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CHARACTERIZATION OF PROPAGATION PATH LOSS AT VHF/UHF BANDS FOR ILORIN CITY, NIGERIA

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Abstract:
Path loss exponent, standard deviation and building penetration loss are used in all distance path loss models. Once these data are known for an environment, coverage planning and propagation analysis could be done easily. Many countries across the world, such as Japan, United Kingdom, Germany, and the USA have already published their propagation data, mostly, the path loss exponent for their various cities. However in Nigeria, these data are not available. In this work, measurements were conducted at 203.25 MHz and 583.25 MHz frequencies along ten routes in Ilorin City in Kwara State of Nigeria. Least squares regression method is used to fit the measured data with log-normal propagation path loss model to characterize the path loss parameters. Results of the experiment indicate that the path loss exponent for Ilorin City varies from 1.4 to 4.94 with an average value of 2.80. The work further investigates the behaviour of the TV signals in the same environment in terms of standard deviation and building penetration loss across the routes, and some selected building structures.

Keywords: Path loss exponent, TV band, Ilorin, Propagation model, Partition losses

1. Introduction

The fundamental principle in the design of any wireless system is the design of transmission strategy that will optimise the coverage and minimize interference. Understanding the behavior of the radio propagation channel in an environment is essential for the success and deployment of any technology built to operate on such environment. In all frequency bands, signals undergo attenuation which increases with distance this is referred to as path loss. Multiple signals may arrive at the receiver constructively or destructively; this will cause small variation of the signal or multipath fading. The multipath fading arises from reflection, diffraction and/or scattering of the signal due to physical objects in the environment. Path loss model can be use to efficiently estimate the receive signal level, signal-to-interference ratio and the carrier-to-interference ratio. Path loss can be represented by the path loss exponent, whose value is normally in the range of 2 to 4 (where 2 is for propagation in free space, 4 is for relatively lossy environments) [1]. In some environments other than the free space, such as buildings, stadiums, and other indoor environments, the path loss exponent can reach values in the range of 4 to 6. These values are influenced by terrain contours, environment (urban or rural, vegetation and foliage), the distance between the transmitter and the receiver, and the height and location of antennas which all depends on the propagation environment [2]. Path loss exponent is one of the most important parameter in all distance path loss models [3] and once it is known for an environment coverage planning and propagation analysis will be done easily. It has significant impacts on the capacity and outage probability of a channel [4]. In [5], the effects of path-loss exponent and noise level on the transmit power and energy per successfully received bit (EPSB) for wireless communication systems were investigated. Analysis of the results shows that path loss exponent and noise level affect the bit error rate and success probability. Also, the transmit power and EPSB decrease with the increasing path loss exponent.

2. Related work

Many countries across the world such as Japan, United Kingdom, Germany, and the United States, have already obtained and published the propagation data, mostly the path loss exponent for various cities of their country as reported in [6]. These data are not available for many cities In Nigeria. One exception is the work presented by Adebayo [7] which characterized propagation path loss at 1.8 GHz for Benin City. In the work, propagation path loss for GSM 1800 was investigated and concluded that the path loss exponent for Benin City ranges from 2.8 to 3.7 with an average value of 3.8. This is a remarkable achievement as it is the only published work that provides the exponent for a City within Nigeria. There are many published papers that aimed to provide techniques for estimating path loss exponent (n) in a wireless environment. [8] provides a dynamic path loss exponent and distance estimation in a vehicular network using Doppler effect and received signal strength, this method is fundamentally based on the Doppler Effect and can be implemented within networks with mobile nodes. [9] advocates that path loss exponent is estimated based on measured received signal strength, RSS, between a moving station and at least three fixed base stations with known positions. [10] performs measurement of path loss exponent in the mobile environment. The achieved results were used for network design and coverage analysis. Perez-Vegas and Garcia, [11], investigated the frequency behavior of a power low path loss model in the VHF and UHF bands. In the work, measurements was carried out in the urban area of the city of Santander in the Cantabric coast of Northern Spain using the signals of three broadcasting transmitters at frequencies of 96.9 MHz, 535.25 MHz and 807.25 MHz. The three transmitters were located on the same place with antennas in the same tower. The field strength measurements were conducted in a range of distance between 9.5 km to 11 km from the transmitter site using a portable field strength meter. The results indicate that the mean value of the path loss exponent is fairly constant at different frequencies in a similar propagation environment. In [12], similar approach to [11] was presented by the same authors to investigate the power low path loss model for indoor communications at 1.8 GHz. In the work, the exponent of the distance is treated as a random variable and its behavior was studied through experiments conducted under various propagation conditions. The value of n for more complex environments can be obtained via a minimum mean square error (MMSE) fit to empirical measurements as reported in [2], or an empirically-based model that takes into account frequency and antenna height [18].

