ANALYSIS OF A DEVELOPED BUILDING PENETRATION PATH LOSS MODEL FOR GSM WIRELESS ACCESS

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ABSTRACT - In this paper a building penetration path loss model was developed. The model involved the combination of three mechanisms of signal propagation; refraction, reflection and diffraction. The penetration through the building walls was modelled as refraction using Fresnel Refraction Coefficient and the propagation through the roof was modelled as diffraction using the principle of knife-edge diffraction. The total losses from the transmitter to the receiver was modelled as a combination of three different effects; losses due to free-space propagation from transmitter to building; the penetration loss as a combination of the wall penetration loss and the diffraction loss. To confirm the viability of this model, measurements were conducted in four different locations in Rivers State, Nigeria on buildings made with different material using MTN, Etisalat, Airtel and Globacom networks. The model simulation result showed that a total loss in GSM transmission as 124.07dB of which penetration loss as 37.95dB which accounted for 30.59%, the freespace loss as 86.12dB which accounts for 69.41% of the total losses. The results corresponded with the measurement results. Secondly, the developed building penetration path loss model was also compared with some existing path loss models namely, Log distance path loss, Okumura, HATA and COST-231 models and the results showed that the models compared accurately with the Okumura model and other existing path loss models. Hence, it can be stated that the developed building penetration path loss model can be used to accurately predict signal attenuation in buildings located in an urban environment.

Keywords: Attenuation, Building, Path loss, Propagation models, Penetration, Signal

1.0 INTRODUCTION Wireless access network has become vital tools in maintaining communication especially at home and work places due to communication models [3]. Signal propagation models can be classified as both empirical models and deterministic models. The empirical models are based on practical measured data. They include Okumura, HATA , COST-231 HATA , models and many others. Deterministic models require enormous number of geometry information about the site and also requires very important computational efforts [3]. They are RayTracing model, Ikegami model and many others [28], [3].

Attenuation is the reduction of signal strength during transmission and it is very important in communication system design [6].

Wireless signal transmission is based on radio wave propagation. Generally speaking, the signal strength is attenuated by three basic physical phenomena: reflection, diffraction, and scattering [6]. Communication engineers are generally concerned with the application of mobile radio link parameter which consists of the path loss exponent that indicates the rate at which a signal depreciates with increase in distance. A unique mean path loss exponent (n) is assigned to each propagation environment which is established by means of the experiment. To the system engineer, this parameter would help in model formulation that is appropriate for certain geographical areas. The aim of this paper is to compare a developed building penetration path loss model with some existing empirical path loss models such as Okumura, HATA, COST-231 and Log Normal models and measurement results.

2.1 Some Existing Propagation Models

2.1.2 Log-distance Path Loss Model

Log distance path loss model is an extension to Friis free space model. it is used to predict the propagation loss over a wide range of environments whereas the Friis free space model is restricted to unobstructed clear path between the transmitter and receiver [6]. Friis Free space is a condition rarely met in a radio channel. In a realistic channel, the signal will be band limited and suffer from large and small scale fading. Even if the situation is lineof -sight (LOS) there will be reflections from large objects such as buildings and nature formations like hills. The very same objects may also cause shadowing giving us a non-line-of-sight (NLOS) situation. When roaming around with the receiver, this will cause slow variations in the path loss around a local mean. Smaller objects, foliage, and edges will cause the signal to diffract or scatter and hence cause rapid variations in the received signal strength. A path loss model taking this into account is the Log-distance Path Loss Model shown in equation (1) where the loss is calculated over a distance d [5][16][23].

$$L_P(d) = L_P(d_0) + 10n\log\left(\frac{d}{d_0}\right) + \chi \qquad (1)$$

The variable d0 represents a close-in reference distance, is a zero mean Gaussian distributed random variable in (dB) and is the path loss exponent representing how fast the path loss increases with distance. For free space calculations, the variable equals 2 and for built up area, equals 3.5[9] [26]. If the variable is zero as used in this paper since the shadowing effect was not considered, then equation (1) results in the logNormal fading model which shall be called Log Normal Model.

