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Indoor Modeling for Determination of G.S.M Signal Penetration Level: A Case Study of Mud, Block and Steel Building Materials in Ekpoma

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Abstract: Interest involves the determination of G.S.M signal strength in Mud, Block and Steel buildings in Ekpoma. Existing path loss exponent values were studied to determine the extent to which building characteristics (in terms of its construction and materials) affect propagated signal. Measurements of signal level taken at different building type were recorded to determine the path loss exponent values, which were 7.33, 8.33 and 12.67dBm for Mud, Block and Steel buildings respectively. A model was statistically developed for each of the building considered such that the signal level in the building can be approximately predicated once the Transmitter-Receiver (T-R) distance is known. The values obtained by the developed models were in the range of the measured values.

Key words: G.S.M signal, building material, attenuation, modeling

INTRODUCTION

The Global System for Mobile (G.S.M) communication is a second-generation cellular system standard that was developed to solve the fragmentation problem of the first cellular system in Europe. G.S.M was the first world's cellular system to specify digitals modulation and network level architectures and service and is the world's most popular 2G (second generation) technology. G.S.M success has exceeded the expectation of virtually everyone and it's now the world's most popular standard for new cellular radio and personal communication equipment through out the world (Theodore, 2003).

In Nigeria the government of Olusegun Obasanjo's administration brought us a deregulated telecommunication sector, which gave birth to G.S.M in Nigeria (Akpaida and Anyasi, 2004).

However, this research takes a look at GSM signal strength in buildings. For the design and maintenances of indoor wireless service, the knowledge of the signal propagation can either be outdoor or indoors. In outdoor propagation, the signal strength may be affected by obstacles within the surrounding like trees, building and moving car etc but for this study we shall dwell more on indoor propagation. Indoor propagation is one of the most complicated propagation topics based on specific types of building structure and material used (Pavel *et al*., 1999).

Empirical modeling based on statistics seem to be the most efficient approach since there is no need of precise definition of the building interior (Bullington, 1947). On the other hand, such models can fail in anomalous indoor situation where a precise site-specific model should be used e.g ray tracing. For example, in the city of Prague, most of the empirical model could only be used with necessary modification made (Ramo *et al*., 1965). In this research the various indoor propagation models were studied and used to compute GSM signal strength in Mud, Block and Steel buildings in Ekpoma town. Values obtained from models were compared with those from actual measurements.

Aims and objectives of the study: 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.

This study will provide a better insight into GSM signal propagation in an indoor environment and it is specifically aimed at the following:

- Development of a mathematical model that will be used to calculate the attenuation factor of various construction materials that constitute our architectural structures.

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- Conduct outdoor and indoor measurement of signal strength within the coverage area of a choice network provider to prove the validity of the mathematical model developed.
- Examine the reliability of the various network providers in relation to the various construction materials.
- To investigate the extent to which building characteristic i.e. construction material and building layout affect propagation.

MATERIALS AND METHODS

Location: Ekpoma in Esan \Vest local government area of Edo state, Nigeria is situated between latitude 6° 10° and 6° 45° North of the equator and between longitude 6° 10° and 6° 40° East of the Greenwich Meridian Line. The area is bounded in the North by Etsako East camps found on these slope e.g. Ukpenu, Illeh etc these settlement are unable to attract social-economic facilities because of their size and the ruggedness of the topography (Akinbode, 1983).

Drainage: The area have tributaries of Ossiad river which drawn into the Benin river, these tributaries include the Orle Stream. The river is characterized by deeply incised valley which penetrates almost the centre of the plateau. The most remarkable observation about the Ishan drainage system is that no stream or river of any size runs across the region, so that the water supply is a problem except where boreholes are dung.

Climate: The studied area experiences the human tropical climate which is characterized with wet and dry season. The dry season which lasts between November and March usually coincides with the period of low sun while he wet session which lasts between April and October coincides with the period of high sun.

