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Determination of Probability Distribution Function for Modelling Path Loss for Wireless Channels Applications over Micro-Cellular Environments of Ondo State, Southwestern Nigeria

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ABSTRACT

In this research, the most appropriate probability distribution function for modelling RF signal path loss values in both wet and dry season months over urban, suburban and rural environments of Ondo State are presented. The data used consist of a drive test measurement campaign carried out in a typical urban, suburban and rural areas of Ondo State, South-western Nigeria in both wet and dry season months. The received signal strength (RSS) values were collected and recorded in log files alongside other environmental parameters using TEMS investigation tools. Path loss values were deduced from the measured RSS values. Some selected probability distribution function namely: gamma, lognormal, extreme value, logistic, Weibull and normal distributions function were fitted to the measured path loss values and the best suited one determined using three different metric measures. Results obtained show that normal distribution presents the best probability distribution curve for modelling the RF signal path loss over different micro-cellular environments of Ondo State. A typical result of the rural environment indicates that in wet season months, the normal distribution has RMSE of 7.060 dB, Relative Error of 12.480 % and R^2 of 0.988, in dry season months, the RMSE is 9.060 dB, Relative Error of 13.450 % and R^2 of 0.985. When compared with other distribution models, the same trend could be seen in other environments, although with different values of RMSE, Relative error and R^2. The mean and the standard deviation parameters for the normal distribution estimated, vary seasonal-wise and are environment dependent. However, the rural environment exhibited a wider seasonal variations when

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compared with the other environments. The results of this research is useful as a first-hand information in the planning of future wireless propagation channels in the studied environments.

***Keywords*:** probability distribution function, Path loss, normal distribution, wet and dry season

1. INTRODUCTION

In mobile communication systems, the obstacles between the base station and mobile station considerably influence the strength of the transmitted signal by attenuating the transmitted radio frequency signal, this attenuation is known as path loss [1]. The probability distribution models and prediction models have a major role in the optimization of radio frequency coverage, analysis of interference and efficient utilization of the available network resources [2]. It is essential to accurately maintain and estimate the interference at a minimum level. Since the terrain profile vary to a large extent, the behaviour of radio wave signals in a wireless channel is dependent on the terrain profile of the propagation environment, in view of this, path loss distribution models cannot be generalized. This draw back can be overcome by measuring the Received Signal Strength (RSS) of transmitted signals at different point in space and fitting the measured data with different probability distribution models in order to obtain the best suited distribution model to the path loss values for a particular environment [3].

Knowing the probability distribution model and the parameters of the distribution of any time series data such as path loss values and solar radiation of a location allows researchers to be able to generate data that will have the same characteristic as the actual values of the location in future. This is essential as it can serve as the starting point for design analysis of any network design.

Some probability distribution functions have been used to model wireless signal path loss values in literatures: the prediction error between eight empirical path loss models and actual path loss values of TV signals were distributed in [4] using Gaussian normal distribution model. Davidson and CCIR empirical models showed better results than the other path loss models used. Gamma and Nakagami-m distributions were used to model the shadow fading in [5]. In the same manner, the comparison results of three different distribution fitting models with measured GSM signal shadow fading are also presented in [6]. The results indicated that the lognormal distribution model fits the measured shadow fading better. However, Segun et al [7] reported that different probability distribution functions may be used to model the RSS of different sectors of a base station, judging from the measurement of received signal strength made along Lagos-Badagry expressway, Nigeria. Although, the path loss values of some base stations in Nigeria environments have be modelled using different empirical models, only [7] has modelled RSS values using different probability density functions to the best of the authors' knowledge but they did not put into consideration different Nigerian micro-cellular environments and the two major seasons in Nigeria.

In this paper, the most probability distribution model that best model the path loss values of the studied environments in two different seasons is determined using statistical goodness of fit and the parameters of the distribution obtained. The rest of the paper is organised as follows: Section 2 presents a brief overview of five probability distribution models. Methodology adopted is described in section 3. Result presentation and discussion are presented in section 4 and the conclusion is presented in section 5.

2. OVERVIEW OF PROBABILITY DISTRIBUTION MODEL

It is impossible to present all statistical distribution functions because they are too numerous to be accommodated in this paper. However, several probability distribution models were tested and the best six among them have been reported. They include: logistic, gamma, lognormal, weibull, normal and extreme value distributions. The other probability distribution models not listed here are far from fitting the measured path loss values.

2. 1. Logistic Distribution Function

The logistic distribution function uses the mean and standard deviation as the Location parameter and scale parameter respectively, the probability density function (pdf) is expressed as [8].

$$\mathrm{f}(x|\mu, s) = \frac{\exp(\frac{x-\mu}{s})}{s(1+\exp\{\frac{x-\mu}{s}\})^2} \tag{1}$$

where: x is the measured path loss, μ is the location parameter (mean) and s is the scale parameter of the probability distribution function. The parameters can be evaluated using (2) and (3) [8].

$$\mu = E(x) \tag{2}$$

$$s = \sqrt{\frac{3\,var(x)}{\pi^2}} \tag{3}$$

2. 2. Gamma Distribution Function

The gamma distribution probability density function (pdf) is expressed as [8].

$$f(x|a, b) = \frac{x^{a-1}}{b^a \Gamma(a)} \exp[-\left(\frac{x}{b}\right)]\;, a, b > 0 \tag{4}$$

where: x is the measured path loss values, a is the scale parameter and b is the shape parameter of the gamma distribution and $\Gamma(.)$ is the gamma function.

