Experimental Determination of Path Loss Exponent For GSM 900 and 1800 Bands in Ilorin Metropolis

Ayeni Adeseko A., Onidare Samuel O., Quadri Adebowale R. and Adeniran Temitayo C.

***Abstract*—The path loss exponent of an environment describes the propagation behaviour of the environment. This paper determines the path loss exponent of the GSM 900 MHz and 1800 MHz bands in Ilorin, Kwara state of Nigeria. A comprehensive signal strength measurement campaign, using an Agilent spectrum analyzer, was carried out in 12 different routes representing, virtually, the entire metropolis of Ilorin. In computing the path loss exponent, a different approach from the more frequently used linear regression approach, was used. The experimental data reveal a lot of findings, chief amongst which is the strong influence of the terrain profile on the path loss of the environment. Consequently, the path loss exponent obtained, especially for the GSM 900, is lower than the expected value as reported in the literatures.**

***Index Terms*—Path loss exponent, Free Space Path Loss, P_0.**

I. INTRODUCTION

The signal propagation characteristics of an environment play a very significant role in the initial design, roll out and future expansion, of any wireless communication network, the GSM cellular mobile communication inclusive. Amongst other propagation characteristics is the large scale path loss or path attenuation. The path loss exponent, $\boldsymbol{n}$, describes the rate of signal attenuation along a path. In [1] the relation is expressed mathematically as:

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n \qquad (1)$$

where $\overline{PL}(d)$ represents the average path loss, as a function of distance, d and d_0 is a reference receiver distance from the transmitter.

The importance of path loss exponent, in determining the propagation characteristics of an environment had been repeatedly and comprehensively expounded in several literature. The average path loss and by extension, its exponent provide a basis for determination of the frequency reuse plan, signal -to- interference ratio ***SIR***, cell coverage area as well the capacity in the design of a typical cellular mobile communication network. Furthermore, path loss exponent, defines and characterizes some path loss prediction models, such as the free space path loss model FSPL and the log-distance path loss model, and, it is even a component of some empirical models that incorporates FSPL in the model definition.

The path loss exponent (PLE) of an environment describes the radio propagation profile of the environment, hence, its variation with different propagation environments. This fact, coupled with its importance in the effective design and performance of a mobile network, underscores the need to determine its value for a given mobile environment. As a result, several researchers had carried out experimental measurements to determine the path loss exponents of different environments worldwide. For the above-mentioned reasons, no efforts should be spared in ensuring an accurate determination of the path loss exponent of an environment.

The (measurement and analysis) approach employed in this work is different from the common linear regression method such as 'line of best fit' hitherto used by many researchers in determining the path loss exponent $\boldsymbol{n}$ of an environment. The analytical approach employed in this work make use of more measurement data sample in estimating the path loss exponent, than the 'line of best fit' approach. Moreover, considering the peculiarity of the GSM network, such as several transceivers in a cell site, frequency re-use, antenna characteristics (such as the height, azimuth, beam width, tilt, etc), there is a need to measure and analyze the signal propagation pattern of the several channels of the base stations to obtain the path loss exponent in a particular route/environment.

Previous work by Ogungbayi et al [4] focused on the 900 MHz band in Ilorin while Adebayo and Edeko [3] determined the propagation characteristics for the 1800 MHz alone in Benin. This work covers both the 900 MHz and the 1800 MHz in Ilorin. Even though some literatures argue that the characteristics of these two bands are similar because they have similar interface, this work intends to provide a practical veracity, or otherwise, of this claim. Thus, there will be a comparison of the path loss exponent at these two frequency bands and an investigation of the extent of the frequency dependence of signal attenuation