The rain usually falls from conventions storms and hence is unevenly spread throughout the days of the wet season. The mean annual rainfall is estimated at 1.556 mm. The month of July and September have the highest rainfalls in the year. During the dry season, the prevailing North East winds also referred to as the harmattan bring cold, dust and rainlessness to the area.

Vegetation: The pre-dominant vegetations are the moist deciduous forest which is very rich in timber resources. The canopy is more open that in the rain forest region which lies to the south.

Apart from the tropical hard wood, timber such as Iroko, Obeche etc industrial and food crops found in the area include oil palm, rubber, plantain and many local important fruits thrive well in the forest. These forest products are the basic raw material for the saw millers and furniture industries enhances the standard of living in the urban centre thereby aggravating the disparate in the quality of life between the larger and smaller settlements in the study area.

Soil: These soils are less leached and consequently retain the advantage of a good rooting depth were they contain a fair clayey content, they provide a good growing medium for cocoa, rubber and other tree crops.

RESULTS

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). 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.

Generation of models for the building types: The model development is based on the building types under consideration. Viz; Mud, Block and Steel buildings. The model generated was totally statistical and the steps followed are outline:

- The mean of the path loss characteristics for a particular building type was computed.

Table 1: Service providers and their frequency bands

Network provider	Frequency band 900MHz	1800MH z
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

Table 2: Description of building

Building symbol	Material Type	GPS/location	Description
B_1	Block	N06^0 45.419^1 E006^0 07.221^1 Multi-story office (block) at Ambrose Alli University (FEST Building) Ekpoma	This is two-story building constructed with blocks. The floors are made of rein enforced concrete. The interior is relatively uncluttered and has a suspended ceiling. Fluorescent lighting are fixed on each floor. The structure is rooted with aluminum roof.
B_2	Block	N06^0 44.529^1 E006^0 04.501^1 Single-classroom block building (short Hall 3 at Ambrose Alli University, Ekpoma (FET Building)	The structure is roofed with aluminium roof. The interior is sparsely populated with wooden desk
B_3	Block	N06^0 45.221^1 E006^0 06.199^1 Block building at Eromon street	The interior is made of chair, table, shelves and has an asbestos ceiling.
S_1	Steel	N06^0 44.481^1 E006^0 06.285^1 Steel Kiosk at Ujemen, Ekpoma	It has a steel type roof and has an area of 12 by 14m. The interior is fitted with wooden shelves
S_2	Steel	N06^0 45.284^1 E006^0 04.671^1 Steel Kiosk at Ambrose Alli University, Ekpoma	The interior has a concrete floor and is Sparely populated with plastic chairs. The roof is made up of corrugated iron roofing sheet
S_3	Steel	N06^0 44.325^1 E006^0 08.151^1 Steel building at Aburimen street, Ekpoma.	The interior has a concrete floor and is sparsely populated with plastic chair. The roof is made up of corrugated iron roofing sheet. The interior is made of chairs and tables and with an asbestos ceiling.
S_4	Steel	N06^{0}45.230^1 E006^0 04.532^1 Steel building at Uwenodia, Ekpoma	The interior has a concrete floor and is sparsely populated with plastic chair. The roof is made up of corrugated iron roofing sheet.
M_1	Mud	N06^{0}45.210^1 E006^0 05.322^1 Single-family detached mud building at Ujemen, Ekpoma	It has wood framed corrugated iron roof and cemented floor
M_2	Mud	N06^{0}45.418^1 E006^0 07.223^1 Detached single mud classroom building at Uendova, Ekpoma	This is open spaced structure, has asbestos ceilings and concrete within the classroom
M_3	Mud	N06^{0}44.405^1 E006^0 08.128^1 Mud building at Aburimen street, Ekpoma	The floor is of concrete type and has an asbestos ceiling.
M_4	Mud	N06^{0}45.425^1 E006^0 04.152^1 Mud building at Uwenodia, Ekpoma	The floor is of concrete type and has an asbestos ceiling.

- The average value of the measured power for outdoor propagation was computed.
- The average value of the measured power for the indoor system was also computed.
- The difference in values between the indoor and outdoor received power (measured) were represented as x which compensated for the losses due to barriers (wall, furniture e.t.c) in the buildings.

