Measurement and Modeling of Path Loss for GSM900 in Sub Urban Environment over Irregular Terrain

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Abstract
This work present measurement and modeling of path loss propagation for GSM900 in Mubi town. Model Equations were developed for the major three Global system for mobile communication (GSM) network Operators in (Mubi) base on the applicability of the factors studied in the environment investigated. The model developed predicted that the minimum and maximum path losses of the investigated environments range between $2 \leq 7$dB. It was observed that as the distance of measurement increases path loss also increases, the average mean square errors determined for all the GSM network operators were less than (<0.25dB), the model developed may help in planning and optimization of better network for rural and sub urban environments in Nigeria provided the environments to investigate have the same or almost the same features with the environment considered in this work.
Keywords: Signal strength, Model, Investigation, Propagation, Environment, Obstacle and GSM.

1. Introduction

Radio path loss is a particularly important element in the design of any radio communication system or wireless network, the radio path loss will determine many elements of radio communication system especially the transmitter power, antenna gain, height and general location [3]. Radio path loss also affects other elements such as the required receiver sensitivity, form of transmission used and several other factors [7]. As a result it is necessary to understand the reason for radio path loss in relation to coverage area and to be able to determine the level of the signal loss for a given radio at a particular distance. Since the introduction of Global system for Mobile communication (GSM) phone in Nigeria as the size of subscribers increases GSM service becomes unreliable, there are alot of complains such as frequent call drop, echo during radio conversation, cross talk, network congestion (network busy), poor inter and intra connectivity and many others, this may be attributed to poor quality of the GSM signal delivered to the end user of GSM phone which may be caused due to transmission inferences, GSM use atmosphere as the medium of transmission and this transmission lines are geographically dispersed over a wide area which may not hitch free from transmission impairments [12]. The purpose of this study is to develop a model that may help in network planning in order to address the complains of the customers in Mubi.

1.1 Theoretical Propagation Model

In this work the theoretical propagation models are first considered which is divided into four basic types these are, free space propagation, flat or smooth earth propagation model, atmospheric refraction and precipitation model depending on the weather condition.

1.2 Free Space Propagation Model

The propagation model starts with free space propagation, in free space propagation the wave is not reflected or absorbed but ideal propagation implies equal radiation in all directions from the radiating source and propagation to an infinite distance with no degradation [8]. Free space attenuation increases as the frequency goes up for a given unit of distance this occurs because higher frequencies have shorter wave lengths [4], and cover a given distance, consequently the higher the frequency the shorter the wave length. By having identified the power flux, if the receiver antenna is place at a particular point the power received by the mobile station (MS) can be calculated. Consider a transmitter with $P_{(t)}$ coupled to an base station (BS) which radiates equally in all directions at a distance (d) from the BS where the power density is detected, then the radiated power is distributed uniformly over an area of $4\pi d^2$ (that is the surface area of a sphere of radius d) so that the power density is given by

$$s = \frac{P_T}{4\pi d^2} \qquad (1)$$

Then the path loss depends on how much of this power is captured by the MS. If the capture area, or the effective

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aperture is given by (A_R), the power which can be delivered to the receiver assuming no mismatch or feed line losses, is simply

$$P_R = SA_R \quad (2)$$

For hypothetical isotropic receiving MS, we have

$$A_R = \frac{\lambda^2}{4\pi} \quad (3)$$

Where λ is the wave length of the propagation [2], combining Eq. (1) and (3), we have

$$P_R = P_T\left(\frac{\lambda}{4\pi d}\right)^2 \quad (4)$$

While Eq. (5) illustrate the path loss (L_P), given by

$$L_p(dB) = (P_T) - (P_R) \quad (5)$$

Substituting Eq. (4) into (5), it yield Eq. (6)

$$L_P(dB) = 20\log_{10}(4\pi) + 20\log_{10}(d) - 20\log_{10}(\lambda) \quad (6)$$

