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Path Loss Modeling for Adamawa State University Mubi Using Multiple Probability Models

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Abstract— Path loss is the reduction in the Global System for Mobile Communication (GSM) signal strength (SS), its significant increase can lead to poor quality of service (QoS) received by the end-user of the 'GSM' network. In this work, path loss measured at Adamawa State University (ADSU), Mubi environment was modeled using multi probability models such as Lognormal, Nakagami, Rayleigh, and Rician distributions, the goodness of fit was applied to determine the best fit model, probability of the path loss exceeding the critical point was obtained, Hata model was adopted and optimised and "BTS' height capable of improving the 'SS' was also obtained. The results show that mean of the path loss measured using the probability models: for Air Tell operator were 101.16dB, 103.30dB, 90.151dB, 101.43dB, for Global Com are 92.368dB, 95.232dB, 85.087dB, 95,377dB, for MTN are 91.368, 91.368dB, 91.594dB and 91.377 respectively. Goodness of fits (GoF) were obtained for Air Tell as 0.0025, 0.0125, 10.992, 0.0005, for Global Com as 0.0275, 0.0149, 10.179, 0.0001, for MTN as 0.0202, 0.095, 9.7819 and 0.0001 respectively. Probabilities of exceeding critical points were determined as 0.0210, 0.0151, and 0.0100 for Air Tell, Global Com, and MTN respectively, average mean square error of all operators were evaluated as 0.976, and Base Transceiver Station height was computed as 35m. It was observed that Air Tell operator experienced more path loss followed by Global Com and MTN is the least. Rician Distribution model was obtained as the best model because it has the least goodness of fit. This means that the GSM network QoS received at the university is mostly affected due to ground reflection. The path loss may exceed the critical point by an average of 3.17% and the BTS height at 35m can improve the QoS of the network in ADSU.

Keywords/Index Terms— Models, Goodness of fit, Probability of exceeding critical point, Optimization, Quality of Service

1. Introduction

It is generally known that Global System for Mobile Communication (GSM) network engineers (NE) use path loss (L) models to plan, design and analyse telecommunications system link budget (LB) (Danladi, *et al*, 2017 & Robert *et al*, 2020). 'L' simply means the fading away of the electromagnetic wave (power density) usually refers to as attenuation when the 'GSM' signal strength propagates through the atmosphere between the Base Transceiver Station (BTS) and Mobile Station (MS).

It is reported by 'NE' and many authors that the GSM signal strength (SS) is not always hitch free from transmission impairments such free space loss, reflection, refraction, diffusion, diffraction, absorption caused due to objects the 'BTS' and MS, foliage, dry and moist air. In addition, the signal is also affected by the nature of the terrain, vegetation, human activities, antenna height, and locations.

A significant increase in 'L' reduces the spectral efficiency of the network especially when there is no proper line of sight (LOS) (Susil & Prafulla, 2011), consequently, the quality of service (QoS) received by an end-user of the network is compromised as discussion in (Goshwe *et al*, 2013).

The primary aim of any network provider is to provide perfect or near-perfect 'QoS' to her end-users without or little interference as also highlighted in (Danladi & Vasira, 2018). In this regards, 'GSM' network providers need to regularly monitored and modeled their networks for effective communications to take place using probability or mathematical models to model and forecast the network condition (Shu *et al*, 2015 & Segun *et al*, 2018). Probability models (PMs) have been used by different authors to model 'L' and other fields, for example in (Meanggi, 2005; Edward & Vivgi, 2007; Hill, 2008; Daragana *et al*, 2013; Saikat & Amitabha, 2020). However, in the modeling choice of the appropriate model is important and it depends on the nature of the environment.

It is always good for every area to have a separate 'LB' of a specific environment to have efficient network service (Danladi, *et al*, 2018 & Robert *et al*, 2020). 'PMs' such as Reyleigh, Rician, Nakagami, Weibull, Lognormal and Gaussian distributions to mention but a few have been used to model radio propagation wireless channels in terms of shadow, multipath, slow and fast fading phenomena (Choudhury & Gibson, 2007; Shanka, 2011; Samimi, 2011; Wang, Lin & Kam, 2016;), for instance, (Mouhamed & Yousef, 2013) applied Lognormal Distribution (LD) to model wireless communication network and found that power density is attenuated due to large buildings and hills of the area under review (Chi– Bao & Dinh–Thuan, 2020) utilized Nakagami Distribution(ND) to assess the transmission quality in a radio communications fading channels and revealed that 'SS' is affected due to 'L'.