II. Review of related works

In [2], a nokia handset equipped with the net monitor software was used to measure signal power during an active call between the mobile and the base station. The measurement was carried out between November 2013 and April 2014 in Amukpe-Sapele. The average estimated path loss exponent obtained was 2.8. In [3], a measurement campaign at GSM 1800MHz band was conducted in fifteen different locations spanning the city of Benin, Nigeria and representative of the different terrains of the city. Different path loss exponents for the different locations, arriving at an average of 3.3 for the city, were obtained. In [4], measurements were taken in 12 different environments. The Base Station signal strength in each of the twelve environments was measured at intervals of 200m, up to 3,000m (3km) from the base station. It was concluded that the average path loss exponent of 2.6 obtained, explained the low quality of GSM signal and network failure of the studied area. The works reported in [3] and [4] concentrated only on one GSM band, even though the studied area in [4] is the same as this work. [5] investigated penetration losses of three different building material types in Delta state of Nigeria, from which the path loss exponent of these materials were obtained. This focuses on indoor path loss exponent and not outdoor, like other cited works. [6] did a comparative analysis of received signal strength prediction models using Okumura-Hata, Cost-231-Hata and standard propagation models. They concluded that the standard propagation models are most suitable for the city of Ilorin. The work of Oseni et al described in [6] emphasized path loss model suitability, and not path loss exponent, for the same studied area under consideration. The work of [7] characterized path loss using two television stations, Kwara TV and NTA Ilorin, broadcasting on 583.25 MHz and 203.25 MHz respectively. The work involved measurements taken along ten (10) different routes in Ilorin with path loss exponents obtained, ranging from 1.40 to 4.94. It should be noted that, even though the value of $\boldsymbol{n}$ obtained is for Ilorin, it was for a different frequency band, the TV band. A statistical path loss model for the 1.9 GHz frequency band in sub-urban environments of the United States of America was presented in [8]. Using a linear curve fitting of the decibel path loss to the decibel distance for data collected in 95 macrocell sites, the path loss exponent of different terrain categories was obtained. The work shows that the path loss exponent and the standard deviation of the shadow fading varies randomly from one macrocell to another. In the work reported in [10], the path loss exponent $\boldsymbol{n}$ was used to characterize three different path loss prediction models investigated for the study environments. The obtained measurement data was used to compute $\boldsymbol{n}$ for the different environments studied. A comparative analysis of the obtained values expectedly revealed that for open plan buildings, the path loss exponent is close to 2, while it is higher for environment with more obstructions. The work further revealed that site specific information can be used to more accurately determine the propagation profile of an environment. The work reported in [11] proposed and studied three different algorithms for path loss exponent estimation in wireless network taking into cognizance node location uncertainties, m-Nakagami fading and interference. The aim of the methods described in [12], is to address the shortcomings of many path loss exponent techniques that requires peculiar information of the wireless network under study or some other external information. The two methods proposed are expected to 'solely and locally' self estimate path loss exponent for various wireless networks and applications. The first method is a linear regression model which employs a closed-form total least squares method to estimate the PLE. The second method used a closed-form weighted total least squares to suppress estimation error. In all these cited works, a similar approach was employed in estimating the path loss exponent.

The work in [13] presented a power propagation path loss model for determining how the mean wide-band channel path loss changes as a function of distance between a base station and a mobile station. It was shown that changing the reference distance from 1 km to 100 m can change the perceived propagation power law exponent from 3.0 to 2.7, where free space propagation is assumed from the transmitter to the reference distance. The focus of the authors of the work reported in [14], is dynamic estimation of path loss exponent and distance of two moving nodes based on Doppler effect and received signal strength. The proposed method basically used measured powers and Doppler shifts over a period of time during which path loss factor assumed to be constant. In [15], path loss results and models for four different environments in Vehicle - to- Vehicle (V2V) systems was presented. It was found that the estimated path loss exponents are low for all the studied environments, which is an indication that designs which are robust to interference from other users should be considered for V2V systems. In [16], the authors investigated the dependency or otherwise of path loss exponent on frequency. The results obtained from the work shows that PLE at differentfrequency is similar in the same propagation environment. The work reported in [17] focused on the effect of PLE on the information secrecy in wireless networks. The result obtained indicated that there is a correlation between the varying value of PLE according to the different types of propagation environment and the boundaries of secured communication in wireless networks. The draw-back of received signal strength (RSS) based location techniques was the focus of the authors of [18]. In addressing this, the research effort was geared towards providing a more accurate characterization of the different propagation of signals between a mobile station (MS) and different base stations (BSs), than provided by the generic traditional path loss models. The method adopted in achieving this objective was dynamic estimation of the PLE of the different propagation paths between a MS and the different BSs within its reception range. An experimental determination of path loss exponent and standard deviation of shadowing in a typical urban and suburban mobile-to-mobile environment at 900 MHz band was presented in [19]. It was suggested that could be combined with a simple power law path loss model to predict relaible communication ranges for future mobile-to-mobile communication systems. The work in [20] shows the results of PLE values and variance of the random variable model the effects of fading and shadowing derived from narrowband path loss measurements in an urban and rural area at the 900 MHz band. In [21], Path loss and PLE prediction with Cost231 Hata, SUI, ECC33 and Cost231 W-I was compared with the measured path losses in cells. Based on the result obtained, an optimized Hata model was developed. The optimised model showed high accuracy in between 25-40% and is able to predict path loss with smaller path loss and path loss exponent as compared to the Cost231 Hata model. The aim [22] was to predict path loss from field measurements and represent them in a more convenient form for the proposed Fuzzy Logic modeling. A unique mean path loss exponent (n) is assigned to each propagation environment, which is established by means of the experiment. The results indicated that the path loss increases at the rate of 26.7 dB per decade with distance. Study on analysis of six empirical path loss models with respect to measured data for plane area in state of Punjab and Jammu (India) was presented in [23]. The investigated models are COST- 231, Hata, Okumura, free space model, extension of Hata model and Hata Davidson model. Measurement was carried out in Gurdaspur in the 100w FM radio transmitter and transmitting antenna height of 45m, and 10 kw FM transmitter at Kathua. The results indicated that Cost–231 model is best suited for plane area in northern region of the border district of Punjab (India). [24] examined path loss for GSM mobile networks for urban, rural and suburban regions of karnataka.

III. DATA COLLECTION AND ANALYSIS

This section is divided into two. The first part describes the experimental procedure for data collection while the second describes the approach adopted to analyze the collected data.