From the results of indoor and outdoor measurements, it is evident that the signal strength indoor is lower than that of outdoor environment
We denoted these differences as Y_M, Y_B and Y_S
The statistical mean of these values were obtained as;

Y_M = 7.33dBm
Y_B = 8.33dBm
Y_S = 12.67dBm

Where, Y_M, Y_B and Y_S are the Building types M, B and S attenuation factors respectively.

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

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

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

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

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

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

$$C_0 = \text{Modeled loss constant} = \frac{\text{Average power measured}}{\text{Power calculated}} \tag{6}$$

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

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

Were, C_i is the loss constant at every distance d_i

Table 4-6 present a comparison of computation from our generated models and calculations obtained using Log-Distance Path Loss Model (Bernhard, 1989).

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

DISCUSSION

Upon a cursory look of the Table 3, it can be assumed that; the path loss exponent that were computed from measured parameters range from 4.25-5.48 in obstructed in-building (indoor) which is within the range of path loss exponents for obstructed in building which lies between 4-6.

Also, it was observed from the results and calculations that the power received has logarithmic relationship (T-R) distance. The received power decrease with an increase in distance from the transmitter. The received power computed when the path loss exponent for indoor and outdoor was n = 6 and n = 5 respectively (Table 4-6) were close to those obtained from the

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 of measured mean R×L and Modeled R×L for indoor of building type 'M'

Distance (km)	Measured mean R×L	Modeled Mean R×L
1	-63	-62.23
2	-70	-72.43
3	-	-78.33
4	-82	-81.13
5	-83	-83.53
6	-	-85.63
7	-	-87.33

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

Distance (km)	Measured Mean R×L	Modeled Mean R×L
1	-63	-63.23
2	-74	-73.53
3	-	-79.33
4	-81	-82.13
5	-85	-84.53
6	-	-86.63
7	-	-88.53

Table 6: Comparison between measured mean R×L (dBm) and modeled mean RXL (dBm) for building type S

Distance (km)	Measured Mean R×L	Modeled mean R×83.L
1	-68	-67.57
2	-78	-77.77
3	-79	-83.67
4	-85	-86.47
5	-	-88.87
6	-	-90.97
7	-	-92.67