Simplifying the expression of Eq. (6) in terms of frequency produces the generic free space path loss formula; this is stated in Eq. (7)

$$L_P(dB) = 32.4 + 20\log_{10}(d) + 20\log_{10}(f) \quad (7)$$

As early stated propagation path loss is a function of distance. According [9] propagation path loss is given by an expression

$$P_L(dB)d^{\alpha} \quad (8)$$

Expression of Eq. (8) is further simplified in terms of logarithmic form as

$$P_L(dB) = P(L_P) + \alpha\log_{10}(d) \quad (9)$$

Where $P(L_p)$ is now the propagation constant known as the free space loss

1.3 Smooth earth propagation model.

The free space propagation model does not consider the effects of propagation over ground. When reflection surface is reasonably smooth and it has sufficient area that can provide gain to the reflected signal such that its amplitude may be equal or exceed the amplitude of the direct signal. When a radio wave propagate over flat or smooth earth such as desert, water or wet ground, empty parking lots, road surfaces, glass surface such as windows, building roof and many other flat reflection surface, some part of the power would be reflected due to the presence of the flat or smooth earth and then received by the mobile phone user. If the effect of the reflected power is analyzed and determined then we can say the free space model is modified, which referred to as "flat or smooth earth reflection" propagation model. The vector sum of the flat or smooth earth reflected signal and direct signal from the main source now formed the modified equation of the flat or smooth earth reflection that base described the path loss propagation.

$$Lp = 32.4 + x\log(d) + 20\log(f) - 20\log(h_B) - 20\log(h_M) \quad (10)$$

Where, x is unknown parameter which depends on the nature of the environment and the average distance to be considered.

1.4 Atmospheric Refraction Model

Atmosphere consist of number of gases, vapors, and water molecules these materials strictly depend upon the local geophysical features of the area that is time of the day or weather condition or season (dry or wet season). Since the investigation environment consist of trees, building, and many human activities, these activities may influence the atmospheric content by adding some materials which may consequently affects the propagation of the GSM signal strength. Population –to – vegetation density varies with the area. Biologically the vegetation (trees) consumes carbon (IV) oxide during photosynthesis and produce oxygen which then consume by human being and vice versa, the process continuous as long as life exist in the environment , other activities like building, driving, etc also generate or increase the density of the atmosphere. These materials may be sum up to make the atmospheric density ticker and consequent affect the GSM signal propagation. Therefore for any study of path loss propagation to take place careful understanding of the atmospheric refraction must be taking into consideration. Figure 1 shows how the GSM signal is refracted.

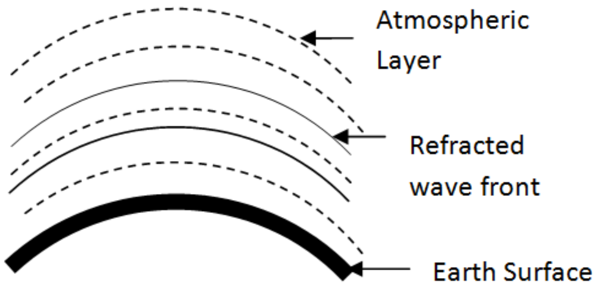

Figure 1: Atmospheric Refraction

Under normal condition atmospheric density varies or decreases linearly with altitude resulting in a propagation velocity differential between the top and bottom of a wave front [6]. If we consider the top velocity to be C_T while the bottom velocity to be C_B the velocity of the atmospheric, the model equation of the velocity may be express as,

$$\frac{\partial C}{\partial t} = \frac{\partial C_T}{\partial t} - \frac{\partial C_B}{\partial t} \quad (11)$$

We know that atmospheric density is directly related to the GSM signal speed, frequency and wavelength of the propagation. Usually electromagnetic wave propagates at the speed of light in free space as a result the materials present in the atmospheric content affects the wavelength and frequency of propagation as well as the velocity. The materials in the atmospheric content can slow down the propagation of the radio wave approximately 99.97% [6] of their speed in free space which may cause significant path loss and may affect the end user of GSM phone. The model Equation of the atmospheric refraction may consider the following input parameters; frequency, wave length, antenna heights and the speed of the propagation may be given as

$$L_{at} = 20\log(f) + 20\log(h_B) + 20\log(h_M) \quad (12)$$

Moreover the atmosphere is always dynamic and never constant as the weather changes the model Equation may varies slightly from Eq. (12).