(a) Field Strength Measurement Campaign

A handheld spectrum analyzer (Agilent N9342C,) equipped with an omni-directional antenna, mounted on a vehicle, was used to measure and record the signal strength of base transceiver stations, along twelve different routes, in Ilorin. A total of forty nine (49) cell sites, covering about two hundred and fifty (250) transceivers, were involved in the measurement campaign. The spectrum analyzer takes measurement in the direction of the moving vehicle, and also records the GPS co-ordinates at the each position. This was used to compute the transmitter- receiver distance of each measurement point. The field strength measurement, covered over 70 Km and over 17,000 data points were collected.

The cell sites along each route were identified and the spectrum analyzer was tuned to the operating channels of the transmitters in the sites. For most of the sites, there are six transceivers with the exception of some few sites with just three. Since the spectrum analyzer can measure twenty channels simultaneously, it was possible to take measurements of several cell sites along a path/route. In fact, in most instances, because of frequency re-use, it was possible to cover up to four or, at times, five (5) cell sites along a route. Also, in a bid to cover as many as the cell sites as possible some portions of the routes overlap, thereby ensuring that channels not measured in a measurement trip were measured in another. Table 1 shows details of the measurement campaign.

Table 1: Details of Field Strength Measurement

Route ID	Route(propagation path)	Sites location along route	No. of Channels
I	Abayawo-Post Office	Emirs Palace	16
		Balogun Fulani	
		Opo Malu	
		Anifowose	
		Sakele St.	
		Adangba	
II	CIS-Tanke Junction	Unilorin P.S	19
		Iyeru Okin	
		Sanrab	
		Bolumo St.	
		Block 4-Unilorin	
III	Gaa Akanbi - Tanke Oke Odo	Revolution Chapel	20
		Rick Oladele	
		Iyeru Okin	
		CBN Quarters	
		Sanrab	
IV	Gaa Akanbi - Maraba	Revolution Chapel	12
		GSS	
		Opo Malu	
V	Olunlade - Challenge	Olunlade	20
		Miracle Centre	
		Offa Garage	
		Revolution	
VI	Sabo Oke - Kwara Poly	Kwara Poly	20
		Kulende	
		Basin-Zango	
		Yakuba	
		GSS	
VII	Sabo Oke - Sobi Rd	Balogun- Fulani	15
		GSS	
		Sobi Road	
		Alalubosa	
		Isale Dumai	
VIII	Sabo Oke - Ogidi	Adabata Baboko	19
		Okaka Lane	
		Popojiwa	
		Ogidi	
		Oloje	
		Kaima Road	
IX	Sabo Oke - Tipper - PS Gate	Kwara Hotels	19
		Conoil Fate	
		Sanrab	
		Tanke Ile-Iwe	
		Bolumo	
X	Taiwo - Saw Mill	Hassanat Hospital	17
		Stadium	
		Saw Mill	
XI	Saw Mill - Geri Alimi	Olusanya Motors	18
		Odokun	
		Saw Mill	
XII	Geri Alimi - Kuntu	Kuntu Ward	17
		Adewole	
		Agbo-Oba	
		Odokun	
		Olorunsogo	

(b)

I. Path Loss Exponent Determination

In [2], [3], [4], the path loss exponent was estimated by applying regression curve fitting to a plot of the received power or path loss, against the log-distance. Similarly in [7], linear regression was used to minimize the difference between estimated path loss (using the log-distance path loss model) and the measured path loss, equating the derivative of which yields the exponent.

According to [1], the propagation measurements in a mobile radio channel shows that the average received signal power $\boldsymbol{P_r}$ at any point decays exponentially with the transmitter - receiver distance $\boldsymbol{d}$. Mathematically, this is expressed as:

$$P_r = P_0 \left(\frac{d}{d_0}\right)^{-n} \quad (2)$$

or by linearization,

$$P_r(dB) = P_0(dB) - 10n log \left(\frac{d}{d_0}\right) \quad (3)$$

$\boldsymbol{P_0}$ is the received signal power at $\boldsymbol{d_0}$, a close-in reference transmitter -receiver distance usually taken as 100m or 1000m in outdoor propagation environment, while $\boldsymbol{n}$ is the path loss exponent. The reference distance, $\boldsymbol{d_0}$, is assumed to be free space reference distance [1], hence, the chosen d_0 for this work is 100m. This is so because at distance of 1000m from the transmitter, it is practically unrealistic to assume free space considering the fact that the studied environment is a well built up area.

Equation (3) is further simplified to:

$$P_r(dB) = P_0(dB) + 10n\,(log\, d - \log d_0) \quad (4)$$

Thus we have,

$$P_r(dB) - P_0(dB) = 10n\,(\log d - 2) \quad (5)$$

$$n = \frac{P_r(dB) - P_0(dB)}{20 - 10 log\, d} \quad (6)$$

Using equation (6), the path loss exponent at every point of the measured received signal power, along the route, is computed. The mean path loss exponent per channel for each route is therefore given by:

$$\bar{n} = \frac{1}{N}\sum_{i=1}^{N} \frac{P_{ri} - P_0}{10 log d_i} = \frac{1}{N}\sum_{i=1}^{N} n_i \quad (7)$$

The average of $\boldsymbol{\bar{n}}$ for all the channels in a route provides the path loss exponent $\boldsymbol{\bar{n}_R}$ for that route.

