Path Loss Propagation Model for Gombi Town Adamawa State Nigeria

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Summary
The desire in this work is to develop a model that can help in planning better Global system for mobile communication (GSM) network and to address the complains of the poor quality of GSM network services in Gombi town by the customers. Measurements were conducted to precision, the overall average path loss detected were 144.93, 143.76 and 147.76dB for MTN, ZAIN and GLO and the mean square error obtained were 2, 1.5 and 3dB respectively, these differences may be attributed to the nature of the environments or the location or height of the Base stations (BSs). The new modified Equations were developed using Hata model that can help in planning and optimization of the investigated environment.

Key words:
Network quality, subscribers, environment, empirical measurement and model.

1. Introduction

Gombi experience rapid growth of global system for mobile communication (GSM) telephone subscribers' right from the day the GSM operators came into operation in Gombi, as the number of subscribers of GSM phone user increases the spectral efficiency becomes more critical because the frequency allocation is limited resources. The smaller the frequency reuse the greater the network capacity [10], high spectral efficiency means great achievement by reusing, frequency over irregular terrain such as trees, building and other geographical features.

Gombi experience some call difficulties more especially from 2006 to date Field survey (2010). The GSM reception suffers the following; frequent call drop, network busy,

Poor intra and inters connectivity, cross talk, during conversion.

According to Barry MClarnan (2000) attenuation from trees or buildings/trees are usually of order of 0.05dM/m, since Gombi used 900MHz as the carrier frequency the minimum expected attenuation may be of order of 0.225dB/m this depend strictly on distance where the power density is detected or received or the complexity of the environment

There are many factors that affects GSM signal strength which may include rainfall, snow, fog, reflection, diffraction, free space loss, vegetation and other geographical features but this work emphases on modeling of free space loss, reflection and diffraction effects which happened to be the major effect that could significantly cause path loss or hamper effective communication. This work aim at developing models for each GSM operators which may addressed some of the pronounce effect on the GSM signal strength. This work is also organized in the following manner theoretical modeling of the three components considered in this research followed by the empirical model then results, discussion and conclusion.

1.1 Theoretical Propagation Model

The propagation models are divided into three basic types these are, free space propagation, flat or smooth earth propagation mode and diffraction effect propagation.

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 [5]. Free space attenuation increases as the frequency goes up for a given unit of distance this occurs because higher frequencies have shorter wave lengths [3], and cover a given distance, consequently the higher the frequency the shorter the wave length. By having identified the power flux, the power density at any point at a distance from the radiator, if the receiver antenna is place at this point the power received by the antenna can be calculated. Consider a transmitter with $P_{(t)}$ coupled to an antenna which radiates equally in all directions at a distance (d) from the transmitter where the power density is detected,

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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

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

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

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

Considering (λ in km) and rationalizing the Eq. (6) 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 Rappaport et al (1997) 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 Flat or smooth earth propagation model.

The free space propagation model does not consider the effects of propagation over ground. When a radio wave propagate over flat or smooth earth such as desert, water or wet ground some part of the power would be reflected due to the presence of the flat or smooth earth and then received by the receiver. If the effect of the reflected power is determined then we can say the free space model is modified this is referred to as "flat or smooth earth reflection" propagation model. The vector sum of the flat or smooth earth model 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.

$$L_{fse} = 32.4 + 60\log(d) + 20\log(f)(1)20\log(h_B) - 20\log(h_M) \quad (10)$$

1.4 Diffraction effects

The free space propagation model and flat or smooth earth propagation does not consider the effect of diffraction. A Fresnel zone is a simpler concept to understand diffraction effect, it is just the volume space enclose by an ellipsoid which has two antenna at the ends of the radio link at its foci. A signal that may be received by the receiver may not be completely free from diffraction since the propagation path travels across quite a number of different geographical features such as building, trees and other geographical features, this can cause significant path loss. The electric field receive by the receiver may be described by the combination of the direct signal path propagation cause by diffraction, free space loss and the flat or smooth earth reflected wave may be summed together to give the actually path loss.

