Path Loss Prediction Model for GSM Fixed Wireless Access

P. Elechi and P.O. Otasowie

***Abstract*— This research investigated the effect of building materials on GSM signals quality. Measurements were conducted on the GSM network in Nigeria, (MTN, Glo, Airtel and Etisalat) using Radio Frequency Signal Tracker on six different building patterns. The results showed that building with alucoboard wall cladding had the highest signal loss while the sandcrete building/unrusted corrugated iron sheet roof had the least signal loss. Also, a model to predict signal penetration through building walls was developed. It was developed using the principles of Fresnel Refraction Coefficient and the 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 was modelled as a combination of the wall penetration loss and the diffraction loss. The results show that despite the condition of the building walls, movement of people in the environment/room also affected the wireless signal quality as well as the chairs and gadgets in the room. The indoor signal path loss in the rooms increased from when the walls were plastered and continued until when the walls were covered with curtains, both rooms reduced by 4dBm. The mean squared error ranged between 1.6dBm and 2.1dBm with a standard deviation between 11.1 and 11.5**

***Index Terms*— Building, Path Loss, Signal, GSM network, Penetration**

I. INTRODUCTION

The need for mobile and wireless communications in this modern society cannot be overemphasized, statistics has shown that in many countries, the use of mobile phone is already higher than the fixed one. They are used everywhere, not only outdoor, but also indoor. In these environments, customers demand a good coverage and quality of service [1] and [2]. Signal Propagation models are widely used extensively in network planning, particularly for conducting feasibility studies and during deployment. These models are also useful for performing interference studies as the deployment proceeds [3]. Though, there exist numerous signal propagation models for open and urban environments, none of these models adequately describe signal penetration in buildings. According to [2], signal losses in buildings contributes to about 31% of the total GSM signal losses. This is because signal penetration loss is associated with the indoor environment [4] and [5].

The paper is aimed at predicting a path loss model for GSM fixed wireless.

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II. MATERIALS AND METHOD

A. Measurement

Measurements were conducted on five different building made with different materials in Elele, 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 (RFST) 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 were conducted Mud building with thatched roof (MBTR), Mud building with rusted corrugated iron sheet roof (MBCR), Sandcrete building with unrusted corrugated iron sheet roof (SBUR), Sandcrete building with rusted corrugated iron sheet roof (SBCR), Sandcrete building with unrusted corrugated iron sheet roof/POP ceiling (SBPC), and Building with Alucoboard wall cladding (BAWC). In each of the buildings considered, measurements were conducted for both outdoor and indoor

To compare the indoor signal losses, two buildings made with brick wall and concrete wall with dimensions of 5m×3m×4m and 12.7cm wall thickness each were constructed. The doors were made with GMP aluminium and glass material with dimensions (1.5m×0.75m). Several GSM signal measurements were conducted on each building such as:

1) When the walls were not plastered,
2) When the walls were plastered,
3) When the walls were painted,
4) When the walls were tiled,
5) When curtains were hanged on the doors of the rooms,
6) When chairs and gadgets were placed in the rooms,
7) When 4 persons were randomly moving in the room,

and the differences of the losses recorded using equation (1).

$$PL_M = PL_{nM} - PL_{uW} \quad (1)$$

where PL_M is the path loss due to the wall material, PL_{nM} is the path loss due to the new wall material and PL_{uW} is the path loss of the unplastered wall. The signal path loss of the unplastered brick and concrete walls were measured as 22dBm and 32dBm and their difference gives the indoor signal path loss due to the internal condition of the wall.

B. Model Formulation

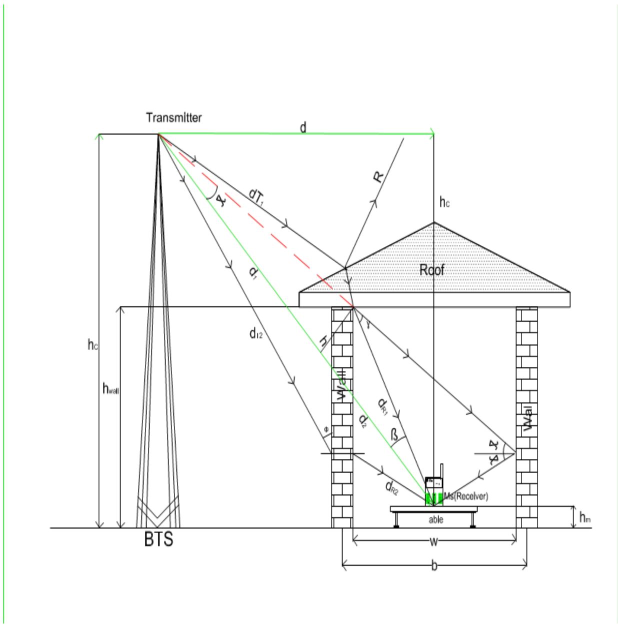

Fig. 1. Complete model of GSM signal penetration into building and parameters used