II. Determination of $\boldsymbol{P_0(dB)}$

According to [1], the path loss at the reference distance, $\boldsymbol{d_0}$, can either be obtained through field measurements or computed using the free space equation. In [8], the expression for calculating this reference distance path loss is given by:

$$PL_0 = \left({4\pi d_0}/{\lambda}\right)^2 \quad (8)$$

By linearization,

$$PL_0(dB) = 20 \log \left({4\pi d_0}/{\lambda}\right) \quad (9)$$

$PL_0(dB)$ is the path loss at the reference distance, $\boldsymbol{d_0}$, while λ is the signal wavelength in m.

But path loss is generally expressed mathematically as:

$$PL = \left(\frac{P_t}{P_r}\right)$$

or

$$PL(dB) = P_t(dB) - P_r(dB) \quad (10)$$

whereP_t is the transmitted power and P_r is the received power.

Since we are interested in the reference distance path loss, then $PL(dB) = PL_0(dB)$ and $P_r(dB) = P_0(dB)$.

Therefore,

$$P_0(dB) = P_t(dB) - 20 log \left({4\pi d_0 f}/{c}\right) \quad (11)$$

IV. RESULTS & DISCUSSION

Table 2: Path Loss Exponent for 900MHz

Route ID	mean path loss exponent per channel ($\bar{n}$)				$\bar{n}_R$	CV
I	2.88	3.00			2.94	2.0%
II	2.81				2.81	-
III	2.81	2.92	2.9	2.92	2.89	1.6%
IV	2.56				2.56	-
V	2.80	3.06	3.00	2.85	2.93	3.6%
VI	2.73				2.73	-
VII	2.88	2.97			2.93	1.5%
VIII	2.95				2.95	-
IX	2.59				2.59	-
X	2.99	2.76			2.88	4.0%
XI	3.11	3.08	3.09		3.09	0.4%

Table 3: Path Loss Exponent for 1800MHz

Route ID	mean path loss exponent per channel ($\bar{n}$)									$\bar{n}_R$	CV
I	2.75	2.74	2.77	2.84	2.88	2.91				2.82	2.3%
II	2.52	2.55	2.60	2.64	2.62	2.53	2.54	2.53	2.55	2.56	1.6%
III	2.66	2.69	2.74	2.76	2.76	2.75	2.79	2.83		2.75	1.8%
IV	2.61	2.58	2.82	2.81						2.68	3.3%
V	2.67	2.89	2.86	2.83	2.75	2.79				2.80	2.6%
VI	2.67	2.66	2.68	2.63	2.66	2.65	2.64	2.57	2.56	2.64	1.5%
VII	2.51	2.76	2.8	2.63						2.68	4.3%
VIII	2.65	2.48								2.57	3.3%
IX	2.43									2.43	-
X	2.71	3.07	2.66	2.66						2.77	5.7%
XI	3.08	3.19	2.97							3.08	2.9%

Tables 2 and 3 present ($\bar{n}$) (mean path loss exponent per channel) and the average for each route, for the 900MHz and 1800MHz respectively. It should be mentioned that not all channels measured in a route are presented because of the frequency reuse concept, in cellular networks. This is so because as the receiver (the spectrum analyzer) traverses a route, there is a possibility that different channels using the same frequency, are measured at different intervals, making it difficult to differentiate between the signal levels of the different channels sharing the frequency. In some instances, some frequencies were re-used about 3 times along the same route. There is also the suspicion that some co-channels, even though not along the route, but at some point close enough, leak power into the receiver path. As a result of these, only those channels that were not re-used on a route and whose co-channels are sufficiently far apart to prevent leakage were presented.

As shown in tables 2 and 3, the route mean PLE $\bar{n}_R$ ranges between 2.56 to 3.09 for the 900 MHz and 2.43 to 3.08 for the 1800 MHz. Consequently, the cumulative average PLE for the studied environment is 2.85 and 2.71 for the 900 MHz and 1800MHz bands respectively. The obtained PLE is in agreement with the expected value as postulated in [1] and other literatures. For the studied environment, it is expected that the path loss exponent should be between 2 and 4 [1]. Another interesting observation along this line, is the fact that routes I, III, V, X and XI, tend to have higher PLE values than the other routes. Most portions of these routes are dense urban areas, with two - three storey building structures, narrow roads, dual carriage with heavy vehicular and human traffic. In fact, routes X and XI span the commercial nerve centre of Ilorin. The average building height, along these two routes, is not only higher than in other parts of the metropolis but also closely packed, hence the expectedly -higher path loss exponent. As can be seen, the highest PLE of 3.09 and 3.08 for both bands was reported for route XI.

The mean path loss exponent per channel ($\bar{n}$) along a route, especially for the 1800 MHz band, shows very strong similarity with most of the values approximately equal or showing negligible difference. This similarity, is expected since the propagation behaviour for a particular route should be uniform, even though several channels are measured. The slight variation is within acceptable limit, as indicated by the coefficient of variation **(CV)** for each route. The average path loss exponent values, across different routes, also show slight differences. In fact, the standard deviation of all the route mean PLE values is 0.15 and 0.16 for the 900 MHz and 1800 MHz respectively. This is attributed to the similarity in terrain topography of all the routes in the studied environment. The terrain profiles depicted in figure 1 represent the general terrain profile of all the routes in the studied environment.

