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Indoor Propagation Modelling in Brick, Zinc and Wood Buildings in Ekpoma

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Abstract: This study investigated network coverage level, path loss exponents and propagation path loss characteristics for some building materials. Measurement of signal strength for three different building types; namely wood, zinc and block with their associated referenced global location were carried out. From the measured values, models were developed to predict the power-received level of G.S.M signal from prevalent network providers (MTN, GLO and CELTEL Nigeria) for both outdoor and indoor environment using Ekpoma and its environs as a case study. Results obtained using the developed models were compared with the measured values and existing ones. From analysis, it was observed that results gotten from the developed models predicted approximate values to the measured values using network monitor.

Key words: GSM signal, attenuation and path loss exponent, modeling, indoor propagation, Nigeria

INTRODUCTION

Interest in the field of signal reception in building has dramatically increased due to the introduction and technological improvement of a variety of indoor wireless and personal communication system. The rapid worldwide growth in cellular telephone subscriber has demonstrated conclusively that wireless communication is a robust, viable voice and data transport mechanism (Rappaport, 2003). The global system for mobile communication GSM was originally developed to serve as the pan-European cellular service and promised a wide range of network service (Monly and Pantel, 1992). Presently, GSM success has exceeded beyond the expectation of virtually everyone and it's now the world's most popular standard for new cellular radio and personal communication equipment throughout the world with over 1.56 billion subscriber worldwide including our own country Nigeria as at 2005 (The Global Mobile Suppliers Association (GSA) www.emediawire.com).

Evidently several thousands of remotely distributed Base Transceiver Station (BTS), operating in the 890-915 MHz (Up link) and 935-960 MHz (Down link) frequency band have cluttered up our cities in an attempt to provide wider network coverage (Ramo *et al*., 1965).

It is not uncommon to hear some subscribers complain of poor signal reception in some parts of their rooms, homes and offices under strong network coverage of our G.S.M network providers (Bullington, 1947).

The major driving force for this research is the limitation of the knowledge in the field of G.S.M signal attenuation as they penetrate through different buildings within the coverage area of a network provider with view of providing answers to why signal strength is high in some rooms, houses or offices and low in others (Cox *et al*., 1983).

This research will provide a better insight into GSM signal propagation in an indoor environment. It is intended to provide answer to this question from the perspective of the constituent materials that make up the buildings in the studied area.

Scope of study: The overall scope of this research work is aimed at the followings:

- Examine previous literature and conduct research in the field of signal penetration in buildings.
- Development of a mathematical model that can be used to calculate the attenuation factor of various construction materials that constitute our architectural structures.
- Conduct indoor measurement of signal strength within the coverage area of a choice network provider to prove the validity of the mathematical model developed.
- Analysis of the factor of deviation of the result obtained from both the mathematical model and true measurement.

MATERIALS AND METHODS

Measurement, calculation and model analysis of signal levels in different buildings are presented in this study. The buildings include Brick, Zinc and wood.

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Signals from three service providers were measured. The service providers and their operating frequencies are shown in Table 1.

For this purpose, the 900MHz frequency band was considered for the service providers listed in Table 1.

The approach taken here was to measure electric and magnetic field strengths of existing GSM signals, both outside (outdoor) and inside (indoor) of a building, thus defining building attenuation as a ratio of the external fields to the fields inside, expressed in decibel-Meter (dBm) (Bernhardt, 1987). The buildings considered as well as their description and geographical locations are given in Table 2.

Test equipment: The net-monitor software is employed in this study in conjunction with two separate NOKIA 6210 MOBILE PHONES. The mobile phone is used to detect the signal for the mobile network while the software determines the power reception level RXL in dBm and the base station parameters serving the test location.

Model generated for the building types: From the results of indoor and outdoor measurements, it is evident that the signal strength indoor is lower than that of outdoor environment

Table 1: Service providers and their frequency bands

Network provider	Frequency band 900MHz	1800MHz
GLO	Down link (945-950) Up link (900-905)	1820-1850
MTN	Down link (950-955) Up link (905-910)	1835-1850
CELTEL	Down link (955-960) Up link (910-915)	1850-1865

We denoted these differences as Y_A, Y_B and Y_C

The statistical mean of these values were obtained as;

Y_A = 9.0 dBm

Y_B = 10.67 dBm

Y_C = 7.33 dBm

Where, Y_A, Y_B and Y_C are the Building types A, B and C attenuation factors respectively.