3. Measurements Campaign

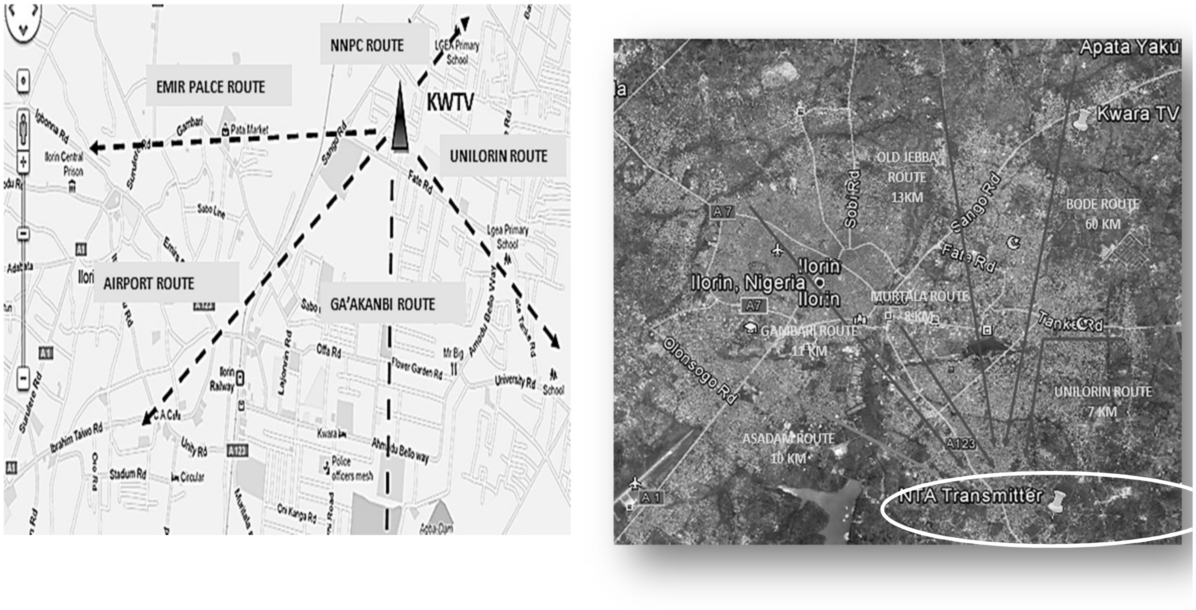
NTA Ilorin and Kwara TV (KWTV) transmitters were utilized. NTA transmits on channel 5 at 203.25 MHz while Kwara TV transmits on channel 35 at 583.25 MHz. While the transmission is taking place, a dedicated Agilent spectrum analyzer was placed inside a vehicle and driven at an average speed of 40 km/h along the routes. Field strength was measured continuously and stored in an external drive for subsequent analysis. Table 1 provides details of the analyzer and transmitter information.

The propagation measurements were conducted in Ilorin (Long 4^{o} 36’ 25”E, Lat 8^{o} 25’ 55’’N) Kwara State, Nigeria. Ilorin is a large city characterized by a complex terrain due to the presence of hills and valleys of varying altitude within the metropolis. Ten routes were covered during the measurement campaign. Fig 1(a) and (b) show the screenshot of the measurement routes for NTA and KWTV respectively. Table 2 shows details of the measurement routes.

Table 1: Measurement equipment and configuration

Spectrum Analyzer Agilent N9342C 100 Hz- 7 GHz	
Displayed average noise level (DANL)	-164 dBm/Hz 20 dB

Preamplifier	10 kHz
Resolution bandwidth (RBW)	203.25 MHz
Center frequency (f1)	583.25 MHz
Center frequency (f2)	
Antenna Type, Diamond RH799	
Frequency range	70 MHz-1 GHz
Form	Omni directional
Height	1.5 m
Gain	2.51 dBi
KWTV Ilorin Transmitter	
Power	1 kW
Frequency	583.25 MHz
Antenna height above the	366 m
ground	SEMI FEX 3/8
Cable Type	50 ohms
Impedance	4° 36' 49''E, 8° 31'
Coordinates	47''N
NTA Ilorin Transmitter	
Power	2.4 kW
Frequency	203.25 MHz
Antenna height above the	185 m
ground	RFS HEL FEX 512
Cable Type	50 ohms
Impedance	4° 36' 25''E, 8° 25'
Coordinates	55''N



(a) (b)

Figure 1: (a) Measurement routes for NTA, (b) Measurement routes for KWTV

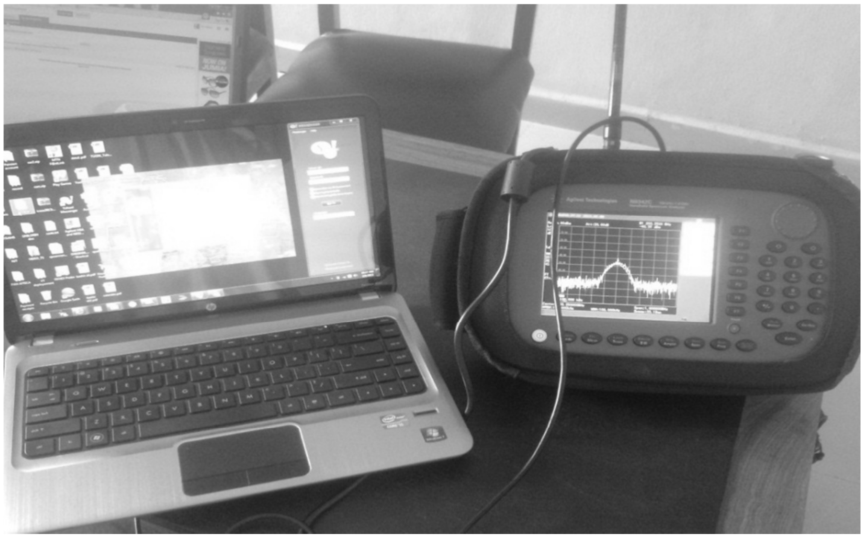


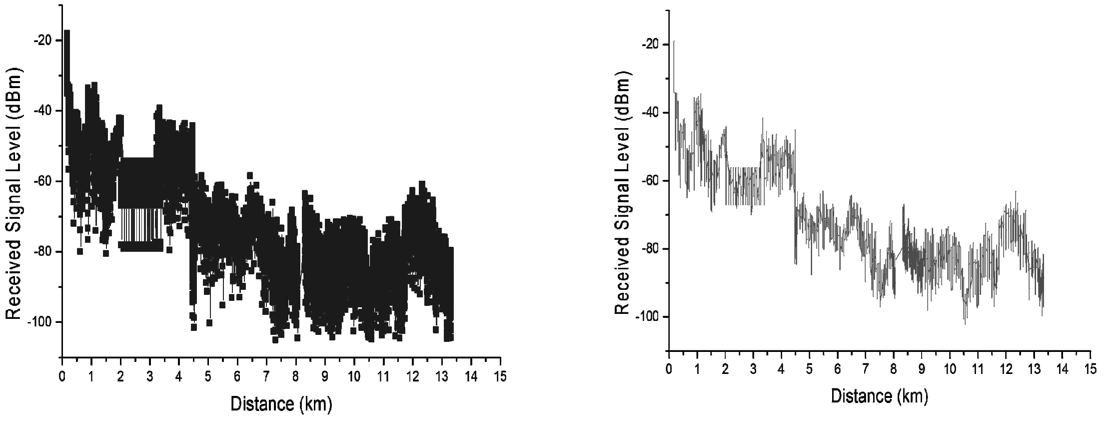
Figure 2: Agilent Spectrum Analyzer 100 MHz-7 GHz