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
	August 5th-26th	9:05-10:35	-47to-58	-54to-74	-64to-80	-64to-81	-54to-79	-	-68to-88
		8:40-9:20	-49to-67	-48to-70	-66to-82	-67to-80	-64to-84	-	-78to-86
		10:50-11:20	-51to-63	-52to-72	-58to-79	-62to-82	-71to-85	-	-71to-86
		11:20-11:55	-52to-60	-54to-74	-58to-80	-60to-81	-70to-76	-	-80to-91
Network A	September 2nd-30th	9:15-9:35	-55to-68	-58to-78	-62to-78	-68to-80	-72to-84	-	-82to-95
		11:10-11:40	-53to-67	-63to-83	-64to-80	-68to-83	-76to-89	-	-82to-91
		9:00-9:25	-47to-58	-55to-79	-68to-79	-70to-90	-75to-94	-	-80to-92
		8:40-9:10	-52to-61	-50to-79	-65to-82	-64to-88	-68to-86	-	-70to-89
		11:00-11:30	-47to-59	-54to-70	-59to-73	-63to-88	-65to-74	-	-68to-80
		10:00-11:40	-44to-60	-46to-68	-55to-72	-62to-84	-68to-78	-	-68to-82
		9:30-10:10	-45to-63	-56to-78	-63to-77	-59to-78	-79to-98	-	-62to-78
		8:05-8:25	-50to-63	-66to-84	-66to-79	-59to-73	-66to-73	-	-62to-82
		10:05-10:30	-45to-62	-49to-67	-60to-78	-57to-80	-58to-76	-	-64to-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	-41to-61	-49to-74	-53to-76	-55to-81	-	-	-
		8:40-9:20	-46to-62	-50to-71	-54to-84	-57to-88	-	-	-
		10:50-11:20	-50to-65	-53to-75	-61to-82	-60to-86	-	-	-
		11:20-11:55	-56to-66	-55to-80	-65to-88	-62to-77	-	-	-
Network B	September 2nd-30th	9:15-9:35	-58to-68	-60to-81	-68to-86	-65to-91	-	-	-
		11:10-11:40	-54to-62	-57to-80	-64to-84	-62to-88	-	-	-
		9:00-9:25	-50to-65	-56to-76	-58to-87	-59to-84	-	-	-
		8:40-9:10	-48to-65	-54to-79	-5782	-56to-74	-	-	-
		11:00-11:30	-41to-63	-51to-78	-56to-87	-58to-87	-	-	-
		10:00-11:40	-43to-67	-53to-79	-63to-86	-64to-90	-	-	-
		9:30-10:10	-53to-68	-51to-75	-59to-85	-63to-80	-	-	-
		8:05-8:25	-47to-62	-52to-76	-56to-80	-55to-78	-	-	-
		10:05-10:30	-43to-60	-50to-73	-53to-76	-60to-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	-43to-65	-52to-77	-	-60to-86	-	-	-60to-80
		8:40-9:20	-49to-66	-59to-79	-	-62to-88	-	-	-62to-85
		10:50-11:20	-55to-70	-54to-78	-	-60to-95	-	-	-65to-89
		11:20-11:55	-43to-60	-50to-71	-	-60to-86	-	-	-70to-93
	September 2nd-30th	9:15-9:35	-47to-62	-53to-75	-	-62to-88	-	-	-73to-100
		11:10-11:40	-56to-66	-50to-73	-	-59to-84	-	-	-68to-95
		9:00-9:25	-53to-68	-60to-81	-	-62to-77	-	-	-66to-84
		8:40-9:10	-43to-67	-57to-80	-	-64to-90	-	-	-65to-97
		11:00-11:30	-50to-65	-52to-76	-	-60to-86	-	-	-62to-84
		10:00-11:40	-41to-63	-54to-79	-	-56to-74	-	-	-63to-86
		9:30-10:10	-58to-68	-51to-78	-	-58to-81	-	-	-64to-95
		8:05-8:25	-48to-65	-53to-79	-	-55to-78	-	-	-61to-91
		10:05-10:30	-54to-62	-55to-80	-	-63to-80	-	-	-62to-93
		Mean R×L	-57.0	-66.0	-	-72.0	-	-	-78.0

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

			Mean R×L at given Distance In dBm						
Building type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
Building D	August 5th-26th	9:05-10:35	-56to-82	-59to-80		-68to-92	-63to-88	-	-
		8:40-9:20	-50to-74	-56to-82		-76to-90	-62to-92	-	-
		10:50-11:20	-53to-70	-53to-81		-72to-99	-66to-90	-	-
		11:20-11:55	-52to-62	-55to-81		-69to-89	-70to-82	-	-
	September 2nd-30th	9:15-9:35	-58to-78	-55to-78		-68to-97	-76to-86	-	-
		11:10-11:40	-61to-82	-61to-85		-78to-93	-76to-92	-	-
		9:00-9:25	-55to-70	-59to-80		-76to-94	-80-98	-	-
		8:40-9:10	-52to-81	-52to-72		-73to-92	-60to-98	-	-
		11:00-11:30	-50to-72	-52to-70		-68to-92	-72to-87	-	-
		10:00-11:40	-56to-82	-59to-89		-71to-89	-80to-102	-	-
		9:30-10:10	-51to-70	-58to-88		-63to-92	-68to-96	-	-
		8:05-8:25	-60to-79	-61to-84		-80to-93	-82to-99	-	-
		10:05-10:30	-62to-72	-60to-84		-75to-93	-80to-98	-	-
		Mean R×L	-63	-70		-82	-83	-	-