Furthermore, because the topography of the studied environment is undulating, in many instances, at high altitudes, there is an increase, instead of reduction, in signal power at far distance from the transmitter. In so many of the measured points, instead of having path losses, we have gains in the signal power. These gains, due to altitude, culminated in reduced path loss and as such a lower path loss exponent. Figures 1 and 2 show the topography of two routes and the signal strength profile. From the figure, it could be seen that the signal strength falls and rises repeatedly, with altitude, without a sustained attenuation in the signal. Except for areas where there are spikes, which depict fading; the slope is gentle or gradual. This pattern is reflected in all the routes, which depicts the general topography of the environment.

A very good observation is the gradual reduction in the rate of signal attenuation after the first kilometer of transmitter-receiver distance. The path loss experienced in the first kilometer is significantly higher than the mean path loss for the length of the distance measured. As a matter of fact, for almost all the routes, the path loss for the first kilometer is of the order of several magnitudes higher than for distances above 1km.

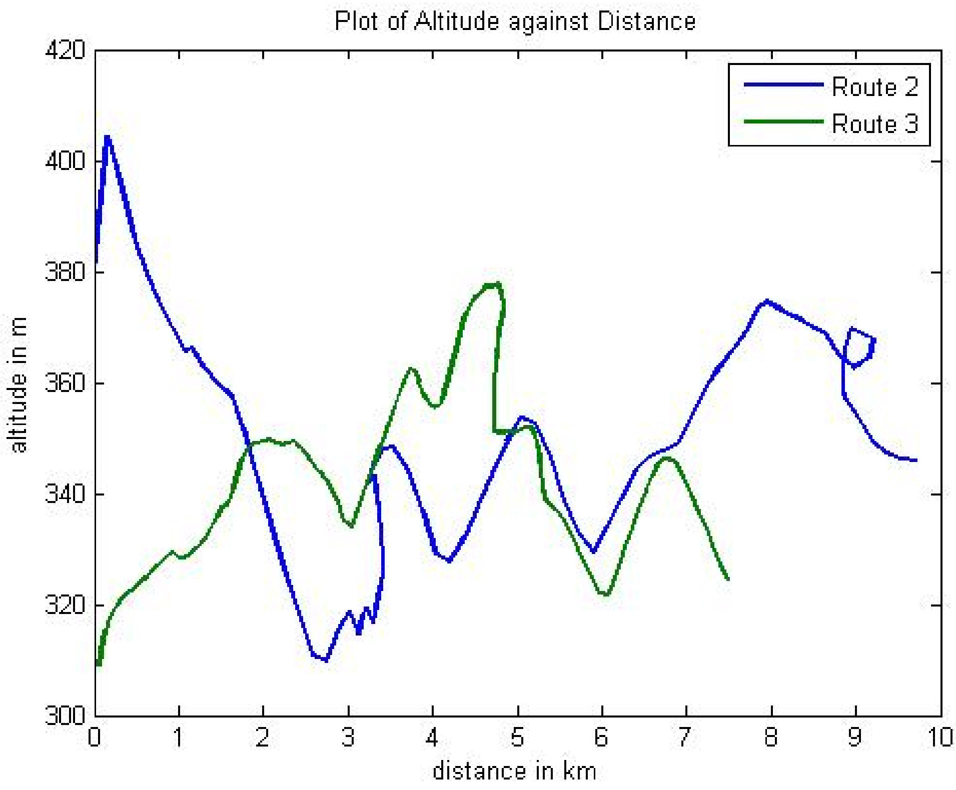

Figure 1: Altitude Profile of Route 2 and Route 3

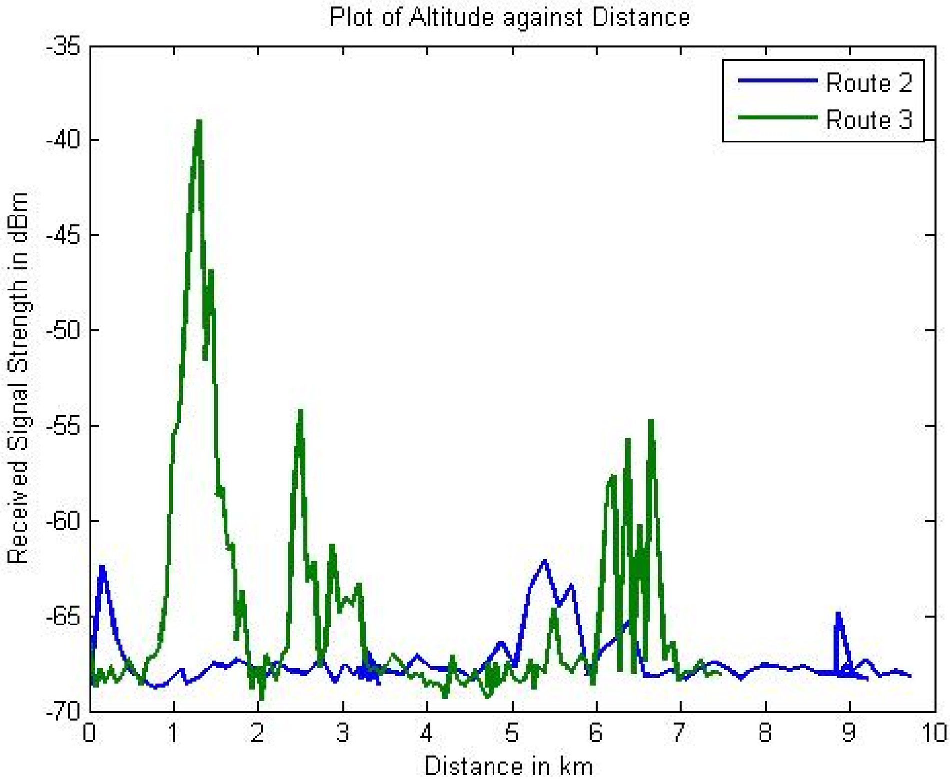

Figure 2:Signal strength profile of Route 2 and Route 3

Figures 3 and 4 show the path loss exponent, of GSM 900 and 1800 respectively, while figure 5, pictorially, compares them. From Figure 5, it could be seen that there are slight differences between the path loss exponents for these two bands. The percentage difference ranges from 0.3% for route XI to 14.79% for route VIII while the overall average percentage difference for all routes is 5.1%.