Fig. 1 is the model used in predicting the amount of GSM signal attenuation through buildings. The model involved the combination of two mechanisms of signal propagation: signal penetration through building wall and penetration through building roof. Though most existing propagation predictions modelled the buildings as being completely opaque to radio signals [6]. The total losses from the transmitter to the receiver was modelled as the combination of different effects; losses due to free-space propagation from transmitter to building, the building wall penetration losses, losses due to trees, human activities, vehicles and other factors. The penetration loss was 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.

Fig. 1 shows a GSM signal transmission from a BTS to a building. The total losses from the transmitter to the receiver is modelled as [2];

$$L_{Total} = L_f + L_p + L_d + G_{ah} + X_\sigma + C \qquad (2)$$

where L_{Total} is the total path loss, L_f is the free space loss, L_p is the penetration loss, L_d is the diffraction loss, G_{ah} is the gain height of the antenna, X_σ is the log normally distributed variable, C is the empirical constant or the Raleigh fading.

- *Free Space Loss*

The free space loss is given as:

$$L_f = \frac{4\pi f d}{c} \qquad (3)$$

where f is the carrier frequency, d is the distance between the transmitter and the building wall and c is the signal speed.

- *Penetration Loss*

The loss of the signal as it passed through the wall is:

$$L_p = -20log_{10} T_s \qquad (4)$$

$$T_s = \frac{2cos\phi}{cos\phi + \sqrt{\varepsilon_r - sin^2\phi}} \qquad (5)$$

where ϕ is the signal angle of arrival and ε_r is the relative permittivity of the building material.

- *Diffraction Loss*

The diffraction loss due to the building obstacle is given as:

$$L_d = -20log_{10}\left(\frac{0.225}{v_0}\right) \qquad (6)$$

$$v_0 = h\,\sqrt{2(d_1+d_2)}\Big/\lambda d_1 d_2 \qquad (7)$$

where λ is the signal wavelength, d_1 is the distance from the transmitter to the diffracting building edge and d_2 is the distance from the diffracting building edge to the receiver. For obstacles with height higher than the transmitter antenna,

$$v_0 = \sqrt{2}\left[(h_o - 2h_R) - \frac{w(h_T - h_R)}{d+w}\right]\sqrt{\frac{dcos^2\phi}{\lambda(dcos\phi)w}} \qquad (8)$$

where h_T is the receiving antenna height, h_T is the transmitting antenna height, d is the distance between the transmitter and the receiver, ϕ is the angle of elevation and h_0 is the medium height of the obstacle.

$$h_0 = \sqrt{r^2 + ((K_e a_e)^2 + 2rK_e a_e sin\phi) - K_e a_e + h_T} \qquad (9)$$

where r is the hypotenuse distance between the transmitter and the receiver a_e is the radius of the earth and $K_e = {}^4\!/_3$ (Standard refraction Coefficient).

- *Gaussian Random Variable*

The Gaussian random variable was applied to examine the variation of the signals due to human activities and other objects that cause strong signal attenuation.

$$C = \frac{L_p}{\sigma^2} e^{-\left[\frac{L_p^2}{2\sigma^2}\right]} \qquad (10)$$

The variations of the measured signal due to human activities and buildings was examined using the log normally distributed variable.

$$X_\sigma = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(L_p - \overline{L_p})^2}{2\sigma^2}} \qquad (11)$$

- *Antenna Gain Height*

The antenna gain height was considered in determine the signal gain with respect to antenna height and expressed as [7]:

$$G_T = 20log_{10}\left[\frac{h_R(h_0 - h_R)}{h_T}\right] \qquad (12)$$

- *Least Square Line Analysis*

Having computed the received powers and their corresponding distances from the BTS, the least square line method was used to obtain the line of best fit because the best fit curve that has the minimal sum of the deviation s squared for a given set of data.
The least square line approximating the set of points (x_1, y_1), (x_2, y_2), ………. (x_n, y_n) has the equation below [8].

$$y = ax + b \quad (13)$$

To approximate the set of data (x_1, y_1), (x_2, y_2), (x_3, y_3), (x_4, y_4), ….. (x_n, y_n) where $n \geq 2$; such that the sum of squares of the distances to this straight line $y = ax + b$ from the set of points is a minimum.

$$b = \frac{(\sum_{i=1}^{n} y_i)(\sum_{i=1}^{n} x_i^2) - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i x_i)}{n(\sum_{i=1}^{n} x_i^2) - (\sum_{i=1}^{n} x_i)} \quad (14)$$

$$a = \frac{n(\sum_{i=1}^{n} x_i y_i) - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n(\sum_{i=1}^{n} x_i^2) - (\sum_{i=1}^{n} x_i)} \quad (15)$$

- *Mean Squared Error*

The mean squared error of the measured empirical data were obtained using equation 16.

$$Mean\ Squared\ Error = [P_D^2 - M_D^2] \quad (16)$$

where P_D is the predicted data and M_D is the measured data.