Hence indoor models for these building types are therefore given as;

$$P_L(\text{dBm}) = P_L(d_0) + 10\omega\log\left(\frac{d_i}{d_0}\right) + Y_A \quad (1)$$

$$P_L(\text{dBm}) = P_L(d_0) + 10\omega\log\left(\frac{d_i}{d_0}\right) + Y_B \quad (2)$$

$$P_L(\text{dBm}) = P_L(d_0) + 10\omega\log\left(\frac{d_i}{d_0}\right) + Y_C \quad (3)$$

$$\omega = xn \quad (4)$$

Where, x is the path loss characteristic obtained as shown in Table 3.

But for outdoor model, we have

$$Pl(\text{dB}) = Pl(d_0) + X10n\log(\frac{d_i}{d_o}) \quad (5)$$

Where, $X = C_{(i-1)}$ for i = 1,2,3,4,5…Km

Table 2: Description of building

Building symbol	Material type	GPS/location	Description
A_1	Brick	N 06^0 44.516^1 E 006^0 08.332^1 Mary the Queen social center market square	Brick walls, Aluminum roof with insulating ceiling room size of (14×14) m with few wooden furniture's
A_2	Brick	N 06^0 45.529^1 E 006^0 08.165^1 Mount Camel group of school Emuado Ekpoma	Brick walls, three storied building measurement was carried out on the ground floor room size of about (24x16) m with out any furniture
B_1	Zinc	N 06^0 44.199^1 E 006^0 04.667^1 NDDC hostel site AAU maim campus	The roof, walls and door made of corrugated iron sheet (zinc). The room is empty and it is (6×8) m without ceiling and windows.
B_2	Zinc	N 06^0 44.38^1 E 006^0 04.991^1 Administration block site AAU main campus	The roof, walls and door are made of zinc with few working tools. The size of the room is about (10×10) m
C_1	Wood	N 06^0 44.387^1 E 006^0 04.673^1 Student village, AAU, main campus	Zinc roof with insulating ceiling wooden walls windows and door. The size of eth room is (10×10) m and stuffed with few office equipment
C_2	Wood	N 06^0 45.014^1 E 006^0 05.222^1 Poultry road Ujemen Ekpoma	Zinc roof, wooden walls, windows and door. Room size of about (10×10) m virtually empty
C_3	Wood	N 06^0 45.529^1 E 006^0 08.165^1 Security division AAU campus	Zinc roof with insulating ceiling wall, doors and windows made of wood. The room size is about (14×12) m with few wooden furniture

$$C_0 = \text{modeled loss constant} = \frac{\text{Average power measured}}{\text{Power calculated}} \quad (6)$$

Therefore, C_0 = 54.8/40.1 = 1.37 (first modeled loss constant) (Table 3).

Table 3: Comparison between the theoretical R×L in (dBm) and the computed mean R×L in (dBm) for outdoor

Distance 'd' (Km)	Theoretical R×L (dBm)	n	Measured mean R×L(dBm)	W
1	-40.1	4	-54.8	5.48
2	-52.1	4	-64.7	4.98
3	-59.2	4	-70.3	4.57
4	-64.2	4	-73.1	4.44
5	-68.0	4	-75.4	-
6	-71.2	4	-	4.25
7	-73.9	4	-	78.6

Note: n→Theoretical path loss exponent, w → Measured path loss exponent

Table 4: Comparison between measured Mean R×L (in dBm) and modeled Mean R×L (in dBm) for indoor of building type 'A'

Distance (km)	Measured mean R×L (dBm)	Modeled mean R×L (dBm)
1	-64.0	-63.8
2	-74.0	-74.1
4	-82.0	-82.8
5	-85.0	-85.1

Table 5: Comparison of measured mean R×L and modeled R×L for indoor of building type 'B'