In another separate study, (Meiling, 2013) also used 'ND' to model wireless channels and observed that the model can perfectly describe the amplitude of received 'SS' after maximum radio diversion is reached. The aim of this work, is to address complaints of poor 'QoS' of GSM network on the Adamawa State University (ADSU), Mubi campus and the following challenges shall be addressed; multiple probability distribution models shall be applied to model 'L' measured, determine the goodness of fits of the distributions in order to select the best fit model (BFM), identify the type of fading phenomenon (shadow or multipath), use the 'BFM' to obtain the probability of exceeding critical point (PECP), adopt and optimise 'ADSU' network status.

It is generally known that the choice of wrong frequency or BTS height can significantly reduce the 'QoS' of GSM networks (Mathias *et al,* 2006). This paper is structured and organized in the following manner: introduction, study area and methodologies, results, discussion and conclusion (Misra 2021)

Table 1: Probability Distribution Applications in Wireless Communication Systems

Model	Application
LD	Considers large obstruction due to hills, large buildings
ND	Is applied when there is multipath scattering, large time delay spread with different clusters of reflected waves
RD	Is utilized when there is no line of sight propagation between 'BTS' and 'MS'
RaD	Is suitable when there is line of sight and ground reflection

2. Study Area and Method of Data Collection

'L' is the path loss measured using Mobile Equipment (ME) and was placed at 1.5m above the ground in a specific location approximately 1.2km to 1.5km from the 'BTSs" at the 'ADSU', Mubi. The measurement was taken at 1:00 pm for a period of 30 minutes daily for one year.

It is expected at that time, sun intensity, temperatures are high, human activities are at top gear. 'ADSU', is interspaced with indigenous trees typically of heights greater than or equal to 8m, buildings above 5m with window glasses, has open areas such football, handball, basketball, tennis cords, open areas between the faculties and several roads.

Three sets of values of 'L' data were measured from the major 'GSM' operators in Mubi; MTN, Air Tell, and Global Com.

2.1 Method of Data Modeling

Four different types of 'PM's were applied to model 'L'. These include Log-normal, Nakagami, Rician and Rayleigh distributions in an attempt to choose the best the model capable of modeling 'L'

Let's assume that 'L' is randomly received at the chosen location as '$L_1, L_2, \ldots\ldots, L_n$'

A. Log-*normal Distribution {LD}*

If 'L' is log - normally distributed, then $Y = \ln(L)$ is normal distributed. Then the two parameters of the probability density function (PDF) can be estimated using expression (1)

$$\text{f } f(L;\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left(\frac{\ln(L-\mu)^2}{2\sigma^2}\right);\ (-\infty \le \mu \le +\infty),\ (0.125 \le \sigma \le 10) \quad (1)$$

where 'L', 'µ' and 'σ' are the 'PL' received, location and the scale parameters respectively.

B. *Nakagami Distribution (ND)*

When 'L' is Nakagami distributed, parameters 'm' and 'Ω' of the 'PDF' may be obtained using Equation (2) given by

$$f = (L\ m, \Omega) = \frac{2m^m}{\Gamma(m)\Omega^m} x^{2m-1} \exp\left(-\frac{m}{\Omega} L^2\right);\ (0.5 \le m \le 5), (1 \le \Omega \le 3) \quad (2)$$

where 'm' and 'Ω' are the location and the scale parameters respectively.

When 'L' is Rayleigh Distributed, the parameter 'σ' of the 'PDF' may be calculated using expression (3) given as

C. *Rayleigh Distribution (RD)*

$$f(L;\sigma) = \frac{x}{\sigma^2} \exp-\left(\frac{L^2}{2\sigma^2}\right);\ (0.5 \le \sigma \le 4) \quad (3)$$

where 'σ' is the scale parameter.

D. *Racian Distribution (RaD)*

If 'L' is racian distributed, then parameters of the 'PDF' can be determined as expressed in Equation (4) as

$$f(L;\nu,\sigma) = \frac{x}{\sigma^2} \exp\left(-\frac{x^2-\nu^2}{2\sigma^2}\right) I_0\left(\frac{L^\nu}{\sigma^2}\right);\ (0 \le \nu \le 4), (\sigma = 1) \quad (4)$$

where 'ν', 'σ' and 'I_0' are the location, the scale and Bassel function parameters respectively.