The expressions for mean and standard deviation of gamma distribution are given in (5) and (6) [8]

$$\mu = ab \tag{5}$$

$$\sigma = \sqrt{ab^2} \tag{6}$$

2. 3. Lognormal Distribution Function

The lognormal distribution is some time called the Galton distribution, it is a probability distribution whose logarithm has a normal distribution. The lognormal distribution is applicable when the quantity of interest must be positive, since log(x) exists only when x is positive. The probability density function (pdf) of the lognormal distribution is expressed as [8].

$$f(x|\mu,\omega) = \frac{1}{x\omega\sqrt{2\pi}} \exp\left\{\frac{-(\ln x-\mu)^2}{2\omega^2}\right\}; x \geq 0 \tag{7}$$

where: x is the measured data, ω is the lognormal shape parameter, μ is the lognormal scale parameter.

The mean and variance of the lognormal distribution can be evaluated using (8) and (9) [8].

$$\mu = \exp(\mu + \frac{\omega^2}{2}) \tag{8}$$

$$\sigma^2 = \exp(2\mu + \omega^2)\,[\exp(\omega^2) - 1] \tag{9}$$

2. 4. Weibull Distribution Function

The Weibull probability density function is only positive for positive values, and zero otherwise. For positive values of the scale parameter a and shape parameter c, the density is [9].

$$f(x|a,c) = \frac{c}{a}(\frac{x}{a})^{c-1}\exp[-(\frac{x}{a})^c] \tag{10}$$

The Weibull mean and variance values are given as [5]

$$\mu = a\Gamma(1 + \frac{1}{c}) \tag{11}$$

$$\sigma^2 = a^2\Gamma\left(1 + \frac{2}{c}\right) - \left[\Gamma\left(1 + \frac{1}{c}\right)\right]^2 \tag{12}$$

2. 5. Normal Distribution Function

The normal distribution is a family of curves of two parameters. The first parameter, is the mean (μ). The second, is the standard deviation (σ). The normal pdf is expressed as [8]

$$f(x|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}}\exp[\frac{-(x-\mu)^2}{2\sigma^2}] \tag{13}$$

The distribution parameters μ and σ are calculated using (14) and (15) [8]

$$\mu = {}^1\!/_n \sum_{i=1}^{n}(x_i) \tag{14}$$

$$\sigma = \sqrt{{}^1\!/_n \sum_{i=1}^{n}(x_i - \mu)^2} \tag{15}$$

where: n is the number of measurement samples and x is the measured path loss values

2. 6. Extreme Distribution Function

Extreme value distribution function has the probability density function expressed as [9]

$$f(x|\alpha,\beta) = \frac{1}{\beta}\exp(-\frac{x-\alpha}{\beta})\exp(-\exp\left(-\frac{x-\alpha}{\beta}\right)) \tag{16}$$

where: α is the location parameter and β the scale parameter. The extreme value distribution parameters can be determined by (17) and (18) [8]

$$\mu = \alpha + 0.5772\beta \tag{17}$$

$$\sigma = \frac{\beta\pi}{\sqrt{6}} \tag{18}$$

3. EXPERIMENTAL SITES, MATERIALS AND METHODS

With Global System for Mobile Communication (GSM) signal at frequency of 1800 MHz, measurements were performed during dry season: November to December 2016 and January to March, 2017 also during wet season months between April and September, 2017 these periods were chosen in order to cover the two major seasons in Nigeria. The measurement campaign consisted of three different environments of Ondo State, South-western part of Nigeria. The field measurement survey was performed on Oshinle, Isolor and Oke-aro environments at 1800 MHz in Akure, the capital of Ondo State. The sites represent typical populated urban environments that are typified with blocks of densely constructed buildings, height of buildings between 3 to 20 meters, hills, mountains, parks, schools market places, and trees of average height. Typically, more than 80% of the area is filled with houses constructed with concrete, blocks and tiles. The second measurement survey was performed in Mobil and Oke-Ibukun in Ore representing a typical commercial suburban environment of Ondo State. These sites consist of lightly constructed buildings of height between 3 and 12 meters, market places, hills, schools, and distributed tall trees. Around 65 to 70% of the areas is filled with houses constructed with concrete and blocks. The third measurement survey was performed in Odigbo and Omifon in Odigbo Local Government Area of Ondo State. These sites reflect rural environments of Ondo state consisting of sparsely constructed buildings, thick vegetation of tall trees, corroded roofs, foot paths, market places and open areas. They are also characterized by some sequence of houses built with muds and planks with less than 60% of houses made of concrete, blocks and tiles. Figure 1 represents one of the base stations investigated in a typical urban environment (Oke-aro) Ondo State.

A drive test was conducted to measure the RSS levels of GSM base station transmitters using a Sony Ericsson TEMS phone. The TEMS phone was connected via a Universal Serial Box (USB) cable to a laptop equipped with TEMS software. A Global Position System (GPS) receiver was also connected to measure the elevation, coordinates, location as well as the distance between the mobile receiver and the transmitter [10]. In each site, a Single Sector Verification (SSV) method was adopted, measurements were carried out at distances ranging from 50 to 1,200 meters along each sector of a base transmitter station. Measured data were also recorded in log files for each of the sites investigated. The transmitting power of the base station is 42 dBm while the receiver has sensitivity of -110 dBm and height of 1.2 meters. Detailed features of the base stations and the characteristics of each of the environments considered are shown in Table 1.