Distance (km)	Measured mean R×L (dBm)	Modeled mean R×L (dBm)
1	-66.0	-66.4
2	-76.0	-76.6
3	-82.0	-82.5
7	-90.0	-91.5

Table 6: Comparison of measured mean R×L and modeled R×L for indoor of building type 'C'

Distance (km)	Measured mean R×L (dBm)	Modeled mean R×L (dBm)
1	-62.0	-62.3
2	-72.0	-72.5
3	-78.0	-78.4
4	-81.0	-81.2
7	-86.0	-87.4

$$C_i = (C_{i-1}) \log d_i / \log d(i-1) \quad (7)$$

Were C_i is the loss constant at every distance d_i

Table 4-6 present a comparison of computation from our generated models, measurement and calculations obtained using Log-Distance Path Loss Model (Rice *et al.*, 1967):

$$PL(dB) = 10\log {}^{pt}\!/_{pr} = -10\log\left[\frac{\lambda^2}{(4\lambda)^2 d^2}\right] \quad (8)$$

RESULTS AND DISCUSSION

The combined path loss (ω) and its' location variability for different environments as shown in Table 3 suggest the following:

- That the path loss decreases as one moves away form the base station i.e decreases with increase transmitter-receiver separation distances.
- That the path loss value is between 5.48 and 4.25. The average value of path loss constant for Ekpoma is 4.865 for Network A, (MTN Network).
- That this path loss value is close and within this range for the other Networks. Hence the model although derived from the readings obtained from network A is valid for the other networks i.e Network B and C, which suggest similarities in the human made structure, multiple-path fading and the topology of the environment. This factor has been given in Eq. 4.

On power received: It is evident from Table 7-9 that the power reception level varies with distances. And also varies with the Network provider as shown in Fig. 1.

Also from Table 7-12, it can be seen that the signal reception level outside a building is stronger than the

Table 7: Measured outdoor received power over given distances for network a (MTN network)

			Mean R×L at given Distance In dBm						
Network type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
Network A	August 5th-26th	9:05-10:35	-47-58	-54-74	-64-80	-64-81	-54-79	-	-68-88
		8:40-9:20	-49-67	-48-70	-66-82	-67-80	-64-84	-	-78-86
		10:50-11:20	-51-63	-52-72	-58-79	-62-82	-71-85	-	-71-86
		11:20-11:55	-52-60	-54-74	-58-80	-60-81	-70-76	-	-80-91
	September 2nd-30th	9:15-9:35	-55-68	-58-78	-62-78	-68-80	-72-84	-	-82-95
		11:10-11:40	-53-67	-63-83	-64-80	-68-83	-76-89	-	-82-91
		9:00-9:25	-47-58	-55-79	-68-79	-70-90	-75-94	-	-80-92
		8:40-9:10	-52-61	-50-79	-65-82	-64-88	-68-86	-	-70-89
		11:00-11:30	-47-59	-54-70	-59-73	-63-88	-65-74	-	-68-80
		10:00-11:40	-44-60	-46-68	-55-72	-62-84	-68-78	-	-68-82
		9:30-10:10	-45-63	-56-78	-63-77	-59-78	-79-98	-	-62-78
		8:05-8:25	-50-63	-66-84	-66-79	-59-73	-66-73	-	-62-82
		10:05-10:30	-45-62	-49-67	-60-78	-57-80	-58-76	-	-64-83
		Mean R×L	-55.0	-65.0	-70.0	-73.0	-75.0	-	-79.0

Table 8: Measured outdoor received power over given distance for network b (GLO network)