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 E	August 5th-26th	9:05-10:35	-50to-82	-58to-89		-62to-95	-79to-88	-	-
		8:40-9:20	-55to-70	-58to-80		-58to-86	-68to-99	-	-
		10:50-11:20	-56to-70	-62to-89		-62to-88	-72to-97	-	-
		11:20-11:55	-54to-72	-64to-90		-65to-90	-89to-100	-	-

Table 11: Continued

			Mean R×L at given Distance In dBm						
Building type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
	September 2nd-30th	9:15-9:35	-60to-78	-69to-80		-69to-81	-82to-96	-	-
		11:10-11:40	-52to-81	-58to-92		-55to-80	-67to-86	-	-
		9:00-9:25	-55to-78	-63to-88		-67to-82	-68to-88	-	-
		8:40-9:10	-52to-72	-58to-88		-58to-92	-70to-91	-	-
		11:00-11:30	-55to-74	-61to-80		-62to-98	-79to-92	-	-
		10:00-11:40	-60to-79	-66to-85		-70to-96	-82to-102	-	-
		9:30-10:10	-61to-85	-68to-90		-68to-92	-89to-100	-	-
		8:05-8:25	-58to-80	-60to-91		-72to-98	-71to-90	-	-
		10:05-10:30	-50to-71	-58to-82		-69to-99	-72to-99	-	-
		Mean R×L	-63	-74		-81	-85	-	-

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

			Mean R×L at given Distance In dBm						
Building type	Date	Time (Am)	1km	2km	3km	4km	5km	6km	7km
Building F	August 5th-26th	9:05-10:35	-60to-86	-62to-91	-62to-96	-69to-93	-	-	-
		8:40-9:20	-53to-82	-72to-95	-70to-98	-76to-98	-	-	-
		10:50-11:20	-50to-86	-75to-99	-65to-99	-77to-94	-	-	-
		11:20-11:55	-51to-74	-70to-88	-70to-99	-70to-102	-	-	-
	September 2nd-30th	9:15-9:35	-55to-82	-70to-96	-72to-98	-77to-98	-	-	-
		11:10-11:40	-58to-80	-65to-88	-68to-82	-68to-98	-	-	-
		9:00-9:25	-52to-79	-69to-90	-62to-94	-79to-102	-	-	-
		8:40-9:10	-61to-88	-72to-79	-74to-98	-78to-100	-	-	-
		11:00-11:30	-52to-77	-65to-92	-74to-102	-72to-91	-	-	-
		10:00-11:40	-50to-78	-66to-82	-69to-92	-72to-90	-	-	-
		9:30-10:10	-53to-80	-61to-88	-65to-90	-80to-86	T-	-	-
		8:05-8:25	-58to-68	-71to-89	-73to-99	-82to-96	-	-	-
		10:05-10:30	-60to-78	-70to-92	-80to-100	-70to-99	-	-	-
		Mean R×L	-68	-78	-79	-85	-	-	-

developed model. Also, the power received computed using the developed outdoors and indoor model was in the range of those measured.

Generally, the outdoor signal levels in all cases considered were better than indoor propagation levels as shown in Table 7-12.

CONCLUSION

The electric and magnetic field strength in the 3 (three) building materials types was measured over the 900MHz GSM frequency range. Contrary to the indications of literature (Cox *et al*., 1984) on the values of path loss exponent for both outdoor and indoor environment, the computed values were at variant as the mean path loss exponent value obtained in this work was in the range of the upper limit of the path loss exponent values.

As expected, the effect of barriers and attenuation factor was higher for the steel building as correlated against the amount of metal in the building. Similarly, the signal strength values observed at the top floors of the building considered reflected better reception levels, hence establishing that at higher attitudes there are fewer obstructions and clearer lines of sight, thus providing for better signal levels.

Building materials had an obvious effect on the signal strength; as attenuation was observed to be due to both path loss exponents' values and barrier factors. For the three buildings considered, Steel made of corrugated iron roofing sheet has the highest attenuation 12.67dBm, followed by Block building of the value 8.33dBm and finally, Mud building of attenuation factor of 7.33dBm.

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