1.4.1 Precipitation Model

Precipitation is another factor under atmospheric content but its effect needs to be understood separately, Precipitation effect is usually experience during rainy reason it occurs in time to time of the day. Precipitation affects the frequency and wave length of signal propagation by 25% of it speed [6] [12]. It slow down the propagation speed remarkably, as we know that frequency and wave length of propagation are directly related to the speed of GSM signal it is therefore important to have in mind that when designing radio network it is important to know the effect of precipitation before undertaking the design of efficient radio network. Assuming the frequency is (f) in MHz and (λ) is the wave length in Km while C is the speed of the propagation then Equation for the speed of propagation may be written as,

$$\frac{\partial C}{\partial t} = \frac{1}{4}\left(f\,\frac{\partial \lambda}{\partial t} + \lambda\,\frac{\partial f}{\partial t} \right) \quad (13)$$

While the model Equation may depend strictly on (13) and antenna heights given as

$$L_{ppt} = 5\log(f) + 5\log(h_B) + 5\log(h_M) \quad (14)$$

1.5 Types of Propagation Models

Path Loss Propagation can usually be model in three different ways, which are

- Empirical model method
- Deterministic model method
- Stochastic model method

Empirical models are based on observations and measurements alone, which are mainly used to predict the path loss, deterministic models make use of the law governing the electromagnetic wave propagation to determine the receive signal power at a particular location or place, the deterministic model often require a complete 3 – D map of the propagation environment for example ray tracing model while stochastic model on other hand model the environment as a series of random variable. They are least accurate but require the least information about the environment and much less processing power to generate predictions. [1], in determining the path loss at each distance empirical method was chosen because of it applicability with the investigated environment and it has advantages over the others model such as high level of accuracy and simplicity and clarity of the method.

The four basic theoretical propagation models discussed above such as free space, flat or smooth loss atmospheric refraction and precipitation model, may require critical detailed of the location, dimension and constitutive parameters of every buildings, trees and other geographical features in the investigation area [8] or cell to be covered. This is far complex, tedious and cumbersome to be practical and definitely it will be difficult to gain an accurate bill of the components in the investigation area but one obvious way for determining these complex effects is through empirical propagation model, there are actually many types of empirical prediction among few are Okumura – Hata model, Sakagami - Kuboi model, Walfisch – Ikegami model and COST 231 Hata model and ECC – 33 model, all these models mention above may address the complains of the GSM customers in Mubi town but COST 231 Hata model and ECC – 33 model are more suitable for this environment because of the characteristics the environment posses, however in this work COST 231 Hata model is chosen.

1.6 COST 231 Hata and ECC – 33 Model

The COST 231 Hata model is characterized by the following parameters; carrier frequency 150 – 1500MHz, the distance from the base station ranges from 1km to 20km, the height of the base station antenna ranges from 30m to 200m and height of mobile station ranges from 1m to 10m [10][11]. Base on field test result predicted, Hata created a number of representative path loss mathematical model for different types of clusters as follows

$$L_U = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - C_H + \left[44.9 - 6.55\log_{10}(h_B)\right]\log_{10} d \quad (15)$$

Been Mubi is a medium size city, the antenna correction factor may be considered as

$$C_H = 0.8 + (1.1\log_{10}(f) - 0.7)h_M - 1.56\log_{10}(f) \quad (16)$$

Substituting (14) into (13), it yield

$$L_m = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - [0.8 + (1.1\log_{10} - 0.7)h_M - 1.56\log_{10}(f)] + \left[44.9 - 6.55\log_{10}(h_B)\right]\log_{10} d \quad (17)$$