III. Result and Discussion

A. Results

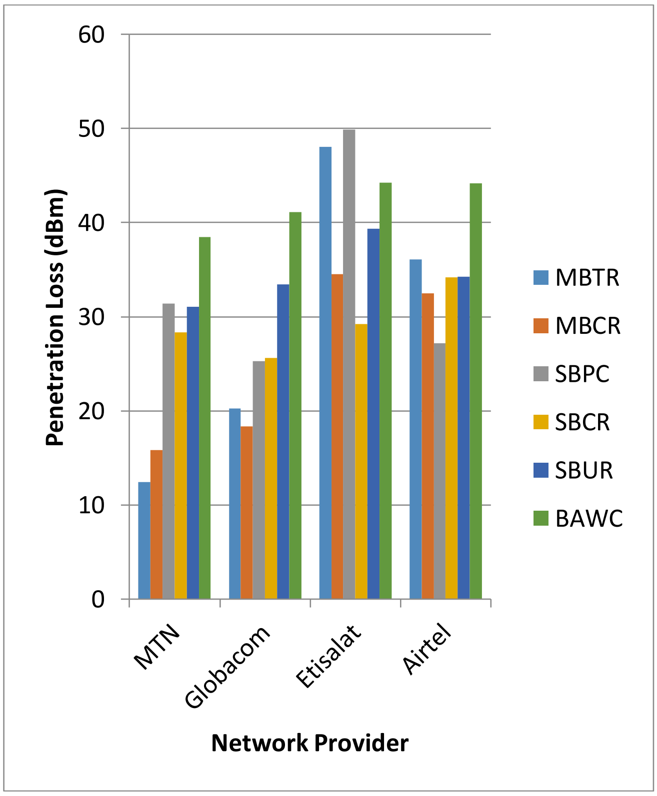

Fig. 2. Average Signal Penetration Loss for Elele

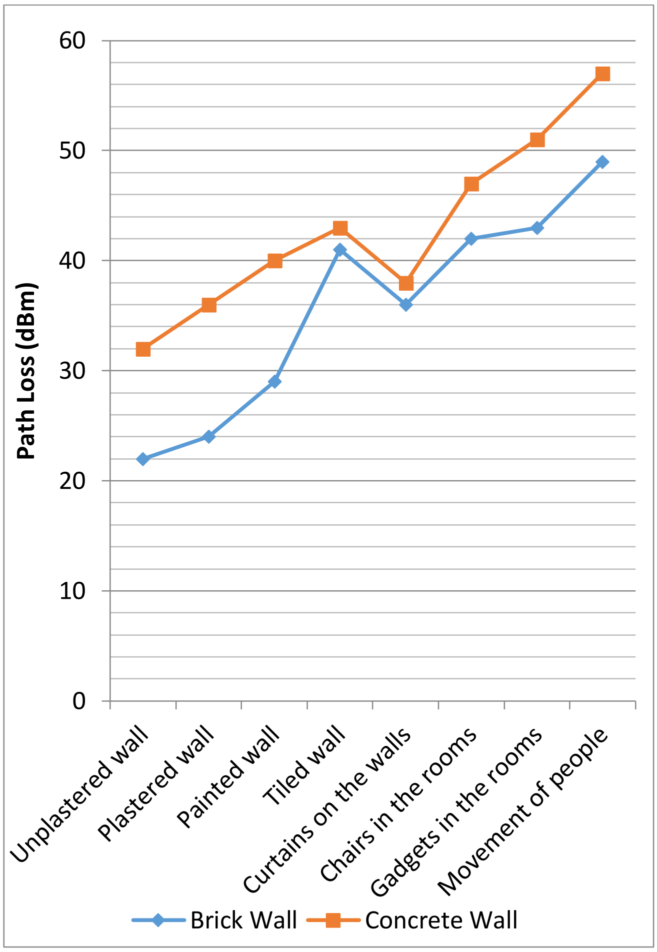

Fig. 3. Indoor Signal Attenuation based on the Building Wall Material

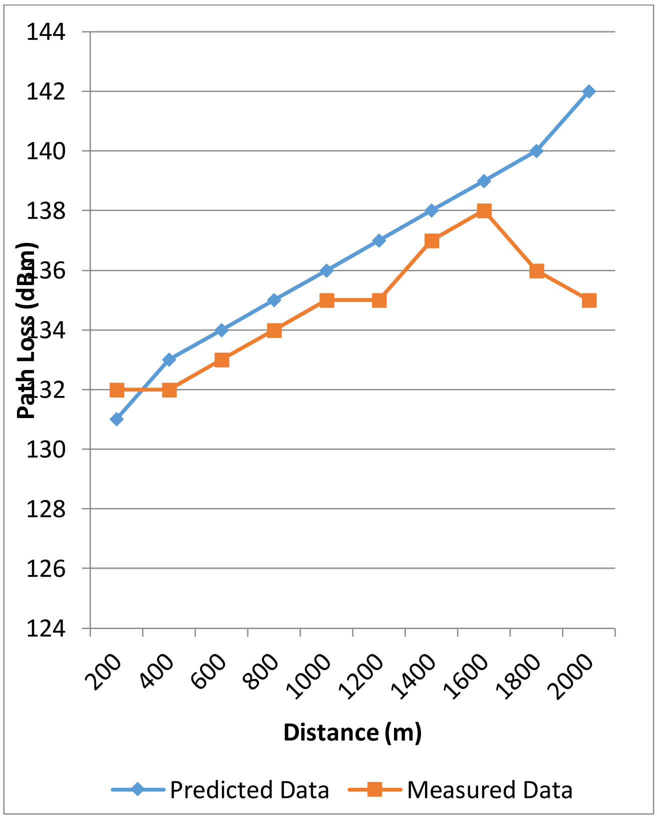

Fig. 4. Signal Propagation Path Loss

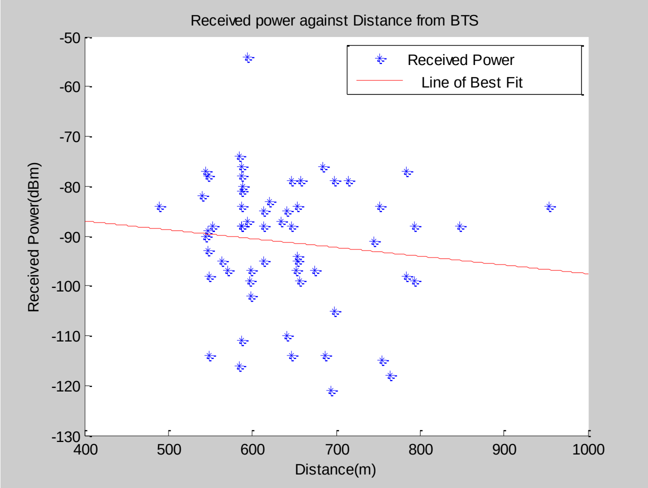

Fig. 5. Scatter points best Fit for Elele Measurements

B. Discussion

Fig. 5 is the scatter points of the measured signal strength and the line of best fit with equation; $y = -0.017629x - 86.95$

This means that for every increase of measurement distance of 1m, the received signal strength decreases by 0.0017629dBm and at a minimum distance of 400 meters from the BTS, the received signal strength is -86.95dBm.

Fig. 2 resents the signal penetration loss for each of the building pattern considered. The results showed that the building with alucoboard wall cladding had the maximum penetration loss while the sandcrete building with rusted corrugated iron sheet roof had the least signal penetration loss.

In Fig. 4, the signal propagation loss is presented and the result shows that the measured data is less than the predicted data with the difference ranging from 1dBm to 7dBm ($1 \leq L_p \leq 7$). Fig. 3 shows the amount of GSM signal attenuation on the different building wall materials considered. The results show that despite the condition of the building walls, movement of people in the environment/room can also greatly affect the wireless signal quality as well as the chairs and gadgets in the room. The indoor signal path loss in the rooms increased from when the walls were plastered and continued until when the walls were covered with curtains, both rooms reduced by 4dBm. This means that polished walls and movements in an indoor environments affect GSM signal quality.

IV. Conclusion

A. Conclusion

In this work, a model that can account for the effect of building materials on GSM signal quality was developed. The results showed the effect of building materials on GSM downlink signal power losses. As the mobile equipment (phone) was moved from outside to inside the building, the path loss increased. The penetration loss of the GSM signal was dependent on the building wall/roof material. The results showed that the building with alucoboard wall cladding had the highest signal penetration loss while the sandcrete building/unrusted corrugated iron sheet roof had the lowest signal penetration loss. The mean squared error lied between 1.6dBm and 2.1dBm and a standard deviation between 11.1 and 11.5

B. Recommendation

This research has presented a new model for predicting signal attenuation in an urban and rural environment. Therefore, it is recommend that this study can be extended to other geographical environments such as high climatic environments for effective network planning.

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