Table 1. Details of the Base Stations and Characteristics of each of the Sites in the studied Environments

Location	Cell id	Coordinate		Elevation (m)	Environment type	Antenna height (m)	Antenna type	Frequency (MHz)	Tx gain (dB)
		°N	ºE						
Oshinle	OD403	7.23	5.19	378.00	Urban	36.00	Sectorial	1800.00	17.00
Isolo	OD2543	7.25	5.19	352.00	Urban	36.00	Sectorial	1800.00	17.00
Oke-aro	OD3447	7.24	5.18	364.00	Urban	36.00	Sectorial	1800.00	17.00
Mobil	OD4727	6.76	4.84	87.00	Suburban	34.00	Sectorial	900.00	17.50
Oke-Ibuku	OD4747	6.75	4.87	93.00	Suburban	34.00	Sectorial	900.00	17.50
Odigbo	OD3835	6.78	4.87	129.00	Rural	32.00	Sectorial	900.00	17.50
Omifon	OD2548	6.83	4.86	157.00	Rural	32.00	Sectorial	900.00	17.50

Figure 1. A typical base station investigated in urban environment of Akure (Oke-aro)

3. 1. Path Loss Calculation

The path loss (dB) is determined from RSS values by the expression [11]

$$P_L = P_T + G_T + G_R - L_T - L_R - RSS \quad (19)$$

where: P_T is base station transmitted power; G_T and G_R are gain of transmitter and receiver respectively; L_T and L_R are transmitter and receiver cable loses in (dB) and RSS is the received signal strength.

3. 2. Evaluation of the Distribution Functions

The performance of the distribution models is evaluated using three different statistical goodness of fits, namely: Root Mean Square Error (RMSE), Relative Error (RE) and Coefficient of Determination (R^2) as recorded in ITU-R. P.311-12 [12].The lower the RMSE and RE, the better the performance of the distribution function. Coefficient of determination is simply used to determine the extent a prediction can be made from a model. The closer the value to 1, the better the fit to the measured values. The expressions for the evaluation of the fitness are given as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(PL_j - Ob_j)^2} \quad (20)$$

$$RE = \sum_{j=1}^{n}\left[\frac{(PL_j - Ob_j)}{PL_j}\right] \times 100 \quad (21)$$

$$R^2 = \left[\frac{\sum_{j=1}^{n}([PL_j - E(PL_j)] \times [Ob_j - E(Ob_j)])}{\sqrt{([PL_j - E(PL_j)]^2 \times [Ob_j - E(Ob_j)]^2)}}\right] \quad (22)$$

where PL_j is the jth measured path loss, Ob_j is the jth estimated path loss and n is the number of observed path loss.

4. RESULTS AND DISCUSSION

Figures 2 to 4 depict the seasonal variation of measured path loss for each urban, suburban and rural environments monitored respectively. In all the environments, the wet season measured path loss values present higher path loss values when compared with the corresponding dry season measurements. In Figure 2, for example, the highest measured path loss in urban environments is during wet season from Oshinle base station which is about 158 dB and the least is around 88 dB during dry season from Isolo base station. Also in Figure 3, in suburban environments the highest path loss is about 148 dB during wet season from mobil base station in Ore while the least value is 90 dB during dry season from mobil station.

In Figure 4, for rural environments, the highest measured path loss value is around 147 to 150 dB during wet season months from Omifon base station and the least value is 90 dB from Odigbo base station during dry season months.

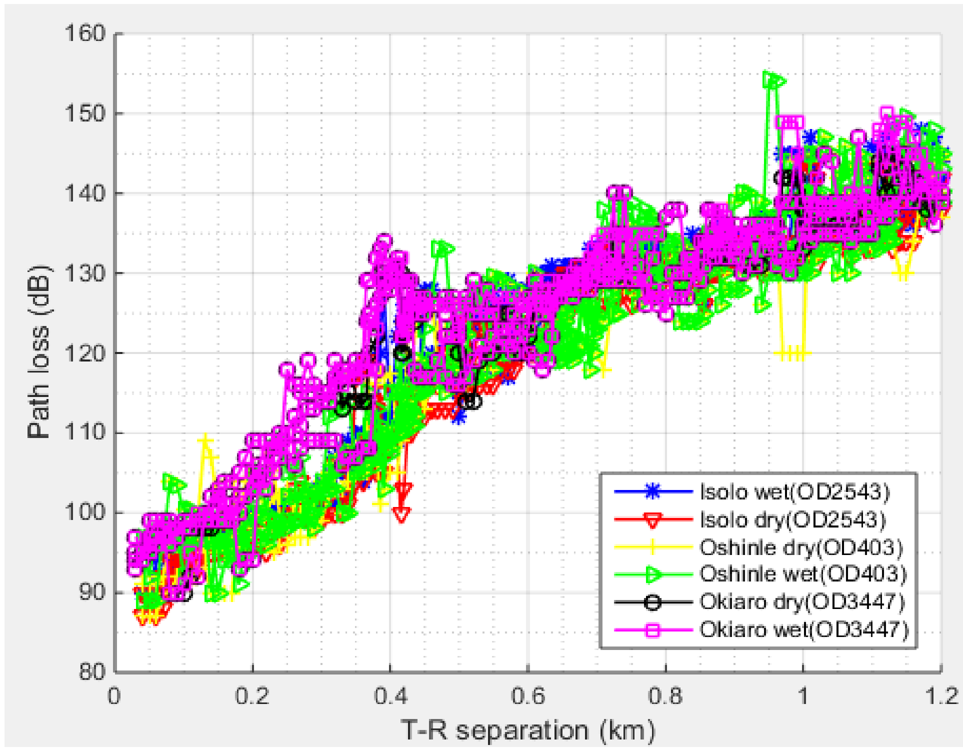


Figure 2. Seasonal variation of measured path loss values in different urban environments