Table 2: Description of measurement routes

S/N	Route	Description	No. Points	Route (km)
1.	KWTV-EMIR PALACE	Dense urban area. It is a historical area with very old buildings around. It is very busy commercial area. The roads are quite narrow.	15,032	15
2.	KWTV-NNPC Via Old Jebba Rd	Suburban. This route spans from the suburban to rural areas. It has regular building structure within the dense area, beyond UITH hotspots villages with two-lane road.	10,415	15
3.	KWTV-AIRPORT Rd	Dense urban area. This route spans through the historical area with very old buildings around. It is very busy commercial area within GAMBARI and ADETA, then regular building structure along the airport Rd.	19,235	15
4.	KWTV-UNILORIN Via TANKE NEW GRA	Suburban are with vegetation cover few meters to the Judges quarters (JQ), then line of sight clearance at the JQ. Regular buildings structures along his route.	6,415	8
5.	KWTV-GA'AKANBI	This route spans through suburban, urban and then rural areas.	17,712	15
6.	NTA-ASADAM	Suburban area. It has regular building structure with dual carriage way. The traffic along the route is relatively fair; however, the route is characterized with complex terrain with varying altitudes.	12,712	10
7.	NTA-UNILORIN VIA PIPELINE	Urban area. It has very complex terrain; some areas are very high whereas some parts are very low. Within the University, heavy trees cover the road and there was line of sight clearance to the transmitter at some certain interval distance. Along the route, the road is very narrow with average 2 storey buildings	24,310	7
8.	NTA-GAMBARI VIA AGAKA	Dense urban area. It is historical area with very old buildings around. It is very busy commercial area	26,634	11
9.	NTA-MURTALA	Urban area. It has regular building structure with average of 3 storey buildings with dual carriage road.	12,004	8
10.	NTA-UITH	Urban area. It has regular building structure with average of 2 storey buildings with 2-lane road.	18,418	13
Total			**145,175**	**102**

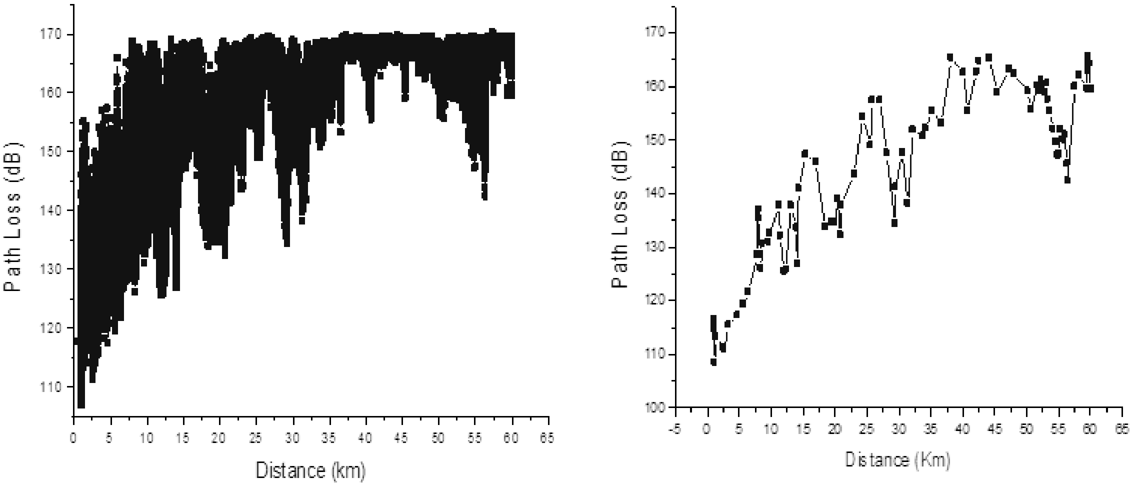
3.1 Data pre-processing

In order to estimate the local mean received power of the path loss, small-scale fading characteristics of the radio signal has to be removed [12]. The first rule is to determine the proper distance interval that will preserve path loss and shadowing effects statistics. The length of a local mean has to be chosen properly. That is, if the length is too short, the fast fading will still be present after the averaging process. If the length is too long, shadowing effects are removed [12]. Figure 3a shows the raw received signal level (RSL) data before filtering. The figure illustrates how a very small sample of data needs to be filtered in order to extract the corrected statistical parameters of interest. In order to achieve this, MicroCal origin 5.0 for fitting and statistical analysis was used. Un-weighted sliding average smoothing algorithm with 10 smooth points was also used for smoothing the data. After the data is filtered the small-scale fading is removed and the path loss and shadowing (variance) effects of the data are preserved as shown in (Figure 3b). In addition, each point (km) has 10 data set points. Before computing the path loss, a pick peaks tool (using a Bayesian second derivative) was also utilized; the peak picker takes proper account of the noise, it finds peak locations and then estimates their height and width. It locates occluded peaks that the eye cannot discern and estimates their statistical significance, reporting the results as signal to noise ratios. Search rectangle width 1, height 1 and maximum height displace options of 0.5 were used. Also, the analyzer's GPS records the coordinates (latitudes and longitudes). It is also important to have picture of the surrounding environment so as to help in determining anomalies in the data and validate clutter. In view of this, the terrain profile is plotted against distance for Old Jebba and Pipeline routes as shown in Fig 4 and Fig 5 respectively.



