presented in section 4 and the conclusion is summarized in section 5.

2.0 Experimental Sites and Methodology

This research work was carried out at Otuoke, a typical suburban environment in Ogbia Local Government Area of Bayelsa State in the Niger Delta region of Nigeria, which has a population of about twenty five thousand people; the environment is partly surrounded by running water and vegetation of averagely trees. About 60% of the area is filled with buildings built of concrete blocks, tiled, bricks, wood and mud which have estimated building heights of 3-10 m. In Figure 1 the Goggle Earth map describing the geographical description of Otuoke is shown.

Figure 1. Google Earth Map of Test Bed, Otuoke Environment, Beyelsa State, Nigeria.

The measurement campaign described in this study was carried out in four different buildings in Otuoke, comprising of different construction materials and layouts. The buildings investigated were tilled building with concrete tilled roof, concrete building with unrusted corrugated iron roof, mud building with rusted corrugated roof and wooden building with rusted corrugated roof, which represent the prevalent building types within the studied area.

Table 1. Details of Base Stations and Environmental Characteristics.

Opt	Cell ID	Location	ET	C/(Lt^{0}N/Lg^{0}E)	Freq. (MHz)	AH (m)	AT	Elevation (m)
MTN	BY3035	Otuoke	Sub urban	4.7850/6.3093	900	34	Sectoral	9.0
Glo	BY4569	Otuoke	Sub urban	4.7754/6.3191	900	34	Sectoral	9.0

Table 2. Building Description and Characteristics.

BT	BH (m)	RT	WT (cm)	SV	SBD	BD (m)	NWR	NDR
BPT	5.0	CT	22.0	Average	Sparse	20.2×11×5	2/sliding (glass)	2/steel pan
C	4.0	CGI	18.0	Sparse	High	15.0×8×4	2/casement (glass)	2/steel pan, 1/wooden
Mud	2.6	RCGI	16.0	Sparse	Average	10×3×2.6	1/casement (wooden)	1/wooden
Wooden	2.4	RCGI	12.0	Average	Average	12×3×2.4	2/1/casement (wooden)	1/wooden

The measurement set up was designed to measure the outdoor and indoor received signal strength as the mobile is moved from outside to inside of the buildings. Table 1 shows details of the base stations investigated and the environmental characteristics; while Table 2 shows the description of each of the investigated buildings and the building views are shown in Figure 2 to 5.

Acronyms Used in the Table

- Opt: Operator
- ET: Environment type
- C/(Lt^{0}N/Lg^{0}E): Coordinate (Latitude ^{0}N/Longitude ^{0}E)
- AH: Antenna height
- AT: Antenna Type
- BT: Building type
- BH: Building height
- RT: Roof type
- WT: Wall Thickness
- SV: Surrounding vegetation
- SBD: Surrounding building density
- BD: Building Dimension
- NWR: Number of window in room/type
- NDR: Number of door in room/type
- BPT: Block with plastered tiles
- CT: Concrete tiled
- C: Concrete
- CGI: Corrugated galvanized iron

RCGI: Rusted corrugated galvanized iron

Figure 2.Wooden Building with Rusted Corrugated Roof.

Figure 3. Concrete Building with Unrusted Corrugated Iron Roof.

Figure 4. Tiled Building with Concrete Tiled Roof.

Figure 5. Mud Building with Rusted Corrugated Roof.

2.1 Description of Measurement Tools

The tools used for the collection of data are:

- A Laptop with TEMS software installed in it.
- TEMS Phone (Sony Ericson)
- Global Position System

The TEMS investigation handset and software version 11.01 were used to collect data of the measured signal. The handset was used with precaution as it is known to have a typical accuracy of $\pm$2.0dBm. The calibrated power is between -115.0 to -45.0dBm. The device used was Sony Ericson TEMS handset given time to settle on a particular range of values. The readouts were made on software in predefined format. A geographical positioning system (GPS) receiver was connected to a laptop with TEMS software installed, this setup as shown in Fig. 6 was used to measure the distance of each building from the Base Station (BTS) belonging to the network providers of MTN and Glo. Other field parameters acquired for this measurement setup are; Logical Channel with information on BTS, Cell Identity Code, Traffic Channel, Timeslot Number, Cell Identity, Longitude, Latitude, Altitude and Neighbor List. The Sony Ericson phone with TEMS 11.0.1 installed in it was used to measure the received signal strength (RSS) of cellular network signals of the two service operators monitored.