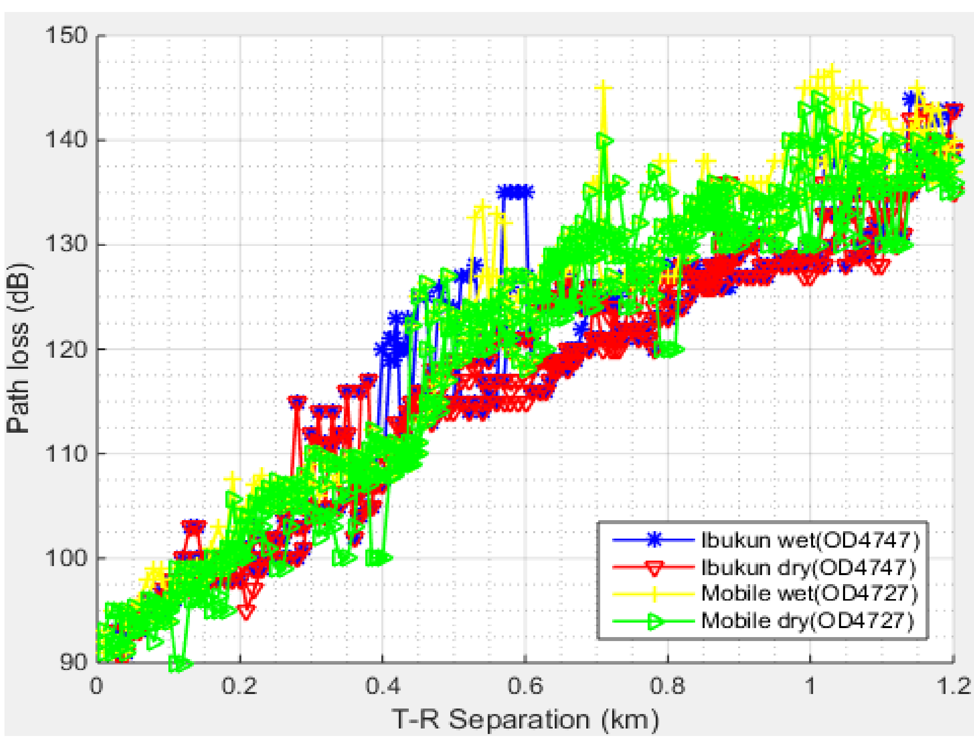


Figure 3. Seasonal variation of measured path loss values in different suburban environments

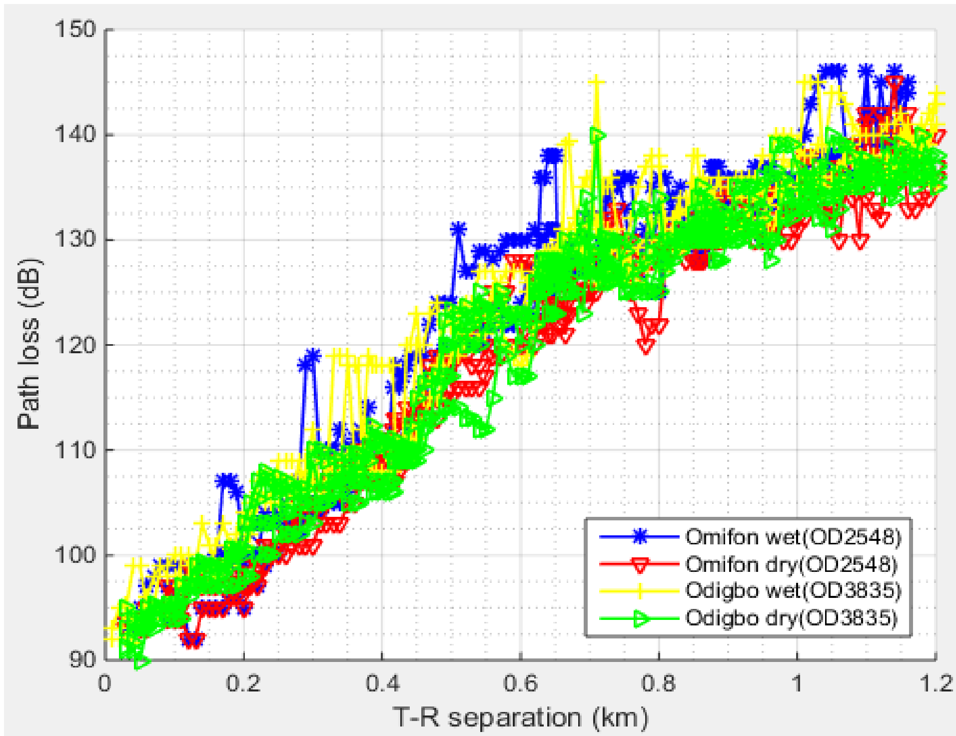


Figure 4. Seasonal variation of measured path loss values in different urban environments

In order to determine the most suitable statistical distribution function that can model accurately the measured path loss in various micro-cellular environments of Ondo state, several probability distribution functions were tested.

However, only six of the tested distribution functions that best suited the measured path loss are presented in this paper. As shown in Figures 5 and 6, the probability distribution functions are fitted to the dry and wet season measured path loss respectively, in Akure, an urban environment of Ondo state.