Where L_u is the path loss for urban area, L_m is the path loss for medium size city like Mubi, h_B is the height of base station (BS) antenna, h_M is the height of mobile station (MS) antenna, f is the operating frequency, d is the distance between the BS and MS in km and C_H is the antenna height correction factor while ECC – 33 model has the following characteristics; design for higher frequency up to 2GHz, for tall buildings, it was proposed for mobile system having omni – directional antenna (mobile Station) sited less than 3m above the sea level [1]. ECC -33 models usually produce better results in urban environment, according to [1] Path Loss is define as,

$$P_L = A_{fs} + A_{bm} - X_b - X_r \quad (18)$$

Where:

A_{fs}, A_{bm}, X_b, and X_r are the free space attenuation, the basic median path loss, the BS height gain factor and MS height gain factor. They are individually define as,

$$A_{fs} = K + 20\log_{10}(d) + 20\log_{10}(f) \quad (19)$$

$$A_{bm} = K_1 + a\log_{10}(d) + b\log_{10}(f) + c[\log_{10}(f)]^2 \quad (20)$$

$$X_b = \log_{10}(h_B/200)\{13.958 + 5.8[\log_{10}(d)^2]\} \quad (21)$$

$$X_r = [42.57 + 13.7\log_{10}(f)][\log_{10}(h_r) - 0.585] \quad (22)$$

Where:
f is the frequency in MHz, d is the distance between the BS and the MS, h_b is the height of the BS and h_r is the height of the MS.
Since ECC – 33 models is design mostly for urban and medium cities, but Mubi does not have tall buildings and use lower frequency this model may not be suitable for this work that is the reason of choosing COST 321 Hata model because of its applicability with investigated environment.

2. Study Area and Method of Data Collection

Mubi falls within the sudan savannah belt of Nigerian vegetation zone in the north east of the country, the zone is made of dry land weeds interspaced by shrubs and woody plants the plants are divided into two; indigenous and exotic woody plants. The indigenous woody plants are Tamarin, Shear butter, Locust bean, Barasus aethiopus “Giginya” their height ranges between 7m – 12m and exotic woody plants are Neem, Mahogany, Date palm “Dipino” cashew and Guava almost of the same height [2]. Mubi lies between latitude $9^0 30^1$ and 11^0 north of the equator and longitude 13^0 and $13^0 34^1$ east of Greenwich meridian it has total population of 759, 045 and land area of 4728.77km^2 [5], Mubi region has hills of approximately 20m – 25m high above the sea level in the eastern part of the town which is roughly 2 -5km away from the main settlement. There are about 8 functional GSM base station (BS) planted in the town in different locations of different GSM network operators namely ZAIN, MTN and GLO, although only three BSs were considered in this work one of each of the GSM network operator. The BSs were installed at 30, 35 and 35m above the sea level for ZAIN, MTN and GLO respectively. In the area where the measurement was conducted the highest building is about

17.5m, the trees and the building are scattered around the town. To generate measurements of signal strength (power density) level for the uplink and the down link at the coverage area for a cell TEM instrument was used. In the measurements maximum open areas were noted first and recorded which is refer to as free space path loss without any form of obstacle, the free space path loss were detected at 350, 200m and 100m for ZAIN, MTN and GLO respectively while the subsequent measurements were taken at 500m up to 5000m for each of the GSM network operators as shown in Table -1. The measurements were conducted from the major three GSM base stations (BS) at a desired distance and neglecting other source of radiations.

3. Results and Discussion

The results of the empirical measurements are shown in Table 1,

Table 1: Measured propagation path loss

Distance (m)	ZAIN (dB)	MTN (dB)	GLO (dB)
500	134.52	132.31	133.20
1000	133.88	132.33	133.88
1500	135.20	132.87	134.04
2000	136.41	133.04	135.01
2500	137.08	134.56	135.86
3000	138.02	135.58	136.02
3500	139.33	138.44	136.44
4000	140.11	138.89	137.20
4500	140.88	137.66	138.00
5000	141.01	138.99	139.41
Overall	137.64	135.47	135.91