$$E_{x(\max)} = \frac{7.01\left[x_2^2 + x_1^2 \times |\rho_h|^2 + x_2 x_1 \times |\rho_h| \cos(\varphi_h - \alpha(x_2 - x_1))\right]}{[x_2 x_1]} \quad (11)$$

$$x_1 = \left[R^2 + (h_T - 1.5)^2\right]^{\frac{1}{2}}$$

$$x_2 = \left[R^2 + (h_T + 1.5)^2\right]^{\frac{1}{2}}$$

$$\rho_h = \frac{\sin\beta - (\varepsilon_r + j60\lambda\delta - \cos^2\beta)^{\frac{1}{2}}}{\sin\beta - (\varepsilon_r - j60\lambda\delta - \cos^2\beta)^{\frac{1}{2}}}$$

Where, ε_r is the relative dielectric constant, λ is the wave length in meter, δ is the conductivity in Siemens/meter and β is the angle of incidence. Therefore the power equivalent of the electric field may be express as

$$p_R = \frac{|E_R|}{30G(\theta)} \times \frac{d}{e^{-j\varepsilon_r}} \quad (12)$$

Where P_R is the power received by the receiver, G (θ) is the directed antenna gain and d is the propagation path length in meter [4], the path loss may be written as from expression (5)

$$L_{de} = P_T - \frac{|E_R|}{30G(\theta)} \times \frac{d}{e^{-j\varepsilon_r}} \quad (13)$$

1.5 Empirical Propagation Model

The three basic propagation model discussed in the theoretical model above such as free space, flat or smooth loss and the diffraction loss would requires detailed knowledge of the location, dimension and constitutive parameters of every buildings, trees and other geographical features in the investigation area or cell to be covered. This is far complex, tedious and cumbersome to be practical and definitely it would yield unnecessary amount details or it is 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 Hata nodel [5] these models can solve the problems of the complexity effects, among the mention models Hata is chosen because of its suitability of the general characteristics of the investigation area.

1.6 Hata - Model

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 t0 10m [7, 8]. Base on field test result predicted, Hata created a number of representative path loss mathematical model for different types of clusters as follows

$$L_U = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - C_H + [44.9 - 6.55\log_{10}(h_B)]\log_{10} d \quad (14)$$

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

$$C_H = 0.8 + (1.1\log_{10}(f) - 0.7)h_M - 1.56\log_{10}(f) \quad (15)$$

Substituting (15) into (14), it yield

$$L_m = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - [0.8 + (1.1\log_{10} - 0.7)h_M - 1.56\log_{10}(f)] + [44.9 - 6.55\log_{10}(h_B)]\log_{10} d \quad (16)$$

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.

2. Investigation Area and Method of Data Collection

Gombi 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 categories; 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, cashew and Guava almost of the same height [1]. Gombi has hills of approximately 20m – 25m high above the sea level in the eastern part of the town which is roughly 10KM away from the main settlement and streams also 15KM away from the main settlement. There are only 3 GSM base station (BS) planted in the town in different locations of different GSM Operators namely ZAIN, MTN and GLO. The BSs were installed at 35, 30 and 35m above the sea level for ZAIN, MTN and GLO respectively. In the area were the measurement was conducted the highest building is about 10.5m, the trees and the building are scattered round the settlements. 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 measurement maximum open areas were noted first and recorded which refer to as free space path loss without any form of obstacle and some measurement were taken behind the trees and the building in the investigation area, the free space path loss was detected at 100m, 75m and 102m for ZAIN, MTN and GLO respectively while the subsequent measurements were taken at 500m up to 5000m for each of the GSM Operators.

3. Results and Discussion

The results of the measurements are shown in Table-1. The measurements were taken at an interval of 500m, 10 times for each of the GSM BSs.

The needs for high quality and high capacity network, estimating coverage accurately has become extremely significant, 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 [5].

Table 1: Measured path loss in (dB)

Distance (m)	Path loss (dB) (MTN)	Path loss (dB) (ZAIN)	Path loss (dB) (GLO)
500	139.33	138.30	140.12
1000	140.73	139.68	139.88
1500	140.22	141.07	142.32
2000	142.11	141.76	144.32
2500	143.16	142.45	145.42
3000	142.81	143.83	147.43
3500	143.51	144.52	150.13
4000	144.21	146.60	154.12
4500	151.87	147.98	155.53
5000	153.26	151.44	158.34
Overall Ave.	144.12	143.76	147.76