			Mean R×L at given Distance In dBm						
Network type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
	August 5th-26th	9:05-10:35	-41-61	-49-74	-53-76	-55-81	-	-	-
		8:40-9:20	-46-62	-50-71	-54-84	-57-88	-	-	-
		10:50-11:20	-50-65	-53-75	-61-82	-60-86	-	-	-
		11:20-11:55	-56-66	-55-80	-65-88	-62-77	-	-	-
Network B	September 2nd-30th	9:15-9:35	-58-68	-60-81	-68-86	-65-91	-	-	-
		11:10-11:40	-54-62	-57-80	-64-84	-62-88	-	-	-
		9:00-9:25	-50-65	-56-76	-58-87	-59-84	-	-	-
		8:40-9:10	-48-65	-54-79	-5782	-56-74	-	-	-
		11:00-11:30	-41-63	-51-78	-56-87	-58-87	-	-	-
		10:00-11:40	-43-67	-53-79	-63-86	-64-90	-	-	-
		9:30-10:10	-53-68	-51-75	-59-85	-63-80	-	-	-
		8:05-8:25	-47-62	-52-76	-56-80	-55-78	-	-	-
		10:05-10:30	-43-60	-50-73	-53-76	-60-86	-	-	-
		Mean R×L	-54.0	-65.0	-70.0	-72.0	-	-	-

Table 9: Measured outdoor received power over given distances for network C (Celtel network)

			Mean R×L at given Distance In dBm						
Network type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
Network C	August 5th-26th	9:05-10:35	-43-65	-52-77	-	-60-86	-	-	-60-80
		8:40-9:20	-49-66	-59-79	-	-62-88	-	-	-62-85
		10:50-11:20	-55-70	-54-78	-	-60-95	-	-	-65-89
		11:20-11:55	-43-60	-50-71	-	-60-86	-	-	-70-93
	September 2nd-30th	9:15-9:35	-47-62	-53-75	-	-62-88	-	-	-73-100
		11:10-11:40	-56-66	-50-73	-	-59-84	-	-	-68-95
		9:00-9:25	-53-68	-60-81	-	-62-77	-	-	-66-84
		8:40-9:10	-43-67	-57-80	-	-64-90	-	-	-65-97
		11:00-11:30	-50-65	-52-76	-	-60-86	-	-	-62-84
		10:00-11:40	-41-63	-54-79	-	-56-74	-	-	-63-86
		9:30-10:10	-58-68	-51-78	-	-58-81	-	-	-64-95
		8:05-8:25	-48-65	-53-79	-	-55-78	-	-	-61-91
		10:05-10:30	-54-62	-55-80	-	-63-80	-	-	-62-93
		Mean R×L	-57.0	-66.0	-	-72.0	-	-	-78.0

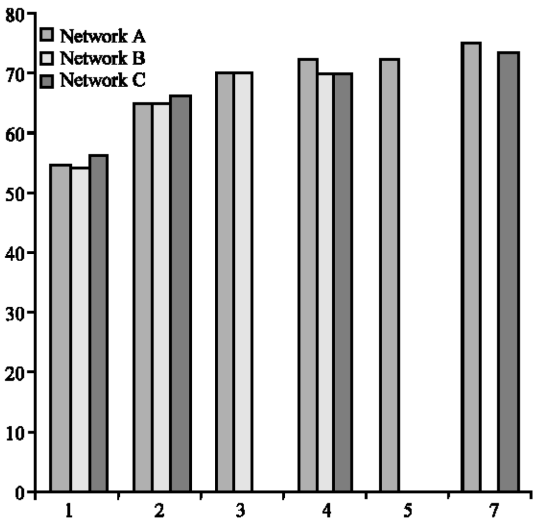

Fig. 1: Outdoor power reception for network A,B and C over given distances

reception level inside a building. The deference is given by attenuation constant Y in Eq. 1-3 which gives the variation of the power reception level with different buildings. This relationship showed in Fig. 2.

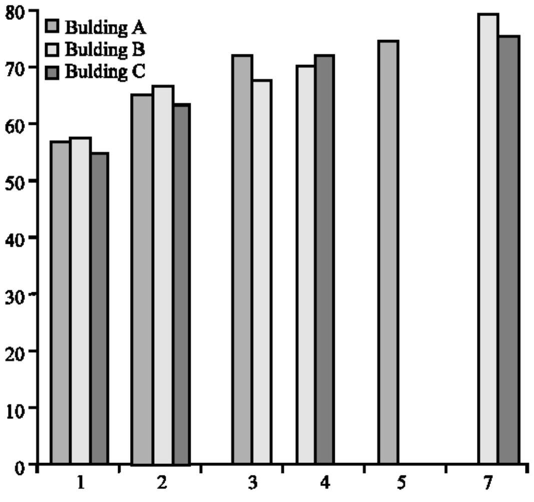

Fig. 2: Indoor power reception for bulding type A,B and C over given distances

Figure 3 shows that the attenuation factor increases in the other of building C-building A-building B.