2.1.2 Okumura Model

This is the most popular and widely used model. It is a model for Urban Areas in a Radio propagation model that was built using the data collected in the city of Tokyo, Japan. The model is ideal for use in cities with many urban structures but not many tall blocking structures. The model served as a base for Hata models. Okumura model was built into three modes which are urban, suburban and open areas. The model for urban areas was built first and used as the base for others. For areas like farmland, rice fields and open fields. For suburban area the categories is village or highway scattered with trees and houses, few obstacles near the mobile. Urban area categories is built up city or large town with large buildings and houses with two or more storey or larger villager with close houses and tall, thickly grown trees. The Okumura model is expressed as:[21]

$$L_m(dB) = L_F(d) + A_{mu}(f,d) - G(h_r) - G(h_t) - G_{AREA} \qquad (2)$$

where; L_m is Path loss, $L_F(d)$ is free space propagation path loss, $A_{MU}(f,d)$ is median attenuation relative to free space, $G(h_t)$ is base station antenna height gain factor, $G(h_r)$ is mobile antenna height gain factor and is gain due to the type of environment given in suburban, urban and open areas correction factors like terrain related parameters can be added using a geographical form to allow for street orientation as well as transmission in suburban and open areas and over irregular terrain. The terrain related parameters must be evaluated to determine the various correction factors [11], [1], [19], [24], [10] and [12].

2.1.3 HATA Model

This is a fully empirical prediction method, based entirely upon an extensive series of measurements made in and around Tokyo city between 200MHz and 2GHz. Hata's formulation is limited to certain ranges of input parameters and is applicable only over quasi-smooth terrain. The mathematical expression and their ranges of applicability are [25], [8], [12] and [24]:

Carrier Frequency, f_c: $150MHz \le f_c \le 1500MHz$
Base Station Antenna Height: $30m < h_b < 200m$
Mobile Station Antenna Height: $1m \le h_m \le 10m$
Transmission Distance: $1km < R < 20km$

$L_{dB} = A + B\ log_{10}R - E$ for Urban Areas (3)

$L_{dB} = A + Blog_{10}R - C$ for Suburban Areas (4)

$L_{dB} = A + Blog_{10}R - D$ open Areas (5)

where

$A = 69.55 + 26.16log_{10}(f_c) - 13.82log_{10}(h_b)$,

$B = 44.9 - 6.55log_{10}(h_b)$

$C = 5.4 + 2[log_{10}\left(\frac{f_c}{28}\right)]^2$,

$D = 40.94 + 4.78[log_{10}(f_c)]^2 - 18.33log_{10}(f_c)$

$E = 3.2[log_{10}(11.75h_m)]^2 - 4.97$ for large city and $f_c > 300MHz$

$E = 8.29[log_{10}(1.54h_m)]^2$ for large city and $f_c < 300MHz$

$E = [1.1log_{10}(f_c) - 0.7]h_m - [1.56log_{10}(f_c) - 0.8]$ for medium or small cities

2.1.4 COST-231

Some studies have shown that the path loss experienced at 1845MHz is approximately 10dB larger than those experienced at 955MHz all other parameters kept constant. The COST-231-HATA's model is used in the 1500-2000MHz frequency range and it can be shown that path loss can be more dramatic at these frequencies than those in 900MHz range. The model is expressed in terms of the following [17], [20] and [12]:

Carrier frequency (f_c) $1500 - 2000MHz$
BS Antenna Height (hb) 30-200m
MS Antenna Height (hm) 1-10m
Transmission Distance (d) 1-20km
The path loss according to the COST-231 model is expressed as [Singh, 2013]:

$L(dB) = A + Blog_{10}(d) + C$ (6)

where A $=46.3+33.9log_{10}(f_c) - 13.28log_{10}(hb) - a(hm)$

$B = 44.9 - 6.55log_{10}(hb)$

C = 0 for medium city and suburban area
= 3 for metropolitan areas

$a(hm) = 3.2[log_{10}(11.75h_m)]^2 - 4.97$ for large city and $f_c \ge 300MHz$

$a(hm) = 8.29[log_{10}(1.54h_m)]^2$ for large city and $f_c < 300MHz$

$a(hm) = [1.1log_{10}(f_c) - 0.7]h_m - [1.56log_{10}(f_c) - 0.8]$ for medium or small cities