Having determined the average path loss of each of the GSM network Operators in Mubi town, we can now find the undefined variable x from the model of Eq. (10) for the smooth earth propagation which may be written as,

$$x = \log_{10}{}^{-1}[L_p - (20\log h_B + 20\log h_M)] \\ / \log_{10} d \qquad (23)$$

Then the model Equation of smooth earth propagation for the three GSM network Operators may also be written as,

$$L_p(Zain) = 2.97\log_{10} d + 20\log_{10} h_B \\ + 20\log_{10} h_M \qquad (24)$$

$$L_p(MTN) = 2.92\log_{10} d + 20\log_{10} h_B \\ + 20\log_{10} h_M \qquad (25)$$

$$L_p(Glo) = 2.93\log_{10} d + 20\log_{10} h_B \\ + 20\log_{10} h_M \qquad (26)$$

Where:
L_p(ZAIN, MTN and GLO) are the path loss for ZAIN, MTN and GLO network operators respectively.
The needs for high quality and high capacity network, estimating coverage accurately has become extremely significant [8], therefore for more accurate design coverage of modern cellular networks the signal strength measurements must be taken into consideration in order to provide an efficient and reliable coverage area [9]. The free space loss measured at 350, 200 and 100m were computed as 37.9, 37.5 and 37.01dB for ZAIN, MTN and GLO respectively. Using Eq. (7), the mean square error (E) of the propagation path loss measured for the three GSM operators were determined using the Eq. (28) derived from expression of Eq. (27) given by,

$$\sigma = \left[\frac{\sum(P_L - \bar{P_L})}{N}\right]^{\frac{1}{2}} \qquad (27)$$

Where σ is the standard deviation of the signal strength and N is the number of terms while the mean square error or the prediction error is also given as,

$$E = \frac{\sigma}{\sqrt{N}} \qquad (28)$$

The average prediction errors were found to be 0.219, 0.244 and 0.136 dB for ZAIN, MTN and GLO GSM operators respectively. The mean square errors were then subtracted from the Equation of Hata model and the modified model Equations for each of the GSM operators is then define as,

$$L_{m(ZAIN)} = 69.33 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) \\ -[0.8 + (1.1\log_{10}(f) - 0.70)h_m - 1.56\log_{10}(f)] \qquad (29) \\ +[44.9 - 6.55\log_{10}(h_B)]\log_{10} d$$

$$L_{m(MTN)} = 69.31 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - [0.8 + (1.1\log_{10}(f) - 0.7)h_m - 1.56\log_{10}(f)] + [44.9 - 6.55\log_{10}(h_B)]\log_{10} d \quad (30)$$

$$L_{m(GLO)} = 69.41 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - [0.8 + (1.1\log_{10}(f) - 0.7)h_m - 1.56\log_{10}(f)] + [44.9 - 6.55\log_{10}(h_B)]\log_{10} d \quad (31)$$

These modified Equations may be applicable to the other GSM base station in Mubi, since they have almost similar installation properties and the geographical features of Mubi remain unchanged, the prediction errors were found to be < 0.25dB in all the empirical measurements, this fall within the acceptable range [13]. It was also observed that the signal strength is a function of distance and antenna height, as we can see in this work the highest antenna has less propagation path loss and as the distance increases the path loss also increases.

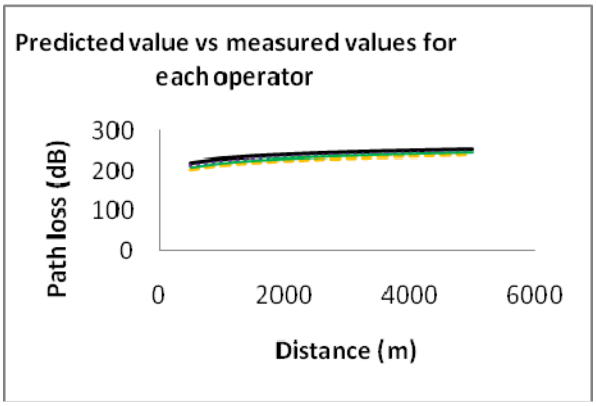

Figure 2: Theoretical model against empirical model

Legend

Theoretical — Zain

Glo — MTN

Figure 2, presents the practical and the theoretical path loss against distance of all the GSM network operators, after determining the path loss of the measured values for each distance, the study then compared the measured and theoretical values. From the plot, the results clearly show that the measured path loss is less than the theoretical path loss this may be cause due the difference in density of the environments and location/height of base stations.