(a) (b)

Figure 3: RSL with pick peak, (a) before filtering, (b) after filtering



(a) (b)

Figure 4: Raw RSL (a) before pick peak (b) after pick peak

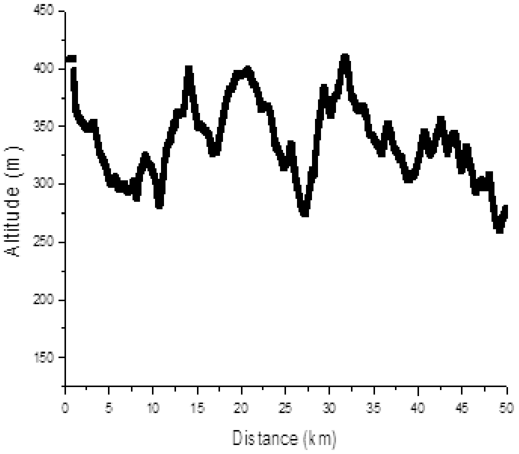


Figure 4: Terrain profile for Old Jebba route

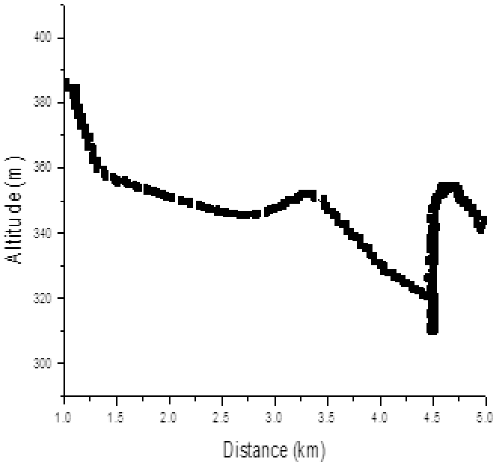


Figure 5: Terrain profile for Pipeline route

4. Path loss characteristic analysis

4.1 Path loss exponent and shadowing effect

In this section, the path loss characteristic of the measurement data is analysed. Several methods of estimating path loss exponent have been reported in [13] [14] and [15]. In this work, received signal measurement distance based technique is adopted. This technique has received considerable research interest, and is considered as the simplest technique. This technique relies on a log-normal radio propagation model [11].

The log-normal distance propagation model is used to estimate path loss model parameters from measurement data. Large scale path loss model $PL(d)$ for an arbitrary transmitter and receiver separation is expressed in [12].

$$PL(d) = A * \log(d) + C \qquad (1)$$

Or, in a generic form

$$PL(d) = \overline{P}L(d_0) + 10 * n * \log(d/d_0) \qquad (2)$$

where n is the path loss exponent, $\overline{P}L(d)$ is the path loss (in dB) at a distance d, and so d_0 is the reference distance. In the case where there are scattering object such as buildings and tress along the transmission path, the signal tends to suffer reflection, scattering and absorption. This phenomenon is called shadowing. The net path loss from (2) becomes;

$$PL(d) = \overline{P}L(d_0) + 10 * n * \log(d/d_0) + \chi \qquad (3)$$

where χ is a normal distributed random variable (in dB) with standard deviation δ.

Using regression analysis, equation (2) can be used to relate variable dependence of the path loss with logarithmic distance between the transmitter and the receiver. The subsequent equation becomes

$$Y_i = a + bX_i \qquad (4)$$

where a represents the intercept or the path loss at the reference position (in this case, path loss at 1 km distance from the transmitter), while b is the slope and represents the path loss exponent.

Figures 6 to 13 show generally increasing trends average path loss with distance. Statistical results of the path loss exponent, path loss intercepts, standard deviation and coefficient of determination are shown in Table 3. The path loss exponent varies from 1.4 to 4.94 with an average value of 2.80. Route 7, which is the University of Ilorin to NTA via Pipeline route, had the least value of 1.4. This route is characterized with very complex terrain; some areas are very high, whereas some parts are very low. Within the University, heavy trees over the road but there was line-of-sight clearance to the transmitter at certain intervals of distance. Along the Pipeline, the road is very narrow with average of two-storey buildings. Distance dependency of the path loss for this route is shown in Fig 10. The correlation value for UNILORIN via Pipeline route was found to be 0.339; this indicates low correlation between the data samples. Fig 5 shows the terrain profile for the route. The path loss at 1 km intercept for all the routes does not seem to vary significantly as there is clear line-of-sight in most cases.