3.0 MATERIALS AND METHOD

3.1 Development of Building Penetration Path loss model

In this section, a model will be used to predict the amount of signal attenuation through buildings. This model will involve the combination of two mechanisms of signal propagation: penetration through building wall and penetration through building roof as diffracted signal. Though most existing propagation predictions modelled the buildings as being completely opaque to radio signals [27]. The total losses from the transmitter to the receiver will be modelled as a combination of two different effects; losses due to free-space propagation from transmitter to building and the building penetration losses. The penetration loss will be modelled as the combination of two losses; the loss when the signal is passing through the building wall and diffraction loss due to signal penetration through the roof. The expression for the losses from transmission through the building to the receiver will be:

$$L_{total} = L_{free-space} + L_{penetration} \qquad (7)$$

Where, L_{total} = *total losses*; $L_{free-space}$ is the free-space losses, $L_{penetration}$ is the penetration loss due to the building

From Figure 1, • $d_{t1}$is the distance from the transmitter to the building roof. •d_{r1} is the distance from the wall edge to the mobile station (receiver) •R is the reflected signal from the roof. •d_{T2} is the distance from the transmitter to the building wall, measured in the perpendicular direction from the transmitter to the building wall. •d_{R2} is the distance from the building wall to the receiver, measured in the perpendicular direction from the obstacle to the mobile station. • ϕ is the angle of arrival, measured from the perpendicular direction to the building and to the direction followed for the propagating signal. •w is the inner width of the room. • b is the width of the building measured from the center of the brick (wall) •h_c is the transmitter height •h_{Hall} is the height of the building wall. •h_M is the height of the table in which the mobile station (receiver) is placed •a is the least departure angle of the signal from the transmitter • β is angle of the diffracted signal with the normal.

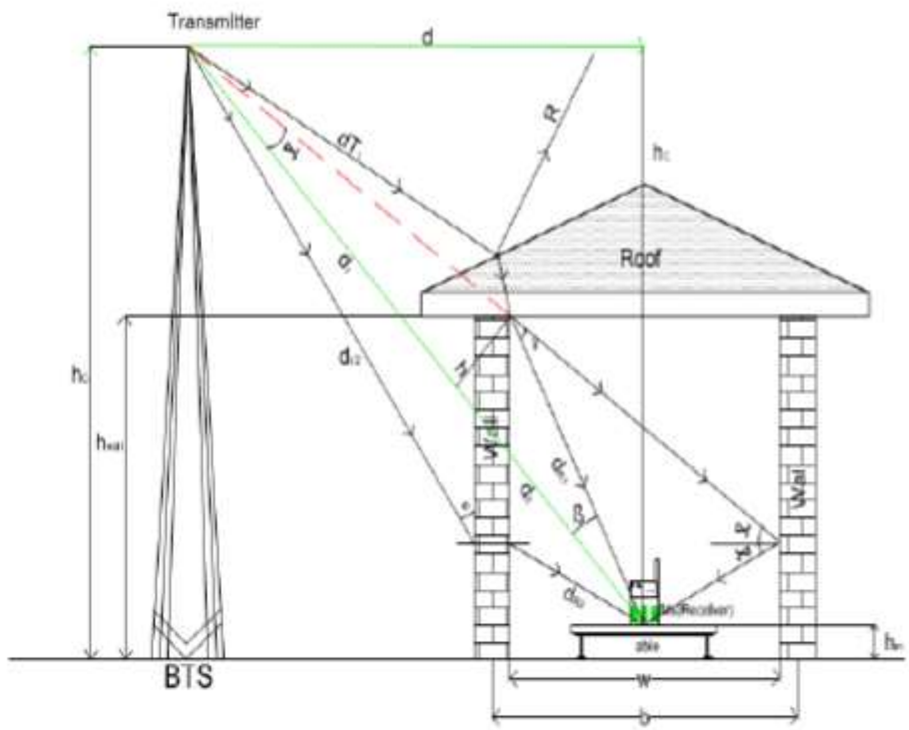

Figure 1: Complete model of GSM signal penetration into building and parameters used

3.1.1 Free-Space Losses

The free-space propagation can be used to predict the received signal when the transmitter and the receiver have a line-of-sight. The equation (8) is known as the Friis free-space equation, it predicts that received power decays as a function of the transmitter-receiver separation distance [6].