2.2.1*Maximum Likelihood Estimations (MLE)*

Since, 'L' is randomly distributed and denoted by $L_1, L_2, \ldots, L_n$, and assumed the unknown parameter (θ) of the 'PDFs' for each value of 'L_i' is $f(x_i, \theta)$, then joined 'PDF' of $L_1, L_2, \ldots, L_n$ is given in Equation (5) as

$$M(\theta) = f(L_1;\theta) \times f(L_2;\theta) \times \ldots\ldots \times f(L_n\ \theta) \quad (5)$$

$$\therefore\ M(\theta) = \prod_{i=1}^{n} f(L_i;\theta) \quad (6)$$

Equation (6) implies that, 'L' is independent, M(θ) is 'MLE' and can be applied to estimate the parameters of 'PDFs' of the 'PMs' as

$$M(\mu;\sigma) = \prod_{i-1}^{n} \frac{1}{L_i} \varphi_{\mu,\sigma}(\ln L_i) \quad (7)$$

2.2 **Goodness of Fit**

Goodness of fit (GoF) can be tested using Anderson Darling test, Kuiper's test, Shapiro test, Jarque – Bera and Kolmogorov – Smirnov (K - S) among others (Oguntunde, *et al*, 2014). In this work, 'K – S' is applied to test 'GoF' of the distributions in an attempt to select the 'PM'. Given the N[th] number of 'L', the test statistics of 'K-S' may be performed using Equation (8).

$$D \equiv \max_{1 \le i \le n} \left(F(L_i) - \frac{i-1}{N}, \frac{i`}{N} - F(L_i) \right) \quad (8)$$

2.3 Probability of Exceeding Critical Point

'PECP' of the fit model may be evaluated using expression (9).

$$F_n(L) = p(L_0 \le L) = 1 - \int_{-\infty}^{x} f(L) dL \quad (9)$$

f(L) is the cumulative frequency distribution (CFD) of the fitted model.

2.4 Optimization of Path Loss Model

Path loss models 'LMs' are usually used for deploying 'GSM' network resources such as antenna height, frequency, coverage area and many other factors for effective communication. These models include Hata, Okumura, Ericsson, SUI, COST 231, to mention but a few. They are usually adopted and optimised based on the empirical data measured of the environments under consideration such as rural, suburban or urban area. Mubi is a suburban area. Therefore, in this work, Hata model for suburban area is adopted and it is characterised by the following conditions (i.e., f_c, = 150 – 1500MHz, h_m= 1 – 10 m, h_b = 1 – 200m and d = 1 –10km) (Parmar & Nimavat, 2015). The model is expressed as given in (10)

$$L_{SU}(dB) = L_u - 2\left[\log \frac{f_c}{28}\right]^2 - 5.4 \quad (10)$$

$$L_U = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} - a(h_b) + (44.9 - 6.55 \log_{10}) \log_{10} d \quad (11)$$

$$a(h_m) = \{1.1 \log_{10}(f) - 0.7\} h_m - \{1.56 \log_{10}(f_c) - 0.8\} \quad (12)$$

Where f_c = transmission frequency, h_b='BTS height, d = link distance between the 'BTS' and 'MS', a (h_b) = antenna correction factor, e = root mean square error and h_m = 'MS' height. 'e' is expressed as

$$e = \sqrt{\sum_{t=1}^{n} \frac{(L_{SU} - L_0)^2}{n}} \quad (13)$$

L_0 is the optimized path loss.

3. Result

Tables 1a and 1b were derived from Figures 1a – 1c, which provide information about the means of 'L' measured for each network service provider in terms of the 'PM' with their parameter estimates. Table 3 presents the goodness of fit of each model using 'K – S' test and Table 4 shows 'RMSE', 'PECP' and 'BTS' height.