The results show that the normal distribution function closely matches the actual path loss values better followed by logistic distribution then lognormal distribution when compared with the other distribution functions. Also, in Ore, a suburban environment of the state, the same curve fitting of actual path loss values with distribution functions has been investigated in both dry and wet season months as shown in Figures 7 and 8.

Results from Figures 7 and 8 show that normal distribution exhibited a better match with the actual path loss values followed by logistic distribution and gamma distribution function fitted least. Similar observation was also observed in Omifon and Odigbo, rural environments of the state in both seasons as depicted in Figures 9 and 10.

The normal distribution function exhibited a better approximation to the actual data, followed by extreme value then weibull distributions when compared with the other distribution functions.

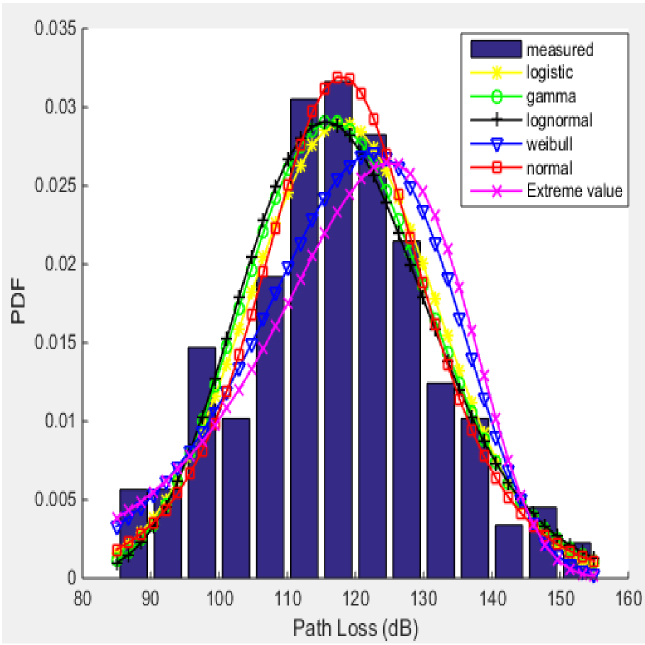


Figure 5. Fitting of probability distribution to the dry season measured path loss values in Akure urban environment.

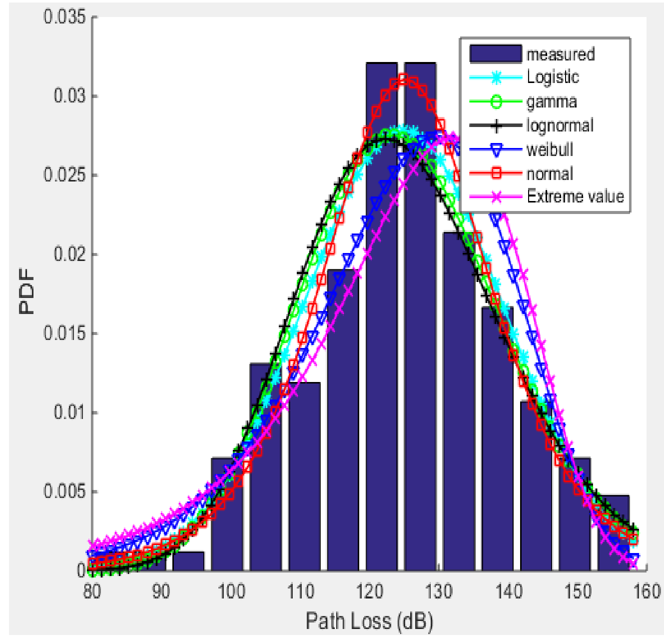


Figure 6. Fitting of probability distribution to the wet season measured path loss values in Akure urban environment.

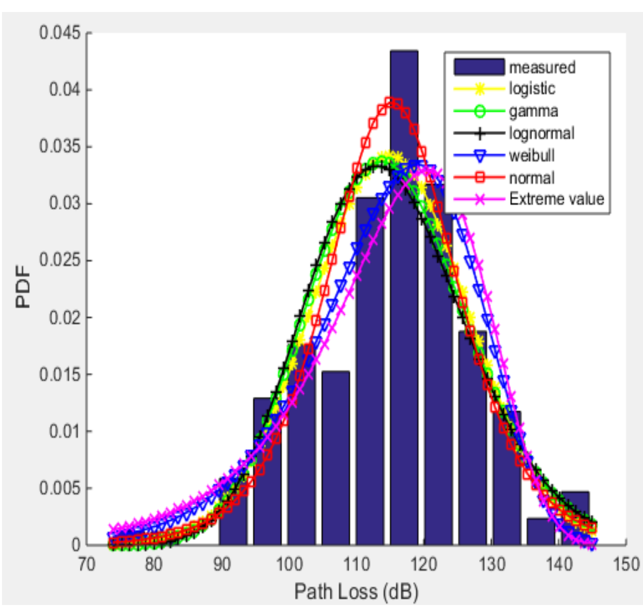


Figure 7. Fitting of probability distribution To the dry season measured path loss values in Ore suburban environments.