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad (8)$$

wherePt is the transmitted power, Pr(d) is the received power, Gt is the transmitter antenna gain, Gr is the receiver antenna gain, d is the distance of separation between the transmitter and the receiver in meters, Lis the propagation loss factor which must be a positive integer and is the λ wavelength in meters.
The path loss is the difference (in dB) between the effective transmitted power and the received power. It represents the signal attenuation measured in dB and may or may not include the effect of the antenna gain. When the antenna gains are excluded, the path loss is given as [7]:

$$PL(dB) = 10log_{10}\frac{P_t}{P_r} \quad (9)$$

$$PL(dB) = -10log_{10}\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \quad (10)$$

From figure 1, the losses between the transmitter and the building is,

$$L_{free-space} = \left[\frac{4\pi f}{c}\right]^2 d_{T2}^2 \quad (11)$$

$$L_{free-space}(dB) = 20log_{10}\left[\frac{4\pi f d_{T2}}{c}\right](dB) \quad (12)$$

where f and c are the frequency and velocity of signal transmission respectively.

3.1.2 Building Penetration Loss

The penetration loss will be modelled as a combination of the refracted signal (refraction loss) and the diffracted signal (diffraction loss). It is modelled as refracted because the signal is passing through a material medium. When a signal passes through a material medium, it is reflected and refracted [7]. For this modelling, emphasis will be focussed on the refracted signal since it represents the signal passing through the building wall to the receiver.

3.1.2.1 Refraction Loss

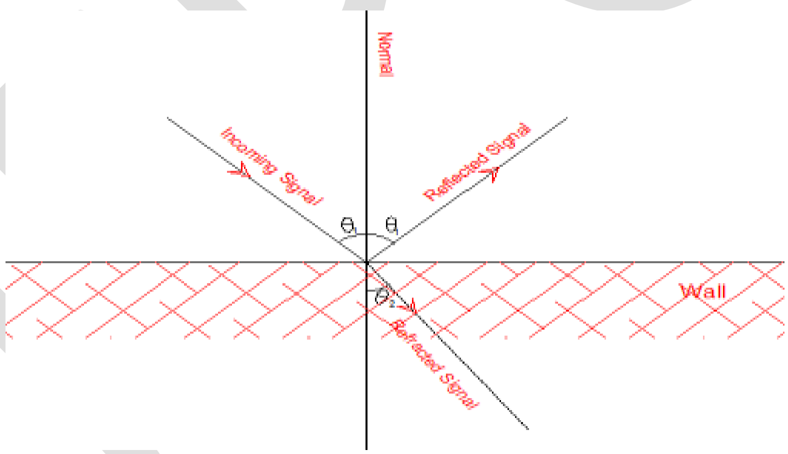

Figure 2: Boundary Condition for the Signal Penetration into wall.
Figure 2, gives a clear illustration that as the GSM signal strikes the building wall, some of the signals are refracted through the wall into the room, while the rest are reflected. The rate of reflection and refraction are dependent on the type of the building material used for the wall.
The refracted signal coming from outside to inside the building will be modelled using the Fresnel Transmission and Reflection Coefficient. This parameter characterises the amount of signal strength coming from outside the building to inside the building [7].
The Fresnel equations describe what fraction of the signal is reflected and what fraction is refracted and also describe the phase shift of the reflected signal [14]. The fraction of the incident signal that will be reflected from the interface is given by the reflectivity, R and the fraction that will be refracted is given by the transmittance or transmissivity, T [14].
According to [22], the Fresnel Reflection Coefficient was defined as follows,

$$R_s = \frac{sin\theta - \sqrt{\varepsilon_r - cos^2\theta}}{sin\theta + \sqrt{\varepsilon_r - cos^2\theta}} \quad (13)$$

where θ is the angle between the reflecting surface and the normal perpendicular to the wall, ε_r is the complex relative permittivity. The relative permeability, μ_r, of the obstacle is equal to 1 [15].