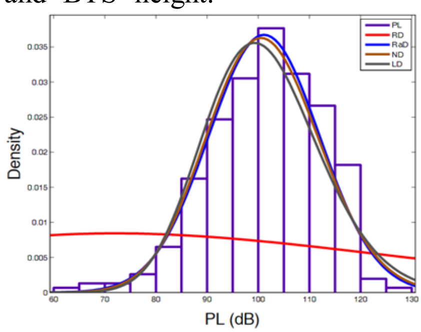

Figure 1a: Parameter Estimates of 'PDM' for Air Tell

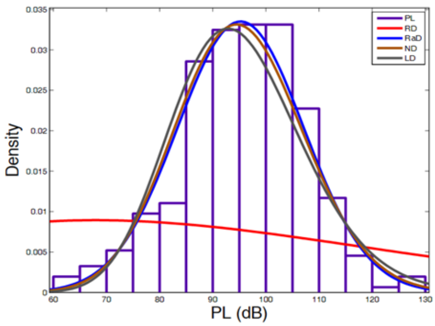

Figure 1b: Parameter Estimates of 'PDM' for Global Com**.**

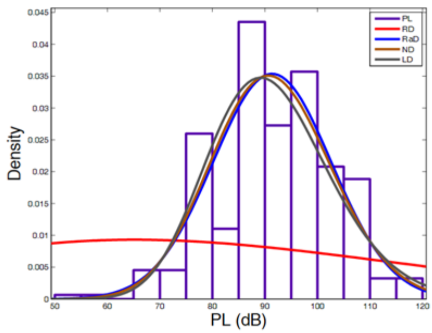

Figure 1c: Parameter Estimates of 'PDM' for MTN

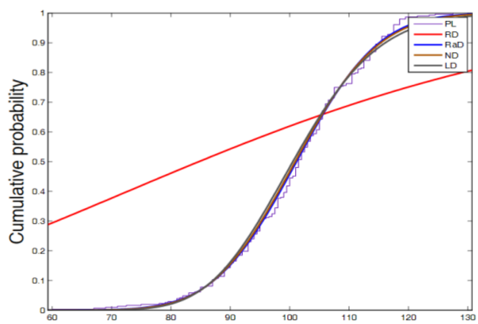

Figure 2a: CDF of Air Tell Path Loss

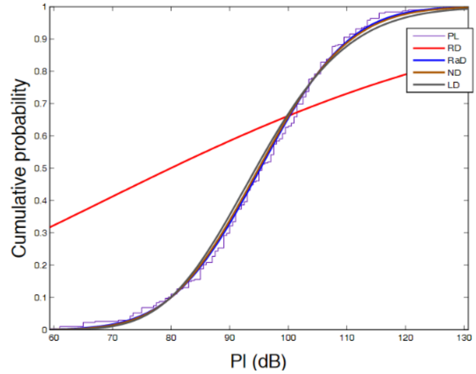

Figure 2b: CDF of Global Com. Path Los

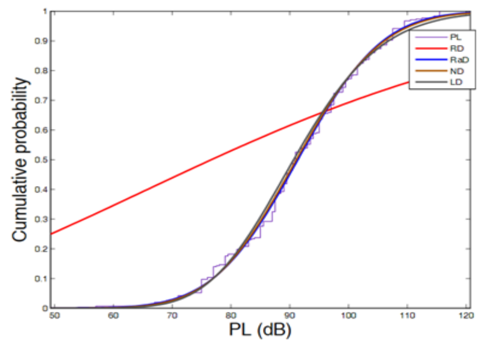

Figure 2c: CDF of MTN. Path Loss

Table 2a: Mean of Air Tell Fitted Distribution and Parameter Estimates

Distributions	Mean	Parameters of MLH	
Lognormal	101.16	$\mu = 4.0887$	$\sigma = -1.02e^{-5}$
Nakagami	101.30	$m = 21{,}327$	$\Omega = 10348$
Rayleigh	90.151	$\sigma = 71.930$	
Rician	101.43	$\nu = 100.55$	$\sigma = 10.893$

Table 2b: Mean of Global Com. Fitted Distribution and Parameter Estimates

Distributions	Mean	Parameters of MLH	
Lognormal	95.274	μ = 4.5482	σ = 0.1305
Nakagami	95.232	m = 15.807	Ω = 9213.7
Rayleigh	85.087	σ = 67.874	
Rician	95.377	ν = 94.488	σ = 11.953

Table 2c: Mean of MTN Fitted Distribution and Parameter Estimates

Distributions	Mean	Parameters of MLH	
Lognormal	91.368	μ = 4.5071	σ = 0.1276
Nakagami	91.368	m = 16.327	Ω = 8477
Rayleigh	81.594	σ = 65.104	
Rician	91.377	ν = 90.667	σ = 11.323

Table 3: Goodness of Fit using 'K – S' Test

Distributions	Air Tell	Global Com.	MTN
Lognormal	0.0125	0.0275	0.0202
Nakagami	0.0125	0.0149	0.0095
Rayleigh	10.992	10.179	9.7819
Rician	0.0005*	0.0001*	0.0001*

Table 4: PECP, RMSE and BTS Height

Network Resource	Air Tell	Global Com.	MTN
PECP	0.0210	0.0151	0.0110
Average RMSE (e) = 0.9716 dB			
Average BTS Height = 35m			