Table 10: Measured indoor received power over given distances for building A

			Mean R×L at given Distance In dBm						
Building type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
Building A	August 5th-26th	1km	2km	3km	4km	5km	6km	7km	
		9:05-10:35	-56to-72	-58to-88	-	-64to-97	-69to-99	-	-
		8:40-9:20	-58to-67	-61to-90	-	-67to-100	-68to-97	-	-
		10:50-11:20	-61to-70	-60to-85	-	-69to-95	-74to-100	-	-
		11:20-11:55	-57to-71	-63to-87	-	-72to-94	-71to-94	-	-
	September 2nd-30th	9:15-9:35	-54to-77	-65to-83	-	-70to-92	-75to-93	-	-
		11:10-11:40	-51to-74	-64to-87	-	-68to-96	-68to-101	-	-
		9:00-9:25	-52to-76	-61to-89	-	-66to-99	-69to-100	-	-
		8:40-9:10	-54to-71	-59to-84	-	-67to-97	-67to-96	-	-
		11:00-11:30	-57to-68	-63to-87	-	-65to-95	-72to-92	-	-
		10:00-11:40	-60to-74	-60to-88	-	-69to-98	-76to-99	-	-
		9:30-10:10	-58to-67	-61to-85	-	-71to-93	-73to-95	-	-
		8:05-8:25	-52to-76	-54to-90	-	-66to-96	-69to-98	-	-
		10:05-10:30	-61to-70	-64to-84	-	-68to-98	-70to-99	-	-
		Mean R ×L	-64.0	-74.0	-	-82.0	-85.0	-	-

Table 11: Measured indoor received power over given distances for building B

			Mean R×L at given Distance In dBm						
Building type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
Building B	August 5th-26th		1km	2km	3km	4km	5km	6km	7km
		9:05-10:35	-54to-78	-60to-89	-68to-96	-	-	-	-72to-108
		8:40-9:20	-52to-77	-63to-92	-66to-95	-	-	-	-71to-106
		10:50-11:20	-55to-80	-66to-86	-69to-98	-	-	-	-74to-109
		11:20-11:55	-59to-73	-64to-88	-71to-93	-	-	-	-77to-102
	September 2nd-30th	9:15-9:35	-62to-74	-68to-85	-73to-97	-	-	-	-79to-98
		11:10-11:40	-58to-79	-85to-87	-67to-91	-	-	-	-78to-101
		9:00-9:25	-60to-70	-62to-84	-70to-90	-	-	-	-82to-103
		8:40-9:10	-53to-72	-67to-90	-75to-94	-	-	-	-76to-107
		11:00-11:30	-64to-68	-71to-83	-72to-89	-	-	-	-73to-104
		10:00-11:40	-61to-71	-69to-81	-74to-95	-	-	-	-75to-105
		9:30-10:10	-57to-79	-62to-86	-69to-92	-	-	-	-80to-100
		8:05-8:25	-53to-75	-66to-88	-66to-94	-	-	-	-71to-107
		10:05-10:30	-61to-71	-64to-90	-70to-98	-	-	-	-73to-109
		Mean R×L	-66.0	-76.0	-82.0	-	-	-	-90.0