The angle θ in equation (14) can be related to the angle of arrival ϕ of figure 2 when both are expressed in degrees.

$$\phi = 90^0 - \theta \qquad (14)$$

Recall, $Sin\ (90 - \theta) = Cos\ \phi$ (15)

As a function of the angle of arrival from equation (15), R_s can be expressed as:

As a function of the angle of arrival from equation (15), can be expressed as:

$$R_s = \frac{cos\phi - \sqrt{\varepsilon_r - sin^2\phi}}{cos\phi + \sqrt{\varepsilon_r - sin^2\phi}} \qquad (16)$$

The Fresnel transmission Coefficient T_s can be related to the Fresnel Reflection Coefficient, R_s as [18]:

$$T_s = R_s + 1 \qquad (17)$$

Hence,

$$T_s = \frac{cos\phi - \sqrt{\varepsilon_r - sin^2\phi}}{cos\phi + \sqrt{\varepsilon_r - sin^2\phi}} + 1 \qquad (18)$$

$$T_s = \frac{cos\phi - \sqrt{\varepsilon_r - sin^2\phi} + cos\phi + \sqrt{\varepsilon_r - sin^2\phi}}{cos\phi + \sqrt{\varepsilon_r - sin^2\phi}}$$

$$T_s = \frac{2cos\phi}{cos\phi + \sqrt{\varepsilon_r - sin^2\phi}} \qquad (19)$$

Since the fraction that is refracted is given by the transmittance, T [14]. The dependence of the penetration loss (through the wall) based on the Fresnel Transmission Coefficient is:
Expressed in dB,

$$L_{wall\ penetration} = -20log_{10}T_s(dB) \qquad (20)$$

This parameter expresses the signal strength passing through the wall into the residential room.

According to [15], the mud is made up of the following percentage material composition; Fe2O3 (44.8%), MnO (0.06%), TiO2 (12.33%), CaO (5.22%), K2O (0.27%), P2O5 (0.45%), SiO2 (5.4%), Al2O3 (16.2%), MgO (0.13%) and Na2O (4.0%). Hence, the relative permittivity of iron oxide (Fe2O3) was used as the relative permittivity for mud since it has the highest percentage composition and this applies for brick while concrete and aluminium has specific relative permittivity. The relative permittivity of the materials under consideration for the wall penetration losses are:

Table 1: Relative Permitivity of Building Materials [15]

Building Material	**Relative Permitivity ( )**
Concrete + Iron	16.5
Mud	14.2
Brick	7.6
Alucoboard +Brick	19.5

The Refracted signal penetration loss for this comparison was computed using the relative permittivity of brick since majority of the buildings have brick wall while others can be obtained by substituting the relative permittivity of the various building materials as shown in table 1 into equation (20) using equation (19), for an arrival angle of to the wall.

3.1.2.2 Diffraction Loss

In figure 1, the signal from the transmitter strikes the roof of the residential room and part of it is reflected, while the other is refracted through the roof and diffracted as soon as it strikes the wall edge and it is receiver by the receiver (mobile phone). Assuming the transmitting signal takes the path of the red broken line and a straight line is produced from the transmitter to the receiver to produce a knife-edge diffraction geometry. Also, consider that there is an impenetrable obstruction of height h, at a distance from the transmitter and from the receiver along the signal path as shown in figure 1. The path difference between the direct path and the diffracted path will be:

$$\delta = \sqrt{(d_1^2 + h^2)} + \sqrt{(d_2^2 + h^2)} - (d_1 + d_2) \qquad (21)$$

Simplifying further gives

$$\delta = d_1\left(1 + \frac{h^2}{2d_1^2}\right) + d_2\left(1 + \frac{h^2}{2d_2^2}\right) - (d_1 + d_2) \quad (22)$$

$$\delta = \frac{h^2}{2d_1} + \frac{h^2}{2d_2} \qquad (23)$$

$$\delta = h^2(d_1 + d_2)\Big/(2d_1d_2) \qquad (24)$$

The phase difference will be:

$$\varphi = \frac{2\pi\delta}{\lambda} = 2\pi h^2\,(d_1 + d_2)\Big/2\lambda(d_1d_2) \qquad (25)$$

Let

$$\gamma = \alpha + \beta \qquad (26)$$

And $$tan\gamma = tan\alpha + tan\beta \qquad (27)$$

Hence,

$$\tan\gamma = tan\alpha + tan\beta = {}^{h}\!/_{d_1} + {}^{h}\!/_{d_2} = h(d_1 + d_2)\Big/_{d_1d_2} \qquad (28)$$

To normalise this, the Fresnel-Kirchoff diffraction parameter , was applied [13]

$$v = h\sqrt{2(d_1 + d_2)\Big/(\lambda d_1 d_2)} \qquad (29)$$

To estimate the diffraction loss, the Knife-edge diffraction model was applied.