2.2 Measurement Procedure

The complete process of data collection via TEMS 11.01 or any other advanced version is not a simplistic task. It involves setting up of GPS and TEMS supported handset for the purpose of data measurement. The first step is to fully charge the laptop to ensure non- interrupted battery charge up during the collection of data. Secondly, a GPS device was connected to the laptop via- 2.0 interface and GPS device was placed on the laptops. Next the TEMS enabled handset was connected via USB 2.0. The Sony Ericson transmission evaluation and monitoring system (TEMS) handset with sim card of MTN and Glo respectively was used to initiate calls from each of the Base Station to the various buildings under study to get the distance to the buildings. In each of the site, signal strength measurements were conducted outside and inside the buildings by moving the mobile TEMS phone from outside to inside the buildings and the received signal strength recorded at each point for each cellular network service provider. The measurements were conducted for a period of twenty seven weeks between the months of April to October in 2017. As started earlier, two existing cellular network operators belonging to MTN and Glo services were used for the investigation, the sites were visited on daily basis between the hours of 7am to 12 noon and 3 pm to 9 pm to ensure every section of the day is included. Measurements were made and recorded at six evenly spaced points along the front wall of each site, both inside and outside the buildings.

Measurements were taken inside the buildings with all windows and doors closed.

Figures 7 and 8 show the pictorial diagram of TEMS phone used for data collection and block diagram of the set up for field experiment.

Figure 6. Set up for Data Collection.

Figure 7. Sony Ericson Mobile Unit with TEMS Software.

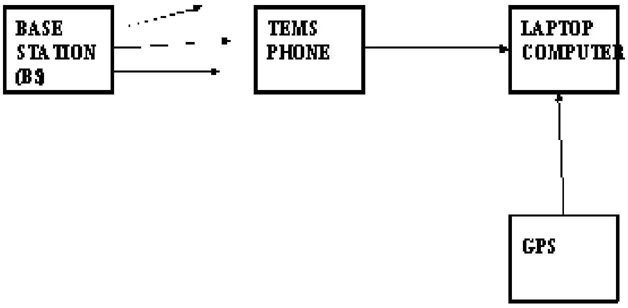

Figure 8. The Block Diagram Representing the Setup of the Field Experiment.

3.0 Penetration Loss Calculation

The building penetration loss (BPL) was estimated using;

$$PBL(dBm) = RSS_{in}(dBm)\text{-}RSS_{out}(dBm) \quad (1)$$

The average building penetration loss (ABL) for a particular building was calculated using [6].

$$\boldsymbol{ABPL\ (dBm) = mean\ RSS_{in}(dBm) - mean\ RSS_{out}(dBm)} \quad (2)$$

Where $\boldsymbol{RSS_{in}}$ is the received signal strength inside the building; $\boldsymbol{RSS_{out}}$ is the received signal strength outside the buildings.

4.0 Results and Discussion

Table 3 shows the average distance in meters measured from the BTS of the respectively cellular network service providers to the buildings investigated.

Table 3. Average Distance from the BTS to the Buildings.

Network Service	Tiled Building	Concrete Building	Mud Building	Wooden Building
MTN	310 m	160 m	740 m	220 m
Glo	520 m	190 m	350 m	100 m

The results of the measured received signal strength for outdoor and indoor propagation and the building penetration losses are tabulated in Table 4 to 7.

Table 4. Measured Signal Strength for the Tiled Building.

Month	Measured Monthly Signal Strength (dBm)					
	MTN at 310 m			Glo at 520 m		
	Outdoor	Indoor	BPL	Outdoor	Indoor	BPL
April	-70	-81	11	-64	-75	11
May	-71	-84	13	-66	-79	13
June	-77	-90	13	-74	-86	12
July	-75	-89	14	-66	-79	13
August	-77	-91	14	-65	-78	13
September	-85	-100	15	-66	-81	15
October	-77	-90	12	-72	-84	12
Average	-76.0	-87.5	13.30	-66.42	-77.8	12.71

Table 5. Measured Signal Strength for the Concrete Building.