The free space loss measured at 100, 75 and 102m were computed as 30.9, 27.5 and 29.01dB for ZAIN, MTN and GLO respectively using Eq. (7), the mean square error of Table 1 were determined using expression (17)

$$E = \frac{\sigma}{\sqrt{N}} \quad (17)$$

Where E is the mean square error, σ is the standard deviation and N is the number of terms.
The average mean square errors (E) of the propagation path loss measured for the three GSM operators were determined using the Eq. (17) as 2dB, 1.5dB and 3dB. The average mean square error is then subtracted from the Eq. (16) of Hata model and the modified Equations for each GSM Operators now becomes

$$L_{m(ZAIN)} = 67.83 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - [0.8 + (1.1\log_{10}(f) - 0.70)h_m - 1.56\log_{10}(f)] + [44.9 - 6.55\log_{10}(h_B)]\log_{10} d \quad (18)$$

$$L_{m(MTN)} = 67.31 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - [0.8 + (1.1\log_{10}(f) - 0.7)h_m - 1.56\log_{10}(f)] + [44.9 - 6.55\log_{10}(h_B)]\log_{10} d \quad (19)$$

$$L_{m(GLO)} = 66.41 + 26.16\log_{10}(f) - 13.82\log_{10}(h_B) - [0.8 + (1.1\log_{10}(f) - 0.7)h_m - 1.56\log_{10}(f)] + [44.9 - 6.55\log_{10}(h_B)]\log_{10} d \quad (20)$$

The new modified Equations of Hata – model in (18 – 20) are then compared with Hata model Eq. (16) to see which one is suitable for planning and optimization of the investigated area as depicted in Fig. 1.

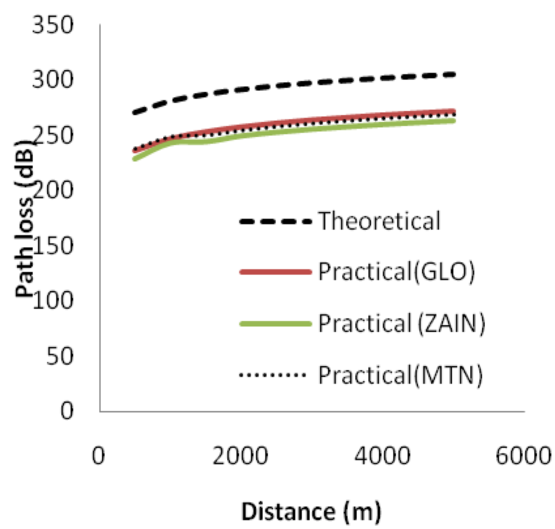

Fig. 1: Path loss verses distance

Fig. 1, presents the practical and the theoretical path loss against distance for all the three GSM 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 path loss for all the measured values is less than the theoretical path loss although it varies from each GSM BSs, this may be attributed to the location or height of the BSs and the compatibility of the environment and trees in the investigation area.

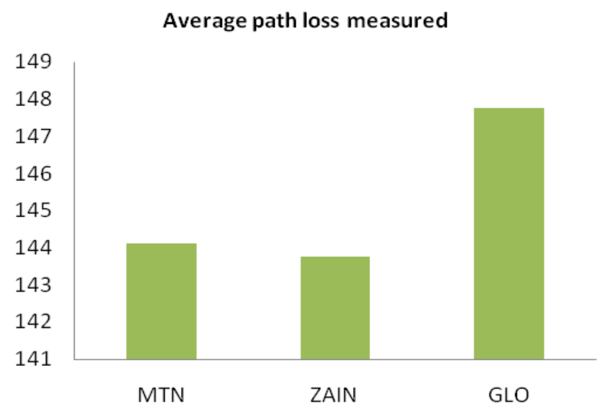

Fig. 2: Propagation path loss

Fig. 2, presents the overall average amount of propagation path loss measured for the GSM Operators. GLO has the highest path loss greater than that of MTN with 1.73dB and that of ZAIN with 1.17dB while ZAIN is the least, the overall average of the path loss measured for all the GSM Operators lies between 1 ≤ 18.22dB, for MTN the maximum difference measured from BS to 5000m is 13.93dB, for ZAIN is 13.14dB while for GLO is 18.22dB this within the acceptable range, since the acceptable range lies between $1 < P_L \leq 20$dB [9].

4. Conclusion

The desire in this work is to develop a model that can help in planning better Global system for mobile communication (GSM) network and to address the complains of the poor quality of GSM network services in Gombi town by the customers. The overall average path loss predicted ware 144.93, 143.76 and 147.76dB for MTN, ZAIN and GLO and the mean square error obtained were 2, 1.5 and 3dB respectively, base on these results the new modified Equations was developed using Hata model that can help in planning and optimization of the investigated environment.

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