The electric field strength, E_d of a knife-edge diffracted wave is given by: [13]

$$E_d/E_o = F(v) = (1 + j)/2\int_v^\infty \exp\left(\frac{-j\pi t^2}{2}\right)dt \quad (30)$$

The diffraction loss due to presence of knife-edge can be given as: [13]

$$L_{diffraction} = -(\frac{0.225}{v})^2 \qquad (31)$$

Expressing in dB

$$L_{diffraction}(dB) = -20log_{10}(\frac{0.225}{v})$$

$$L_{diffraction} = -20log_{10}\left(\frac{0.225}{h\sqrt{2(d_1 + d_2)/(\lambda d_1 d_2)}}\right) \quad (32)$$

3.1.3 Total Losses(Building Penetration Path loss)

Considering the results of sections 3.1.1 and 3.1.2, the expressions for the total path losses from a base transceiver station to the mobile station when the signal propagation path is interrupted by a building is,

$$L_{total} = \left(\frac{4\pi f d_I}{c}\right)^2 \frac{1}{T_S^2} \left(\frac{v}{0.225}\right)^2 \qquad (33)$$

Expressing in dB

$$L_{total} = 20log_{10}\left(\frac{4\pi f d_{T2}}{c}\right) - 20log_{10}(T_s) - 20log_{10}\left(\frac{0.225}{h\sqrt{2(d_{T1}+d_{R1})/(\lambda d_{T1} d_{R1})}}\right) \qquad (34)$$

The following parameter values were substituted into equation (37) to determine the signal path loss from the BTS (transmitter) to the MS (receiver). , .

3.2 Measurements

To confirm the viability of this model, measurements were conducted on five different building patterns in four (4) different locations (Port Harcourt, Elele, Omoku and Emohua) all in Rivers State, Nigeria. The study was carried out on four GSM service providers (MTN, Etisalat, Globacom and Airtel), to determine their signal penetration through buildings made of different materials using Radio Frequency Signal Tracker software. The Radio frequency Signal Tracker installed in a Tecno Tablet was used in carrying out the measurements to determine the signal strength, signal-to-noise ratio (SNR) and the distance from the measurement site to the Base Transceiver Stations (BTS).

The measurements conducted in each of the four different locations were conducted on five different building pattern namely, mud building with thatched roof, mud building with rusted corrugated iron sheet roof, sandcrete building with unrusted corrugated iron sheet roof, sandcrete building with rusted corrugated iron sheet roof and building with Alucoboard wall cladding.

3.3 Calculation of Penetration Loss

For each of the measurements, the penetration loss was computed as:

(35)

Where is the average penetration loss in dBm, is the average signal strength inside the building in dBm and is the average signal strength outside the building in dBm. The positions of the transmitter (BTS) and the dimensions of the window area were considered, as measurements were not conducted on buildings with many and large window areas. Tables 3 through 6 is the measured signal lose for each location using equation (35).