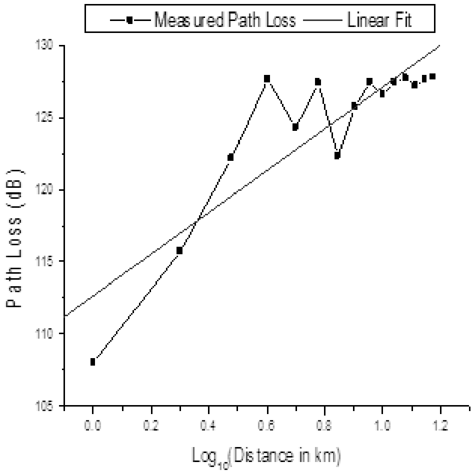


Fig. 6: KWTV Old Jebba Rd

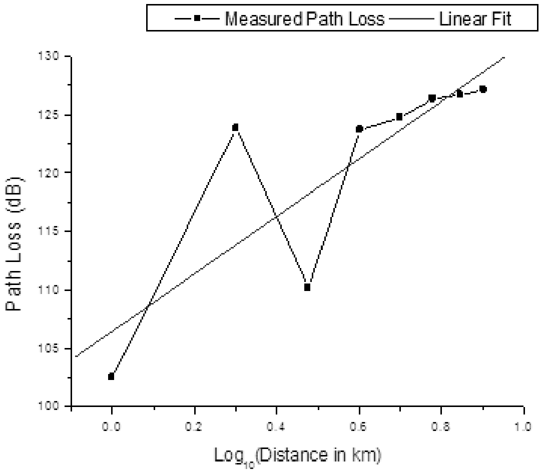


Fig. 7: KWTV UNILORIN Via Tanke New GRA

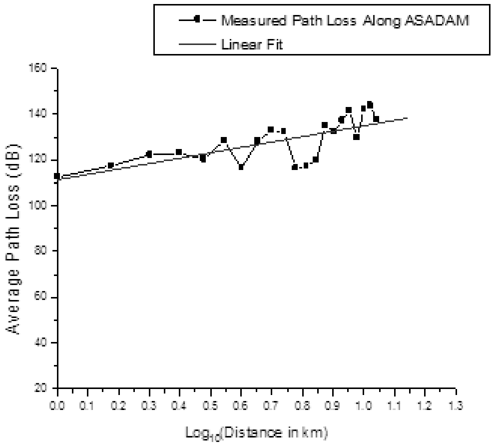


Figure 8: Path loss along ASADAM route

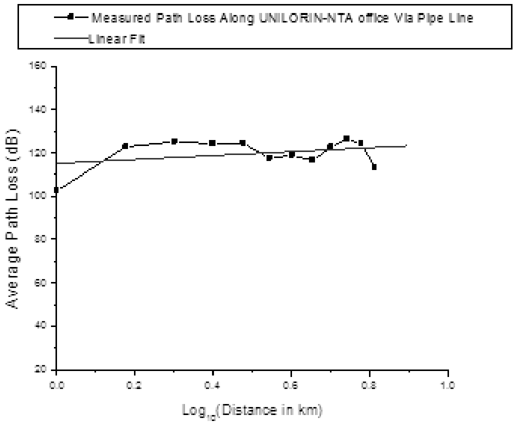


Figure 9: Path loss along UNILORIN-NTA route

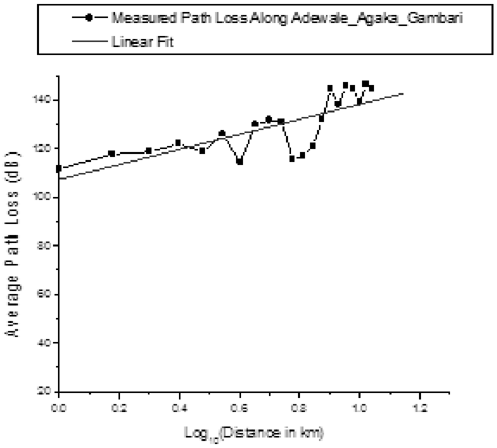


Figure 10: Path loss along Adewale Agaka route

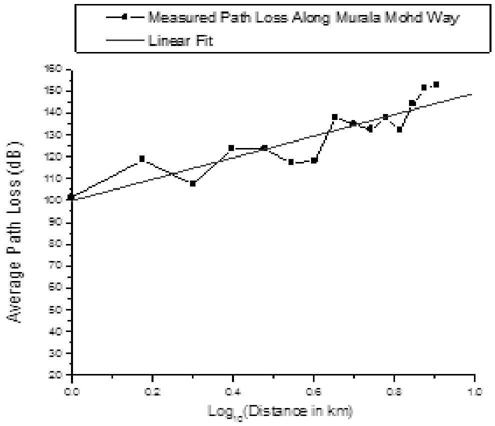


Figure 11: Path loss along Murtala Mohd Way

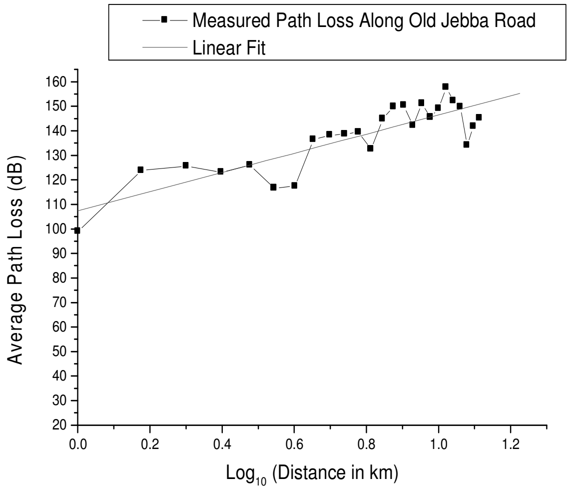


Figure 12: Path loss along Old Jebba Road

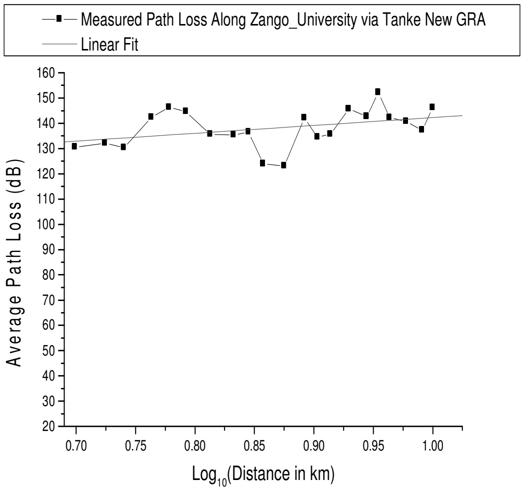


Figure 13: Path loss along Zango via Tanke new GRA

Table 3. Path loss exponent for the measurement routes

Route ID	Path loss exponent (n)	Path Loss 1km intercept (dB)	Standard Deviation (dB)	R^2
1	3.09	103.26	11.87	0.810
2	1.51	112.65	5.78	0.770
3	2.72	106.72	6.22	0.801
4	2.51	106.46	5.62	0.675
5	2.43	105.74	8.45	0.647
6	2.37	111.23	6.87	0.519
7	1.40	115.11	6.70	0.339
8	3.09	107.30	7.84	0.585
9	4.94	99.79	7.03	0.794
10	3.90	107.42	7.44	0.726
Mean	***2.8***	***107.56***	***7.35***	