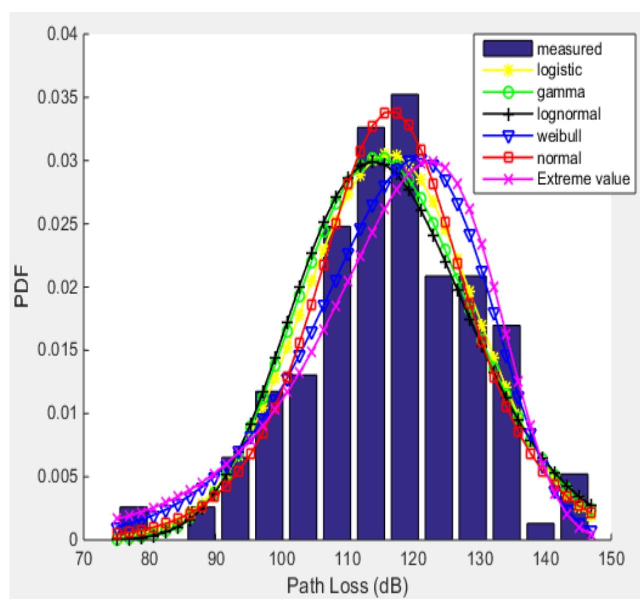


Figure 8. Fitting of probability distribution to the wet season measured path loss values in Ore suburban environment.

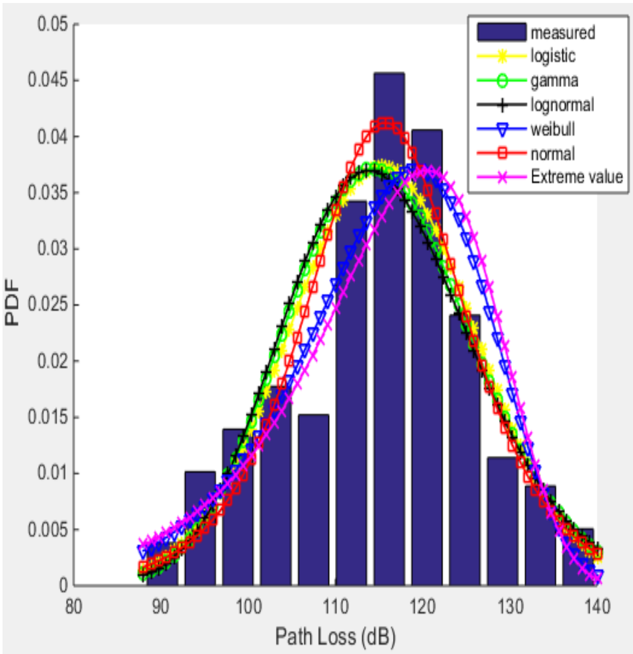


Figure 9. Fitting of probability distribution to the dry season measured path loss values in Omifon and Odigbo rural environments.

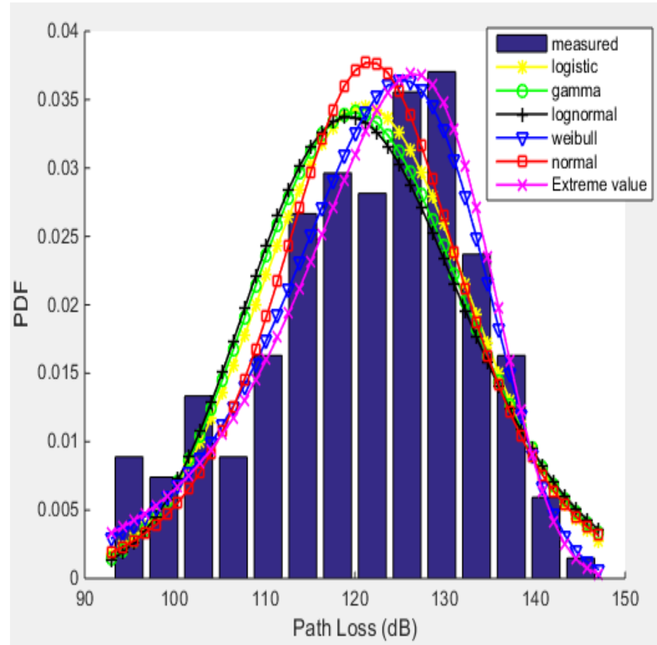


Figure 10. Fitting of probability distribution to the wet season measured path loss values in Omifon and Odigbo rural environments.

Tables 2 and 3 present the summary of RMSE, RE and R^2 of the probability distribution function for modelling the measured path loss values in both wet and dry season months respectively in different environments of Ondo state. The results show that the normal distribution function exhibited the least RMSE and RE values with R^2 closer to 1. This is followed by logistic distribution in both wet and dry seasons in urban environment. Similar trend was also observed in the same seasons in suburban environments with normal distribution having a better fit to actual values. In both seasons of rural environment, normal distribution also exhibited better fits with the measured path values and relatively followed by extreme value distribution function.

Table 2. Performance evaluation of probability distribution for modelling GSM path loss values in wet season in different micro-cellular environments of Ondo state.

Distribution	Urban			Suburban			Rural		
	RMSE (dB)	RE (%)	R^2	RMSE (dB)	R E (%)	R^2	RMSE (dB)	R E (%)	R^2
Weibull	10.801	19.701	0.965	11.730	21.004	0.966	10.011	13.015	0.971
Gamma	9.505	16.606	0.957	10.552	16.503	0.963	12.022	18.050	0.950

Logistic	8.205	14.612	0.973	10.001	15.006	0.971	10.180	13.603	0.967
Normal	7.601	12.702	0.984	6.900	11.550	0.986	7.060	12.450	0.988
Lognormal	8.922	14.006	0.966	10.450	15.800	0.972	10.602	13.800	0.957
Extreme value	11.800	21.722	0.892	12.506	20.000	0.952	8.101	12.701	0.985