Days	Measured monthly signal strength (dBm)					
	MTN at 160m			GLO at 190m		
	Outdoor	Indoor	BPL	Outdoor	Indoor	BPL
April	-70	-79	9	-60	-69	9
May	-76	-85	11	-64	-73	9
June	-79	-89	10	-73	-83	10
July	-66	-78	12	-64	-76	12
August	-64	-75	11	-60	-71	11
September	-79	-91	12	-78	-89	11
October	-71	-84	13	-75	-85	10
Average	-72.3	-82.9	11.4	-65.7	-76.4	10.2

Table 6. Measured Signal Strength for the Mud Building.

Month	Measured monthly signal strength (dBm)					
	MTN at 740m			GLO at 350m		
	Outdoor	Indoor	BPL	Outdoor	Indoor	BPL
April	-73	-80	7	-68	-77	9
May	-78	-87	9	-67	-77	10
June	-83	-92	9	-80	-89	9
July	-75	-87	12	-77	-86	9
August	-77	-88	11	-71	-80	9
September	-79	-90	11	-86	-98	11
October	-79	-89	10	-71	-80	8
Average	-77.9	-88.3	9.86	-69.7	-79.9	9.3

Table 7. Measured Signal Strength for the Wooden Building.

Month	Measured monthly signal strength (dBm)					
	MTN at 220m			GLO at 100m		
	Outdoor	Indoor	BPL	Outdoor	Indoor	BPL
April	-72	-79	7	-72	-79	7
May	-69	-79	10	-75	-85	10
June	-71	-80	9	-80	-88	8
July	-71	-80	9	-75	-83	8
August	-69	-79	10	-73	-83	10
September	-75	-85	10	-78	-89	11
October	-61	-68	7	-79	-88	8
Average	-66.9	-75.9	8.86	-76.6	-86	8.6

Table 8. Average Building Penetration Loss.

Building Type	Average Building Penetration Loss (dBm)		Mean Average Penetration Loss (dBm)
	MTN	GLO	
Tiled	13.30	12.71	13.0
Concrete	11.4	10.2	10.8
Mud	9.86	9.3	9.57
Wooden	8.86	8.60	8.72

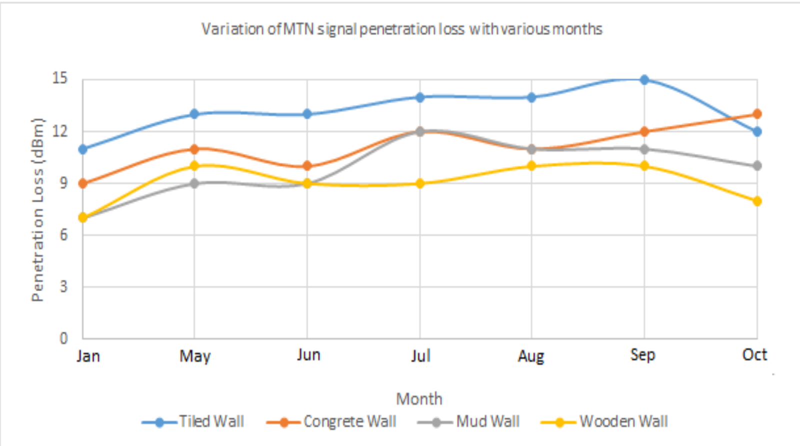

Figure 9. Variation of MTN signal penetration losses in different buildings with various months.

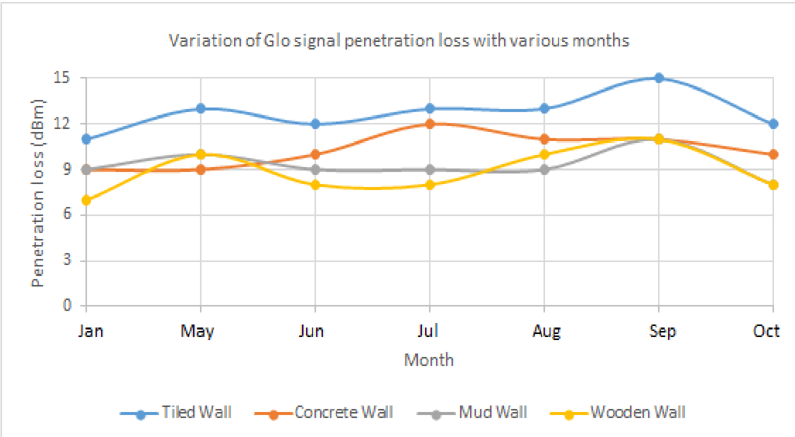

Figure 10. Variation of Glo signal penetration losses in different buildings with various months.