4.0 RESULTS AND DISCUSSION

4.1 RESULTS

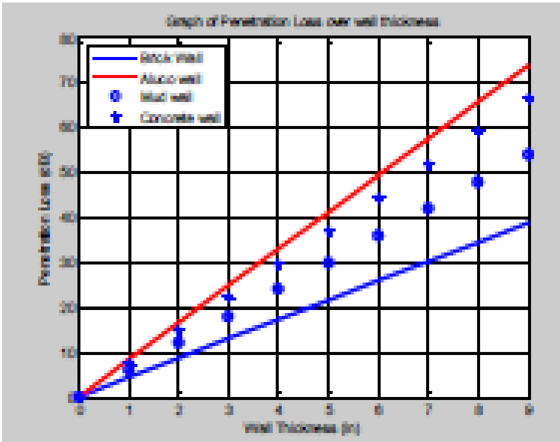

Figure 3: Penetration loss through a 9 inches wall for different materials

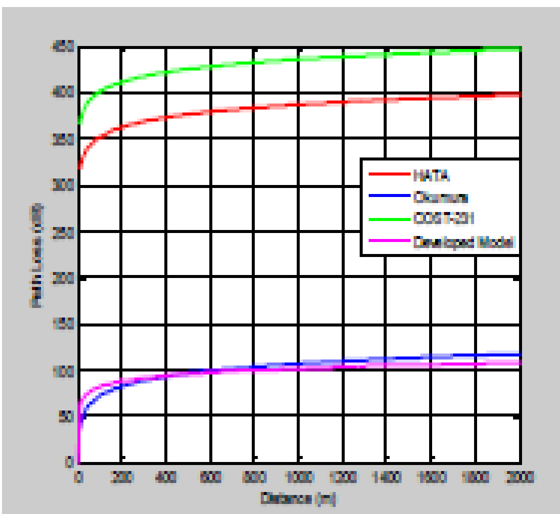

Figure 4: Comparison of developed path loss model with Okumura, HATA and COST-231 models with respect to transmission distance.

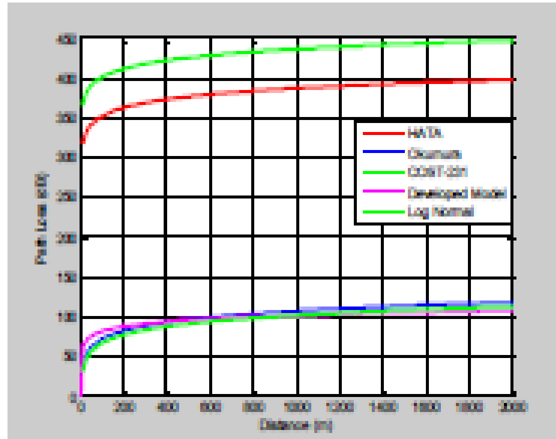

Figure 5: Comparison of the Developed path loss model with Okumura, HATA, COST-231 and Log Normal models.

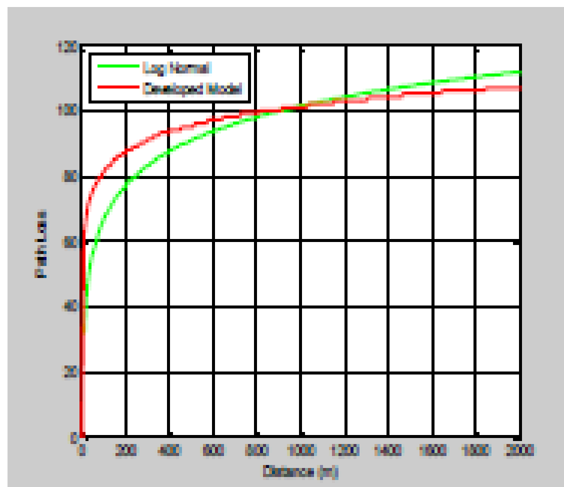

Figure 6: Comparison of the Developed Path Loss model and Log Normal model with respect to transmission distance

Table 2: Loss Values and their Percentage

Type of Loss	Loss Value (dB)	Percentage Loss (%)
Free Space	86.12	69.41
Penetration	37.95	30.59

Table 3: Measured Signal Loss for different Building Pattern in Elele

Network Provider	Building Pattern				
	Mud Building with Rusted Corrugated iron sheet roof in dBm	Mud Building with Thatched roof in dBm	Sandcrete Building with Rusted Corrugated iron sheet roof in dBm	Sandcrete Building with Unrusted corrugated iron sheet roof in dBm	Building with Alucoboard wall Cladding in dBm

MTN	12.42	15.81	28.35	31.04	38.45
Globacom	20.22	18.32	25.65	33.41	41.14
Etisalat	48.05	34.54	29.22	39.32	44.25
Airtel	36.12	32.47	34.21	34.24	44.15