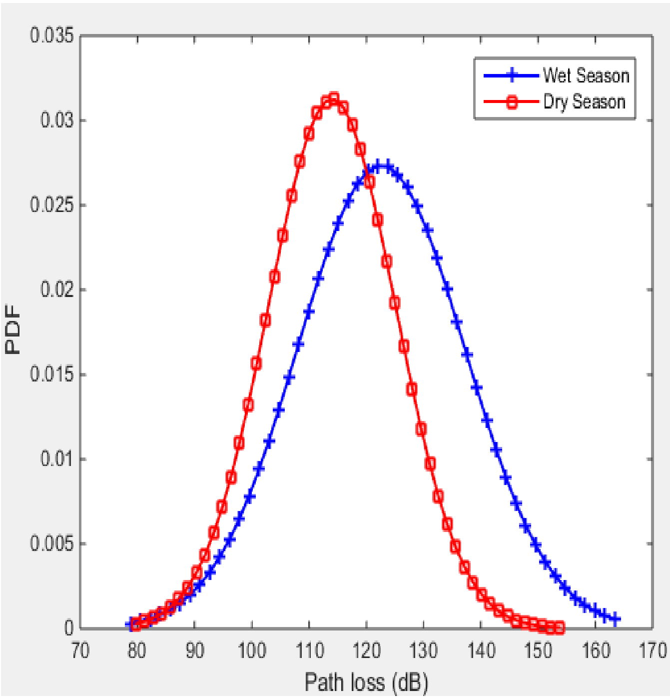
Table 3. Performance evaluation of probability distribution for modelling GSM path loss values in dry season in different micro-cellular environments of Ondo State

Distribution	Urban			Suburban			Rural		
	RMSE (dB)	RE (%)	R^2	RMSE (dB)	RE (%)	R^2	RMSE (dB)	RE (%)	R^2
Weibull	9.501	21.301	0.965	13.730	21.904	0.966	11.011	18.115	0.978
Gamma	9.305	15.506	0.967	11.452	17.503	0.973	13.022	19.150	0.944
Logistic	9.005	15.012	0.988	11.201	16.506	0.981	12.280	18.703	0.957
Normal	8.601	11.702	0.990	9.900	12.450	0.988	9.060	13.450	0.985
Lognormal	9.122	15.906	0.986	11.450	17.100	0.982	12.602	18.800	0.950
Extreme value	10.500	23.722	0.898	14.506	23.200	0.962	10.701	15.701	0.981

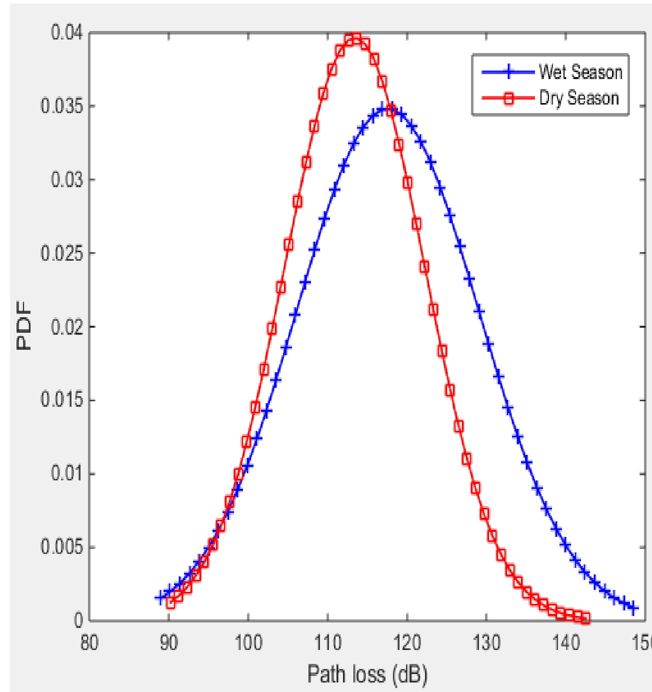
The seasonal variations in normal probability distribution for urban, suburban and rural environments are shown in Figures 11 (a-c). From the results, in all the three micro-cellular environments monitored, the mean value for normal distribution parameters are 125 dB with a standard deviation of 14.12 dB in urban environment, 117.5 dB with a standard deviation of 11.00 dB in suburban environment and a mean value of 122 dB with a standard deviation of 11.50 dB for rural environment for wet season months.

For the dry season measurement, normal distribution parameters are mean value of 120 dB with a standard deviation of 12.00 dB for urban environment, 115.35 dB with a standard deviation of 10.00 dB for suburban environment and a mean value of 113 dB with a standard deviation of 7.50 dB for rural environment.

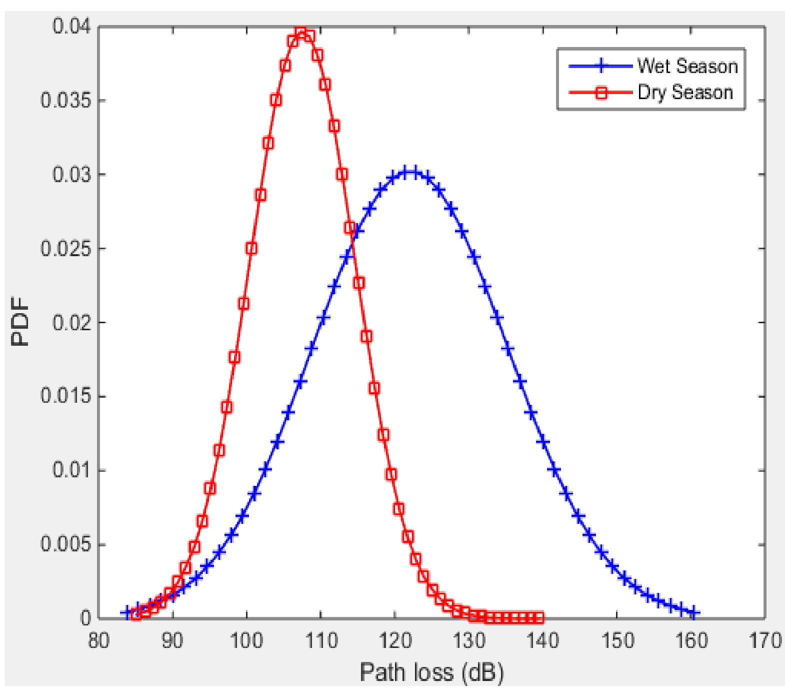
However, the rural environments exhibited a wider variation in the distributions of the two seasons measured path loss values. Table 4 presents the normal distribution parameters for both dry and wet season months.