4. Discussion

'PMs' were employed to model the measured on the campus of 'ADSU' these include the 'LD', 'ND' (RD), and 'RaD' for each of the 'GSM' operators as shown in Tables 2a – 2c. The modeling was performed in terms of the mean value of 'L' measured, shape parameters (m, Ω and μ), and scale parameter (σ). Table 2a presents the results of the analysis of the Air Tell GSM operator, the mean values of 'L' using 'LD', 'ND'. (RD) and 'RaD'

were obtained as 101.16dB, 101.13dB, 90.151dB and 101.14dB respectively, where 'LD' is the highest followed by 'RaD' and 'RD' then 'RD' is the least and seems to deviate from the general trend. The parameters of maximum likelihood were estimated using 'LD' as μ = 4.0890, σ = -1.02e^{-5}, 'ND' as μ = 21.327, Ω = 10348, 'RD' as σ = 71.930 and 'RaD' as ν =

100.55, σ = 10.893 respectively. In similar manner, Table 2bdepicts the mean of 'L' for Global Com. as 95.274dB, 95.232dB, 85.067 and 95.247dB and the parameters of maximum likelihood were obtained for ''LD' as μ = 4.3482, σ = 0.1305, 'ND' as μ = 15.807, Ω = 10348, 'RD' as σ = 67.874 and 'RaD' as ν = 94.488, σ = 11.953 respectively and Table 2c shows that the mean of 'L' of MTN operator were determined as 91.368dB, 91.3686dB, 81.594dB and 91.377dB with maximum likelihood estimated for ''LD' as μ = 4.5011, σ = 0.1276, 'ND' as μ = 16.310, Ω = 8477, 'RD' as σ = 65.104 and 'RaD' as ν = 90.667, σ = 11.323 respectively.

It is noticed that Air Tell operator experienced more 'L' followed by Global Com. and MTN is least. However, all the values of 'L' measured were below the standard values of the 'L' of the first kilometer of the radio link by 8.570dB, 14.623dB, and 18.623dB respectively (Stutzman & Thiele, 1981), whereas the parameters of the maximum likelihood of the best fit model were employed to estimate the 'CDF' (Oguntunde et al, 2014; Mark & Andrew, 2016).

Table 3 provides the 'GoF' statistics of 'L' modeled for three 'GSM' operators using the 'K – S' test. It can be seen that 'RaD' best fits the 'L' measured in all the scenarios with the least GoF statistics ranging from 0.0001 to 0.0005. Therefore, based on this information, 'CDF' of 'RaD model was determined and the 'PECPs' were also obtained using Equation (9) as 0.02, 0.015, and 0.011 for each of the 'GSM' operators respectively as given in Table 4.

It is reported by many modeling experts that 'GoF' is a good tool for describes how close data fits a particular model (Oguntunde *et al,* 2014)**.** The generalised average value of 'e' was obtained as 0.9716 for Air Tell, Global Com and MTN. The 'SU' model for the three 'GSM' network was optimised as given in Equation (17)

$$L_{SU}(dB) = L_U - 2\left[\log \frac{f_C}{28}\right]^2 - 6.3716 \qquad (17)$$

Furthermore, the generalised 'BTS height was obtained using Equation (17) as 35m. This height can significantly improve the condition of the network in 'ADSU' Mubi (Caroline *et al,* 2014 & Danladi *et al,* 2018). Figure 3 shows the average and the optimized 'L'. as clearly depicted, the 'L' is minimised.

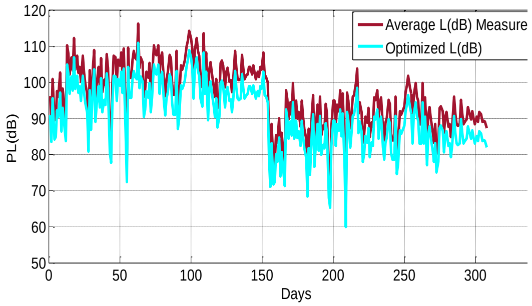

Figure 3 Measured and Optimised Path Loss

5. Conclusion

Path loss of Air Tell, Global Com, and MTN GSM operators in Adamawa State University, Mubi environment has been measured and modeled using multi probability models such as Lognormal, Nakagami, Rayleigh, and Racian distributions and it was found that Air Tell operator experienced more path loss followed by Global Com and MTN is the least. Rician Distribution is the best model because it has the least goodness of fit, which means that the GSM signal was affected due to reflection from the ground especially the open areas within the campus.

The path loss may exceed by an average of 3.17%, this is negligible and the BTS height can improve the QoS of the network in ADSU and recommended that path loss of open areas within the university should be specifically characterised.

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