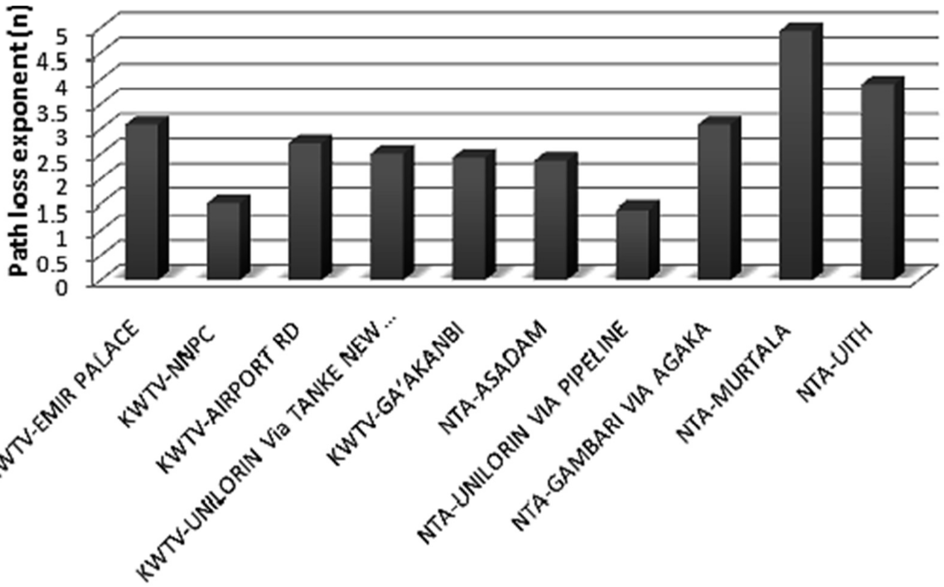


Fig.14: Path loss exponent and measurement routes

Fig 14 shows summary of the path loss exponent and the measurement routes. Murtala Mohd way has 4.94; this is not surprising as it is an urban area with lots of scatters and moving vehicles. The traffic along this route is quite high with dual carriage road. This value is in agreement with typical values (3.7-6.5) for urban macro cells measurements conducted in the 900 MHz and 1.9 GHz bands obtained in [18, 19, 20, 21, 22, and 23]. Another important parameter which this work provides is the standard deviation. In addition to the path loss, signals usually experience random variation due to scattering and blockage from objects in the signal path; this gives rise to a random variation about the path loss at a given distance. The standard deviation gives an idea of how far the path loss deviates from the mean value. Based on our measurements, the value of the standard deviation varies from 5.62 to 11.87 dB as shown in Table 3. Also, the path loss intercepts at 1 km distance vary from 99.97 to 115.11 dB. The question now is what the value of the standard deviation for Ilorin City will be. All the values obtained from measurements are in agreement with most empirical studies conducted for outdoor channels. For example, [24, 25, 26, 27] support a standard deviation (σ) ranging from 5 to 12 dB in macro cells and from 4 to 13 dB in microcells. However, we took the average and arrived that the standard deviation for Ilorin city is 7.35 dB while the path loss intercept at 1 km is 107.56. The values 7.35 dB and 107.56 dB are supported by another literature [28], which shows that obtaining empirical averages based on dB path loss measurements leads to a smaller estimation error.

4.2 Partition losses

When modelling path loss of an environment, it is important to study the extents of shadowing and building penetration loss since the model could also be applied to predict indoor path losses. Researchers, for decades, have focused on building penetration loss for high frequency signals. This was due to the propagation nature of the low frequency waves that do not suffer fading and have the ability to penetrate buildings and foliage. However, with the advent of digital transition, more spectrums will be freed as white space and, as such, TV white space devices (TVWD) are expected to make efficient use of the white spaces. Most of these devices (i.e. TVWD) will be indoor-based. Although, in a few cases, efforts have been made to build indoor models at GHz frequencies, it is however difficult to find indoor model for VHF and/or UHF bands that could cater for the building penetration loss. Indoor environments differ widely in the materials used for walls and floors, the layout of rooms, hallways, windows, and open areas, the location and material in obstructing objects, and the size of each room and the number of floors [2]. All of these could have significant impacts on the path loss in an indoor environment. Thus, it is difficult to find generic models that can be accurately applied to determine path loss in both environments (indoor and outdoor). For a model to be generic it must accurately capture the effects of attenuation across floors due to partitions, as well as between floors. However, recourse is made to add the additional losses incurred to the outdoor model in order to predict losses for indoors scenarios. For these reasons, we embark upon studying the building penetration loss for the TV signal across some selected building structures in the city. Measurements of received signal level (RSL) were conducted in Mr. Faruk's office, University of Ilorin coordinates (4^0 40' 24"E, 8^0 29' 17"N), sample data were collected inside and outside the office for a period of 10 minutes. Fig 15 shows the plot of RSL with time for both indoor and outdoor scenarios.

Table 4, shows the raw data for the received signal level (Rx) for outdoor, indoor and double layer scenario. Two losses were obtained: Loss 1 for the building penetration loss as the result of transition from indoor to outdoor, and Loss 2 for the additional loss incurred when 2-layer structure building is used. This is obtained by taking measurement at the inner office. ADD Loss is the loss difference between Loss 1 and Loss 2 in dB.