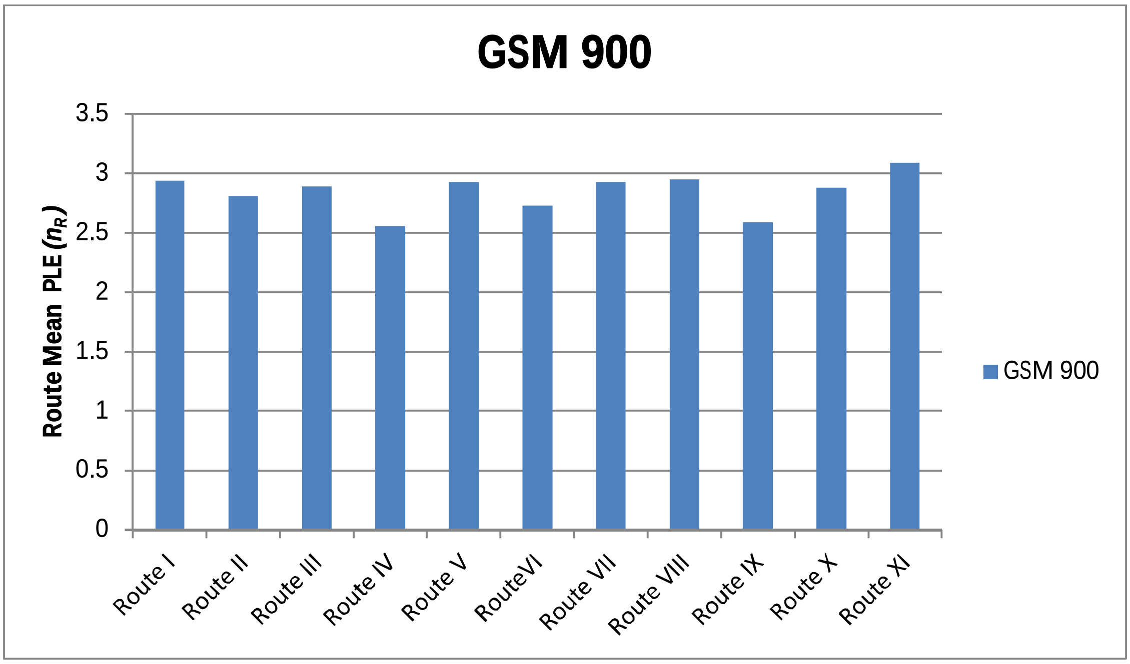

Figure 3: Path Loss Exponent for 900MHz

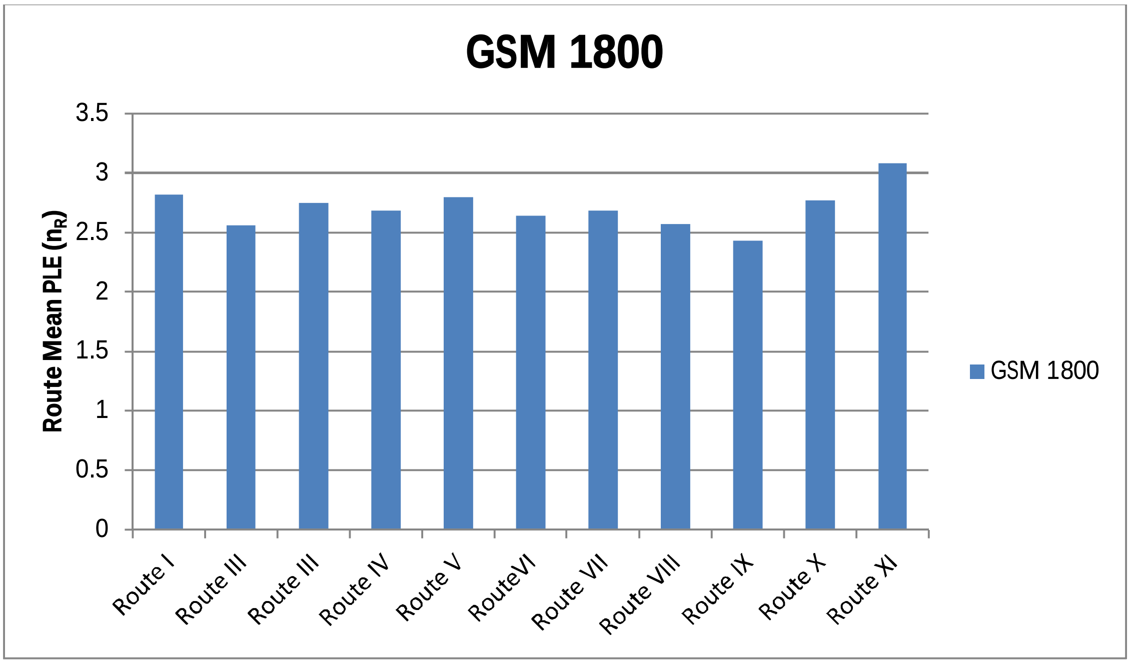

Figure 4: Path Loss Exponent for 1800MHz

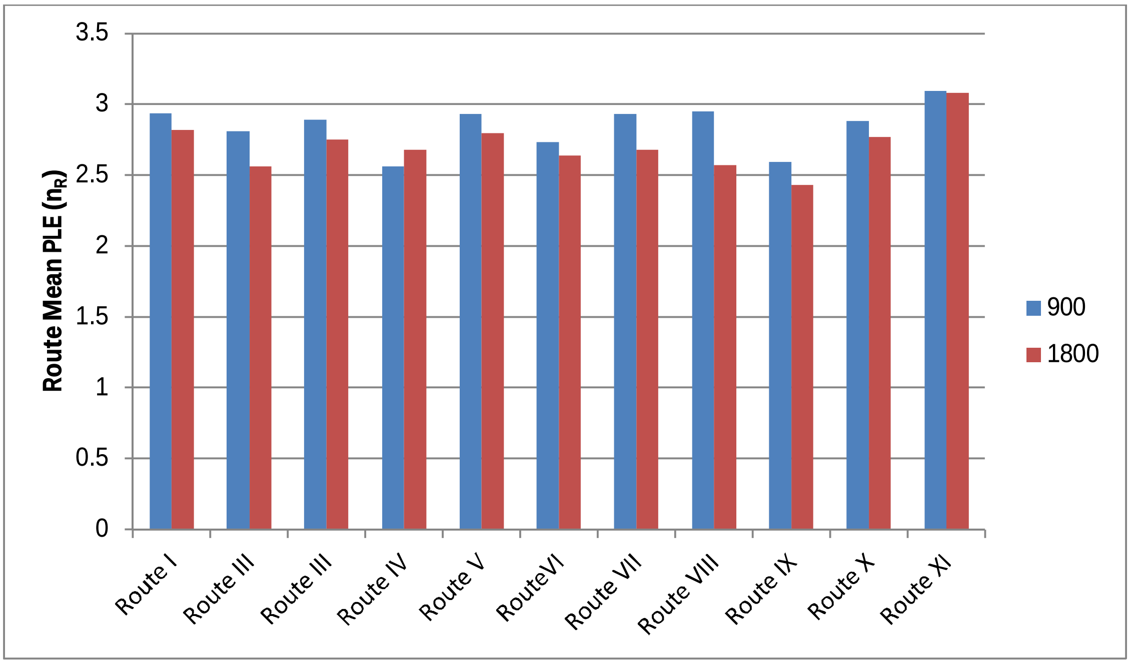

Figure 5: Path Loss Exponent for both 900MHz and 1800MHz

V. Conclusion

This work has shown the path loss exponent of the GSM bands of 900mHz and 1800mHz for Ilorin, Kwara State of Nigeria. From the results obtained, there is a very slight difference in the rate of attenuation of radio waves at these two frequency bands.

The overall average percentage difference for the studied environment is 5.1%, which support the notion that signal propagation in these two frequency bands is similar. We have also computed the coefficient of variation CV for the different channels' path loss exponent values to obtain a more general view of the degree of dispersion for each route. The CV for all the routes, except one in the 1800 MHz band, is less than 5%, which is an indication of good method performance. This is expected since the channels are on the same route; hence, the signal propagation pattern and, by implication, the path loss exponent should be similar. Importantly, a close correlation between the topography of the environment and signal attenuation is observed. An increase in altitude, results in a corresponding increase in measured signal power, across all the routes for all the channels measured. This provides a basis for future work.

REFERENCES

[1] T. S. Rappaport, “Wireless communications principles and practice”, second edition, *Prentice Hall PTR,* 2001.

[2] N. A. Okumbor and O. R.. Okonkwo, "Characterization of Signal Attenuation using Path Loss Exponent in South-South Nigeria", *International Journal of Emerging Trends & Technology in Computer Science (IJETTCS),* Volume 3, Issue 3, pp 100-104, May – June 2014.

[3] T. L. Adebayo, and F. O. Edeko, "Characterization of Propagation Path Loss at 1.8 GHz, A case study for Benin City, Nigeria", *Research Journal of Applied Science, Medwell,* Vol. 1, pp. 92-96, 2006.