(a)



(b)



(c)

Figure 11. Seasonal variation in normal distribution of the measured path loss for **(a)** urban environment, **(b)** suburban environment, **(c)** rural environment.

Table 4. Normal distribution parameters for wet and dry seasons for urban, suburban and rural environments.

Season	Parameter	Environment type		
		Urban	Suburban	Rural
Wet	Mean (dB)	125.00	117.50	122.00
	Std (dB)	14.25	11.00	11.50
Dry	Mean (dB)	120.00	115.35	113.00
	Std (dB)	12.00	10.00	7.50

5. CONCLUSIONS

The most probable probability distribution function for modelling the path loss values of radio frequency signal at 900 and 1800 MHz over urban, suburban and rural environment of Ondo state in both wet and dry season months has been determined and the seasonal parameters of the probability distribution function deduced. From the results of the study, the normal distribution is the most appropriate distribution function for modelling the RF signal path loss of different micro-cellular environments of Ondo State based on fitting accuracy and the selected metric measures. Normal distribution function exhibited least RMSE values, least RE values and coefficients of determination closer to 1 in both wet and dry seasons in all the environments monitored. When compared with the other distribution functions, the normal distribution is relatively followed by logistic distribution as the second probability distribution with better approximation of the measured path loss in urban and suburban environments and extreme value distribution in rural environment. Information from this research will facilitate research advancement in wireless channel characterization that accounts for path loss distribution features of the micro-cellular environments of Ondo state, southwestern Nigeria.

References

[1] A. Bhuvaneshwari, R. Hemalatha, T. Satyasavithri, Statistical Tuning of the Best Suited Prediction Model for Measurements Made in Hyderatebad City of Southern India. *Proceedings of the World Congress on Engineering and Computer Science San Francisco, USA*. Vol II, 23-25 October, 2013,

[2] F.D. Alotibi, Adel A. Ali, TETRA Outdoor Large-Scale Received Signal Prediction Model in Riyadh City Saudi Arabia. *IEEE Wireless and Microwave Technology Conference (WAMICON), USA*. 12, (2006) 4-5.

[3] Luca Chiaraviglio, Josip Lorincz, Yifan Zhou, Zhifeng Zhao, Chen QI., What is the Best Spatial Distribution to Model Base Station Density? A Deep Dive into Two

European Mobile Networks. *IEEE Infocom 2016 (Poster), San Francisco, USA*. April 12, 2016.

[4] Nasir Faruk, Adeseko A. Ayeni and Yunusa A. Adediran, On the study of empirical Path loss models for accurate prediction of TV signal for secondary users. *Progress In Electromagnetics Research B* (2013), Vol. 49, 155-176.

[5] J. Salo, L. Vuokko, and P. Vainikainen, Why is shadow fading lognormal? *Proceedings of the International Symposium on Wireless Personal Multimedia Communications, Aalborg, Denmark* (2005), pp. 522–526.

[6] Fengyu Luan, Yan Zhang, Limin Xiao, Chunhui Zhou, and Shidong Zhou, Fading Characteristics of Wireless Channel in Hilly Terrain Scenario. Hindawi Publishing Corporation, *International Journal of Antennas and Propagation* Vol. 2013, Article ID 378407, 9 pages.

[7] S.I. Popoola, A.A. Atayero, N. Faruk, Received Signal Strength and Local Terrain Profile Data for Radio Network Planning and Optimization at GSM Frequency Bands. *Data in Brief* 16 (2018) 972-981.

[8] K. Krishnamoorthy, Handbook of Statistical Distributions with Applications. Chapman & Hall/CRC, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300 Boca Raton. FL, 334487-2742, (2006) 240-245.

[9] N.L.S Johnson Kotz and N. Balakrishnan, Continuous Univariate Distributions. Vol. 1, Hoboken, NJ: Wiley Interssience (1993)

[10] C. I. Abiodun, S. O. Azi, J. S. Ojo, P. Akinyemi, Assessment of Path Loss Prediction Models for Wireless Propagation Channels at L-Band Frequency over Different Micro-Cellular Environments of Ekiti State Southwestern Nigeria. *World Academy of Science, Engineering and Technology. International Journal of Electronics and Communication Engineering* Vol. 11, No 10, (2017), pp. 1103-1109.

[11] P, Akinyemi, Optimization of Path Loss Model for Macro-Cellular Network Applications in Selected State in Nigeria. Ph.D Dissertation. *Department of Physics, University of Benin, Benin City Edo State Nigeria.* June, 2016, Chapter 3, pp. 97-100

[12] ITU-R. P 311-12. Acquisition, presentation and analysis of data in studies of Radio wave propagation. *International Telecommunication Union Recommendation* (2015), 311-12.