In Table 4, the average penetration loss is 15.59 dB, with additional 4.49 dB for double layer building. The experiment was repeated for 12 different sites/structures within the metropolis. The building penetration loss varies from 8.37 to 16.01 dB for varying sites with an average penetration loss of 11.49 dB. The result is shown in Table 5. These values are in agreement with [23, 24 and 29], all indicating that at 900 MHz the attenuation when the transmitter and receiver are separated by a single floor ranges from 10 to 20 dB. Another important result is the work presented in [21, 30] which shows that the building penetration loss on the ground floor is typically in the range 8 to 20 dB for 900 MHz to 2 GHz, and that penetration loss is a function of frequency, height and the building materials.

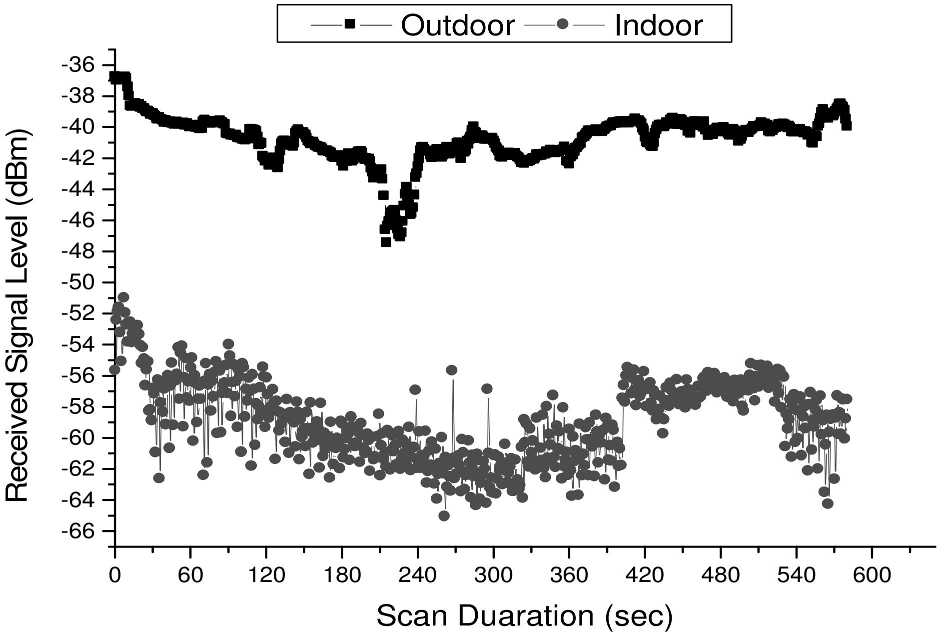


Figure 15: RSL Scan at Mr. Faruk's Office, University of Ilorin.

Table 4. Indoor, outdoor and double layer building penetration loss

S/N	OUTDOOR RX (dBm)	INDOOR Rx (dBm)	2- Layers Rx (dBm)	Loss 1 (dB)	Loss 2 (dB)	ADD Loss (dB)
1	-36.782	-55.684	-55.946	18.902	19.164	0.262
2	-37.035	-52.464	-55.195	15.429	18.16	2.731
3	-37.031	-51.906	-55.629	14.875	18.598	3.723
4	-36.928	-51.642	-57.525	14.714	20.597	5.883
5	-36.904	-53.257	-60.281	16.353	23.377	7.024
6	-36.94	-55.123	-58.593	18.183	21.653	3.47
7	-36.845	-51.024	-58.351	14.179	21.506	7.327
8	-36.804	-51.993	-61.624	15.189	24.82	9.631
9	-36.916	-52.762	-63.152	15.846	26.236	10.39
10	-37.452	-53.859	-60.697	16.407	23.245	6.838
11	-38.05	-52.629	-58.509	14.579	20.459	5.88
12	-38.671	-52.583	-59.408	13.912	20.737	6.825
13	-38.722	-53.892	-65.86	15.17	27.138	11.968
14	-38.673	-53.343	-57.757	14.67	19.084	4.414
15	-38.532	-53.228	-56.718	14.696	18.186	3.49

S/N	**OUTDOOR RX (dBm)**	**INDOOR Rx (dBm)**	**2- Layers Rx (dBm)**	**Loss 1 (dB)**	**Loss 2 (dB)**	**ADD Loss (dB)**
16	-38.531	-53.781	-55.587	15.25	17.056	1.806
17	-38.647	-53.529	-55.827	14.882	17.18	2.298
18	-38.589	-52.812	-57.397	14.223	18.808	4.585
19	-38.586	-53.377	-56.236	14.791	17.65	2.859
20	-38.771	-54.096	-55.185	15.325	16.414	1.089
21	-38.702	-55.253	-55.977	16.551	17.275	0.724
22	-38.854	-54.23	-56.646	15.376	17.792	2.416
23	-38.846	-54.967	-57.885	16.121	19.039	2.918
24	-38.968	-56.674	-57.901	17.706	18.933	1.227
25	-39.067	-55.653	-58.327	16.586	19.26	2.674
26	-39.012	-55.142	-59.918	16.13	20.906	0.262
AVERAGE	***-37.993***	***-53.590***	***-58.088***	***15.596***	***20.094***	***4.498***

Table 5. Building penetration loss for TV signal (203.25 MHz) in Ilorin

SITE LOCATION	A	B	C	D	E	F	G	H	I	J	K	L
AVG LOSS (dB)	15.59	12.34	16.01	9.45	11.92	13.47	11.17	8.37	8.98	10.11	11.98	8.45

5. Conclusion

Path loss exponent is one of the important parameters in all distance path loss models; once it is known for an environment, coverage planning and propagation analysis could be done easily. In this work, log-normal propagation path loss model is used to characterize the path loss parameters in the VHF and UHF frequencies for Ilorin City of Kwara State, Nigeria. Results indicate that the path loss exponent varies from 1.4 to 4.94 with an average value of 2.80. The work further investigates the behaviour of the TV signals in the same environment in terms of standard deviation and building penetration loss. It is concluded that the standard deviation for Ilorin city is 7.35 dB, the average penetration loss is 11.49 dB and the path loss intercept at 1 km at 203.25 MHz and 583.25 MHz is 107.56 dB. With these parameters, coverage planning and propagation analysis in the TV bands can be done easily in the future. However, it should be noted that even though the mean values of the exponent may be similar in different environments, the fading behavior depends strongly on the topography or terrain profile of such environment. Such behavior is reflected in the standard deviation and, for that reason, no assumption can be made about its value for a given environment. For research point of view, worst case value may be used.