Figures 9 and 10 show the variation of penetration losses of the different building types with different months considered for the two service providers. In all the months considered, the month of September has the highest penetration loss of about 15dBm for both network provider followed by the month of July with around 12 dBm with the month of April and October having the lowest penetration between 7 to 10dBm. The tiled wall building showed the highest penetration loss in all the months for both network, followed by concrete wall building, the mud and wooden walls have relatively lower penetration losses across the various months when compared with tiled and concrete walls. Some of the reasons for the variation in signal penetration loses for the different buildings are discussed below.

4.1 The Impact of Building Materials

The field distribution inside a building is dependent on specific features of its structure which includes; layout and construction materials [9]. Typically, different electrical, physical and chemical properties of building construction materials causes variation of signal strength received in these buildings. The tiled building is observed to have the greatest loss of 13.0 dBm followed by the concrete building with average penetration loss of 10.8 dBm which is as a result of the compactness of the buildings. The tiled wall is an aesthetic material that reflects the propagating electromagnetic waves therefore reducing the signal strength, also the embedded steel rods in both the tiled and concrete buildings being conductors tends to reflect the incident electromagnetic waves, thereby reducing the forward energy that succeeded in penetrating through the wall. In addition, the glass windows of the concrete building is known as one-way transparent glass which has a good visibility from the inside to the outside but a poor visibility from the outside to inside, this one-way transparent glass is with a thin metal coating, so it reflects the electromagnetic wave therefore causing loss.

4.2 Absorption of Moisture by Building Materials

It is generally reported that under water absorption the relative permittivity of building materials increases, resulting in increased losses when compared with the dry case [10]. This research work was carried out in rainy season and some of these months are known to have high amount of rainfall. It was observed that there was high building penetration loss when measurements were conducted on the days it rained. The worst case was that of the plank building, it was observed to have the highest losses during the raining days; this is due to the fact that plank absorbs water more than the other building types and this building is also known to have the least loss during the dry days. This can be accounted for the fact that penetration loss increases with increased humidity; which inferentially means that penetration loss is proportional to humidity.

4.3 Direction of Incident Wave Arrival

There were slight differences in the direction of incident wave arrival for the MTN and Glo in all the buildings under study. This may be due to the fact that the waves originate from different base stations at different locations as they must have entered the buildings from different directions. Obviously, the direction of incident wave affects penetration loss [4].

5.0 Conclusion

This study documents a measurement campaign designed to determine the building penetration loss of cellular network signals at 900MHz in Otuoke community, Ogbia Local Government Area of Bayelsa State in the Niger Delta region of Nigeria. The building penetration loss which is one of the critical parameters in personal telecommunication systems design has been evaluated for four different building types. The results obtained showed that the tilled building with concrete tilled roof accounted for the highest signal loss of 13.0dBm, followed by the concrete building with unrusted corrugated iron roof having an average signal loss of 10.8dBm, while the building with mud walls was having an average loss of 9.57dBm. Lastly, is the wooden building having the lowest average signal loss of 8.72 dBm. The concrete and mud building average signal loss values were in conformity with the results from studies of similar building structures and types [4,6].

The novelty of this study is on the determination of the building penetration loss in tiled and wooden walls building; because to the best of our knowledge from existing literature this is one of the most recent studies carried out on these kinds of buildings. The transmission conditions, dimension of building, impact of building materials and furniture, absorption of moisture by building materials and direction of incident wave have shown significant influences on the power levels inside these buildings. This study has shown that building penetration loss of any cellular network signal is a function of building walls. It is therefore recommended that researchers, builders and telecommunication engineers should use the results from this study for planning and management purposes.

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