Table 12: Measured indoor received power over given distances for building C

			Mean R×L at given Distance In dBm						
Building type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
Building C	August 5th-26th		1km	2km	3km	4km	5km	6km	7km
		9:05-10:35	-48to-74	-58to-86	-61to-94	-64to-95	-	-	-67to-100
		8:40-9:20	-50to-76	-56to-88	-62to-95	-63to-98	-	-	-70to-102
		10:50-11:20	-55to-69	-59to-83	-65to-87	-69to-93	-	-	-75to-105
		11:20-11:55	-53to-71	-61to-85	-69to-89	-67to-90	-	-	-72to-95
	September 2nd-30th	9:15-9:35	-49to-73	-63to-84	-67to-91	-72to-99	-	-	-77to-97
		11:10-11:40	-51to-75	-57to-87	-68to-84	-64to-91	-	-	-73to-99
		9:00-9:25	-48to-70	-60to-81	-72to-88	-71to-87	-	-	-71to95
		8:40-9:10	-54to-76	-65to-88	-65to-90	-75to-98	-	-	-68to101
		11:00-11:30	-53to-73	-56to-81	-63to-93	-66to-96	-	-	-76to-98
		10:00-11:40	-51to-71	-63to-79	-66to-91	-68to-94	-	-	-69to-103
		9:30-10:10	-49t0-76	-57to-86	-64to-94	-68to-91	-	-	-74to-69
		8:05-8:25	-48to-72	-60to-87	-70to-86	-71to-98	-	-	-71to-103
		10:05-10:30	-52to-75	-58to-84	-62to-92	-65to-97	-	-	-69to-101
		Mean R×L	-62.0	-72.0	-78.0	-81.0	-	-	-86.0

On prediction with measurement: The results of empirical and over deterministic model are compared with the measurement as shown in Table 13 outdoor environment and Table 4-6 for indoor environments show that:

- The developed empirical model predicts accurately compared to the deterministic/theoretically model-(Log-distance path loss model).
- The standard deviation values of the model due to shadowing are more minimal ranging from 0.01-1.38 and can thus be ignored in the model.

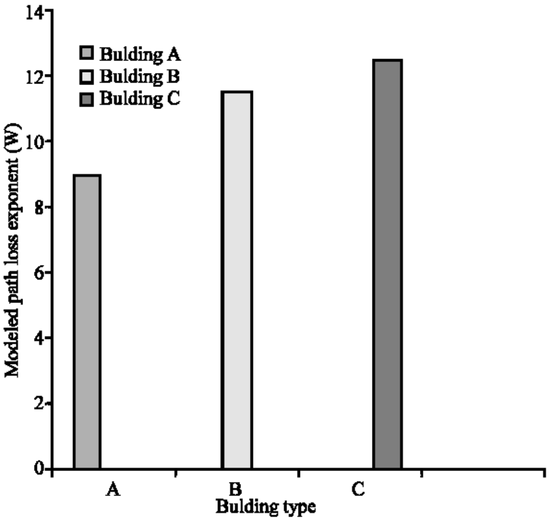

Fig. 3: Model path loss exponent (w) for bulding type A, B and C

Table 13: Comparison between measured mean R×L (in dBm) and modeled means R×L (in dBm) for outdoor

Distance 'd' (km)	Measured Mean R×L (dBm)	modeled mean R×L (dBm)	Standard deviation (dBm)
1	-54.8	-54.9	0.10
2	-64.7	-65.1	0.04
3	-70.3	-71.0	0.70
4	-73.1	-73.8	0.68
5	-75.4	-76.2	0.72
6	-	-78.3	0.02
7	-78.6	-80.0	1.38

CONCLUSION AND RECOMMENDATIONS

In this research work, it was observed that the problem of user location and tracking in both outdoor and indoor environment for three Network providers in Ekpoma has been addressed. It has provided assessment of coverage level and accessibility index of mobile network operators, which is a measure of quality of service provided in Ekpoma. It has demonstrate the attenuation caused by three different building materials prevalent in Ekpoma and models that can be used to predict the signal reception levels in houses made of similar materials for the different buildings considered has equally be developed.

Conclusively, results obtained give the confidence that building constructed from wood has the lowest attenuation to signal reception level of 9.0. Bricks made of super heated clay and with a greater wall thickness of a value of 7.33 gives a higher attenuation. While the poorest of these materials is the corrugated iron roofing sheet (Zinc) which gives attenuation of 10.67. It has the highest attenuation in GSM signal due to the reflective properties of metals. Thereby discouraging the use of Zinc as wall materials for construction of residential houses of Kiosk, such as phone boots if good signal reception is required.

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