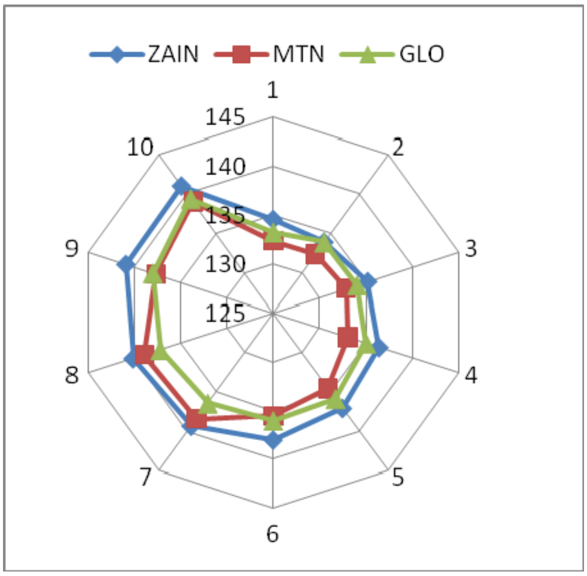

Figure 3: Spider web graphic of Propagation path loss measured for the three GSM network operators in Mubi.

Figure 3, present average amount of propagation path loss measured at different points 500m (point 1) - 5000m (point 10) where the enclosed area in the spider web graph described the total path loss measured from point 1 – 10 for all the GSM network operators. ZAIN has the highest path loss greater than that of GLO with 1.73dB and that of MTN with 1.17dB while MTN is the least, the overall path loss measured for all the GSM operators is ≤ 7dB this within the acceptable range, since the acceptable range lies between $1 < P_L \leq 15$dB [8].

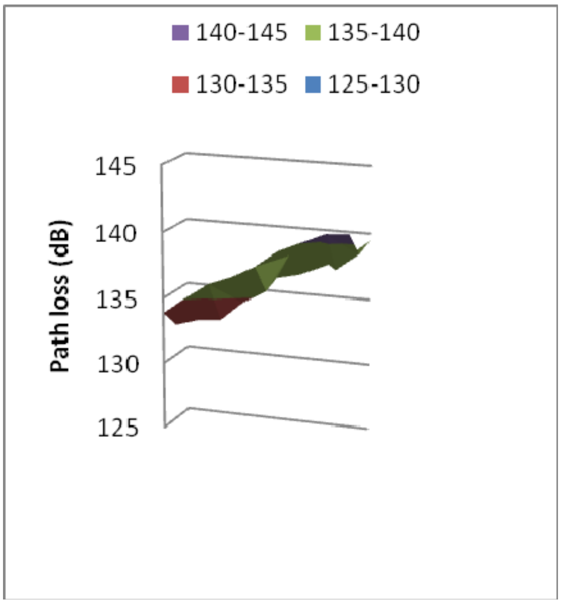

Figure 4: Measured path loss from 500 – 5000m for the three GSM operators.

Figure 4 present the series of measurements conducted from 500 – 5000m for all the GSM network operators; as shown above path loss measured from 135 – 140 dB appeared more frequent followed by 130 – 135 dB while 140 – 145 dB is the least and 125 – 130 dB does not appeared completely

4. Conclusion

This work aim at predicting path loss propagation and to develop model that may address the public complains in Mubi town. The average path loss measured for GSM network operators were 137.64, 135.47 and 135.91dB over 5000m for ZAIN, MTN and GLO respectively, the maximum mean square errors determined were found to be less than 0.25dB . The new modified model Equations developed were base on the applicability of the Mubi environmental factors/terrains. We believe that the model developed would help in planning, expansion and design of new GSM network.

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