[4] P. R. Ogungbayi, A. J. Falade and A. Abdulkarim, "Propagation Path Loss Characteristics at 900 MHz in Ilorin, Nigeria", *Epistemics in Science, Engineering and Technology,* Vol.2 , No.2 , pp. 84-93, 2012.

[5] A. I. Idim, and F. I. Anyasi, "Determination of Pathloss Exponent Using GSM Signal in Orhuwhorun Environ, Delta State", *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE),* Volume 9, Issue 5, Ver. 1, pp 12-20 (Sep - Oct. 2014).

[6] O. F. Oseni, F. I. Popoola, R. O. Abolade, O. A. Adegbola, "Comparative Analysis of Received Signal Strength Prediction Models for Radio Network Planning of GSM 900 MHz in Ilorin, Nigeria", *International Journal of Innovative Technology and Exploring Engineering (IJITEE),* Volume-4 Issue-3, pp. 45-50, August 2014.

[7] N. Faruk, A. A. Ayeni, and Y. A. Adediran, "Characterization of Propagation Path Loss at VHF/UHF Bands for Ilorin City, Nigeria", *Nigerian Journal of Technology (NIJOTECH),* Vol. 32 No. 2, pp. 253-265, July 2013.

[8] V. Erceg, L. J. Greenstein, S. Y. Tjandra, S. R. Parkoff, A. Gupta, B. Kulic, A. A. Julius and R. Bianchi "An empirically based path loss model for wireless channels in suburban environments", *IEE Journal on selected Areas in Communications,* vol 17, No. 7, July 1999.

[9] W. C. Y. Lee, Mobile Communication Engineering, McGraw Hill Publications, New York 1985.

[10] S. Y. Seidel and T. S. Rappaport, "914 MHz Path Loss Prediction Models for Indoor Wireless Communication in Multi-floored Buildings", *IEEE Transactions on Antennas and Propagation,* Volume 40, No. 2, pp 207-307, 1992.

[11] S. Srinivasa and M. Haenggi, "Path Loss Exponent Estimation in Large Wireless Networks", *Information Theory and Applications Workshop,* pp.124-129, 2009.

[12] Y.Hu and G. Leus, "Self-Estimation of Path-Loss Exponent in Wireless Networks and Applications", *IEEE Transactions on Vehicular Technology,* Vol. 64, No. 11, November 2015.

[13] S. Y. Seidel and T. S. Rappaport, "Path Loss, Scattering, and Multipath Delay Statistics in Four European Cities for Digital Cellular and Microcellular Radiotelephone", *IEEE Transactions On Vehicular Technology,* Vol. 40, No. 4, 1991

[14] N. Alam, A. T. Balaie, and A. G. Dempster, "Dynamic Path Loss Exponent Estimation in a Vehicular Network using Doppler Effect and Received Signal Strength", *72nd IEEE Vehicular Technology Conference Fall (VTC 2010-Fall),* pp 1-5, 2010

[15] K., Johan, C. Nikolai, P. Alexander, T. Fredrik and M. Andreas, "Path loss modeling for vehicle-to-vehicle communications", *IEEE Transactions on Vehicular Technology,* Vol. 60, No. 1, 2011.

[16] C. Perez-Vega, G. Jose Luis Garcia, "Frequency Behaviour of a Power Law Path Loss Model", Communications Engineering Department, University of Cantabria, 1998.

[17] T. Chrysikos, S. Kotsopoulos, "Impact of Channel Dependent Variation of Path Loss Exponent on Wireless Information Theoretic Security", *IEEE Wireless Telecommunications Symposium,* 2009.

[18] S. Mazuelas, F. A. Lago, D. Gonzalez, E. J. Abril, "Dynamic Estimation of Optimum Path Loss Model in a RSS Positioning System", *IEEE Symposium on Position, Location and Navigation,* 2005.

[19] J. Turkha, M. Renfors, "Path Loss Measurement for a Non-Line-of-Sight Mobile-to-Mobile Environment", 8th International Conference on ITS Telecommunications, 2008.

[20] F. Zhang, I. Joe, D. Gao, Y. Liu, "A measurement Based Path Loss Model for Mobile-to-Mobile Link Reliability Estimation",*Advance Science and Technology Letters'* vol. 123, pp. 21-26, March 2016.

[21] A.N. Jadhav and, S. S. Kale, "Suburban Area Path loss Propagation Prediction and Optimisation Using Hata Model at 2375MHz", *International Journal of Advanced Research in Computer and Communication Engineering Vol. 3, Issue 1,* January 2014.

[22] V.Ramesh, T.S. Thangaraj and J.V.Prasad, "An Efficient Path loss Prediction Mechanism in Wireless Communication Network Using Fuzzy Logic," *International Journal of Advanced Research in Computer Science and Software Engineering Vol. 2, Issue 1,* January 2012.

[23] P. Pathania, P. Kumar, and S. B. Rana, "Performance Evaluation of Different Path Loss Models for Broadcasting Applications", *American Journal of Engineering Research Vol 03, Issue-04,* pp-335-342, 2014.

[24] N. Rakesh and S.K.Srivatsa, "A Study on Path Loss Analysis for GSM Mobile Networks for Urban, Rural and Suburban Regions of Karnataka State", *International Journal of Distributed and Parallel Systems (IJDPS) Vol.4, No.1,* January 2013.