Table 4: Measured Signal Loss for different Building Pattern in Port Harcourt

Network Provider	Building Pattern				
	Mud Building with Rusted Corrugated iron sheet roof in dBm	Mud Building with Thatched roof in dBm	Sandcrete Building with Rusted Corrugated iron sheet roof in dBm	Sandcrete Building with Unrusted corrugated iron sheet roof dBm	Building with Alucoboard wall Cladding in dBm
MTN	41.05	39.98	37.31	31.48	41.22
Globacom	48.55	47.71	32.66	40.10	48.47
Etisalat	47.50	44.21	26.25	33.05	50.25
Airtel	48.41	40.44	28.35	35.55	51.24

Table 5: Measured Signal Loss for different Building Pattern Omoku

Network Provider	Building Pattern				
	Mud Building with Rusted Corrugated iron sheet roof in dBm	Mud Building with Thatched roof in dBm	Sandcrete Building with Rusted Corrugated iron sheet roof in dBm	Sandcrete Building with Unrusted corrugated iron sheet roof in dBm	Building with Alucoboard wall Cladding in dBm
MTN	43.72	52.10	39.42	29.21	48.23
Globacom	45.91	50.70	33.39	30.21	52.42
Etisalat	59.47	56.42	36.47	31.10	56.25
Airtel	42.74	51.55	40.36	41.53	54.26

Table 6: Measured Signal Loss for different Building Pattern in Emohua

Network Provider	Building Pattern				
	Mud Building with Rusted Corrugated iron sheet roof in dBm	Mud Building with Thatched roof in dBm	Sandcrete Building with Rusted Corrugated iron sheet roof dBm	Sandcrete Building with Unrusted Corrugated iron sheet roof in dBm	Building with Alucoboard wall Cladding in dBm
MTN	32.70	55.12	39.42	29.71	56.20
Globacom	35.80	50.72	37.39	30.25	55.30
Etisalat	49.50	56.41	36.47	31.10	49.24
Airtel	33.72	51.52	40.41	30.66	54.35

4.2 Discussion

In figure 4, the developed building penetration path loss model were compared with the existing path loss models and there was closeness of values with the Okumura path loss model. There is also closeness of values with the log normal model as shown in figure 5. In figure 5, the developed model showed very close comparison with the Okumura and the log normal path loss models. From figure 4, the developed model and Okumura showed the least values compared to the other models and with close relationship with each other. Figure 6 shows the clearer comparison of the developed model with the log normal model, at a distance of 1km away from

the transmitter, both models presented equal losses. In all, the developed model showed very close relationship of results with the Okumura and log normal path loss models. The COST-231 showed high path loss while the HATA showed intermediate results.
The results in table 2 shows that the penetration loss accounts for 30.59% with a loss value of 37.12dB of the total losses which compares with the measurements results for sandcrete building of figures 3 through 6. The free-space loss accounts for 69.41% with a loss value of 86.12dB of the total losses. This means that, the building accounts for 30.59% of the total loss of signal in GSM transmission, though the free space depends on the distance of the building from the transmitter. Figure 3 shows that a 9 inches brick wall will experience a signal loss of 40dB while the concrete wall has a loss 68dB, this shows that the brick wall has the least penetration loss while the building with alucoboard wall cladding has the highest penetration loss. This result also conforms to the measured results of tables 3 through 6. Since the emphasis lies on the building losses, therefore, it will be necessary for builders to use materials with less penetration losses.

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, it can be stated that the developed building penetration path loss model compared accurately with the Okumura and log normal models since they have closeness of values and relationship. The developed building penetration path loss model, Okumura, HATA and COST-231 showed increasing trend with respect to the transmission distance and in all the models used in this research, Okumura model showed similar trend with the developed model as well as the log normal model. It therefore shows that this developed model is a viable model that can be used to predict the signal attenuation in an urban environment. The penetration loss were almost equal with the measurement results. Hence, it can be conclude that the developed model can be used in predicting GSM signal losses in buildings.

5.2 Recommendation

This research has presented a new model for predicting signal attenuation through buildings in both urban and rural environments. Therefore, it will be recommended that this study be extended to other geographical environments such as high climatic environments for effective GSM network planning.

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