References

[1]-Retrieved from http://en.wikipedia.org/w/index.php?title=Path_loss&oldid=436455340" [Accessed 2/12/2012]

[2] Goldsmith, A.” Wireless communications” *Stanford University*, pp 41-42, 2004.

[3]Liechty, L.C. ” Path loss measurements and model analysis of a 2.4 GHz wireless network in an outdoor environment”, Master of Science in Electrical Engineering, *Georgia Institute of Technology*, August 2007. Available on http://smartech.gatech.edu/bitstream/handle/1853/16308/liechty_lorne_c_200708_mast.pdf

[4] Chrysikos, T. and Kotsopoulos, S. “Impact of channel-dependent variation of path loss exponent on Wireless Information-Theoretic Security”, *Wireless Telecommunications Symposium,* 2009. WTS 2009, pp 1-7, April 22-24, 2009.

[5] Shrotriya, A. and Nitnawwre, D. “Investigating path loss effect in wireless sensor networks”, *International Journal of Advanced Research in Computer Science and Software Engineering,* Vol. 2, Issue 5, pp 411-413, 2012. Available

online http://www.ijarcsse.com/docs/papers/May2012/Volum2_issue5/V2I500457.pdf [Accessed on 2/12/2012]

[6] Rautiainen, T. "Verifying path loss and delay spread predictions of a 3D ray tracing propagation model in urban environment. *IEEE Vehicular Technology Conference*, Vol.4, pp 247—2474, 2002.

[7] Adebayo, T.L. and Edeko, F.O."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.

[8] Alam, N., Balaie, A. T. and Dempster, A. G. "Dynamic path loss exponent and distance estimation in a vehicular network using Doppler effect and received signal strength", *IEEE Vehicular Technology Conference*, Sept 6-9, pp 1-5, 2010.

[9] Mazuelas, S., Lago, F. A., Gonzalez, D., Bahillo, A., Blas, J., Fernandez, P., Lorenzo, R. M. and Abril, E. J. "Dynamic estimation of optimum path loss model in a RSS positioning system," in Record - *IEEE PLANS, Position Location and Navigation Symposium*, 2008, pp. 679-684.

[10] Turkka, J. and Renfors, M. "Path loss measurements for a non-line-of sight mobile-to-mobile environment," in *Proceedings 8th International Conference on Intelligent Transport System Telecommunications*, ITST 2008, Phuket, 2008, pp. 274-278.

[11] Perez-Vegas, C. and Garcia., G.J.L. "Frequency behavior of a power low path loss model" Available on http://personales.unican.es/perezvr/pdf/Frequency%20behavior.PDF [Accessed on 2/12/2012]

[12] Perez-Vegas, C., Garcia, G.J.L. and Higuera, J.M.L. "A simple and effificent model for indoor path loss predicition", *Meas. Sci. Technol.* Vol. 8, 1166-1173. Sept. 1997. http://personales.unican.es/perezvr/pdf/articulo%20IOP.pdf [Accessed on 2/12/2012]

[13] Mao, G., Anderson, B.D.O. and Fidan, B. "Path loss exponent estimation for wireless sensor networks localization" *Computer networks, Elsevier,* Vol. 50, pp 2467-2483, 2007. http://nicta.com.au/ data/assets/pdf file/0015/16350/MaoAndersonFidan07 CompNetworks.pdf

[14] Yesim, B. H. and Hakki, I. C. "Mobile Radio Propagation Measurements and Tuning the Path Loss Model in Urban Areas at GSM-900 Band in Istanbul –Turkey", *IEEE* Vehicular Technology Conference, Sept 26-29, Vol. 1, pp 134-143, 2004.

[15] Juan-Llacer, L., Ramos, L. and Cardona, N. "Application of some theoretical models for coverage prediction in macrocell urban environments," *IEEE Transaction on Vehicular. Technology*, Vol. 48, September 1999, pp. 1463-1468.

[16] Rappaport, T.S. "Wireless communications principles and practice", second edition, *Prentice Hall PTR,* 2001.

[17] Costa, J.C. "Analysis and optimization of empirical path Loss models and shadowing effects for the Tampa Bay Area in the 2.6 GHz Band" M.Sc Thesis, Electrical Engineering *Department of Electrical Engineering ,College of Engineering University of South Florida, USA,* pp 30-48, March 21, 2008.

[18]Erceg, V., Greenstein, L. J., Tjandra, S. Y., Parkoff, S. R., Gupta, A., Kulic, B., Julius, A. A. and Bianchi, R. "An empirically based path loss model for wireless channels in suburban environments," *IEEE Journal on Selected Areas in Communications*, pp. 1205–1211, July 1999.

[19] Lee, W.C.Y. " Mobile Communication Design Fundamentals", I*ndianapolis, IN: Sams,* 1986.

[20] Seidel, S. Y. Rappaport, T. S., Jain, S., Lord, M.L., and Singh, R., "Path loss, scattering, and multipath delay statistics in four European cities for digital cellular and microcellular radiotelephone," *IEEE Transaction on Vehicular Technology.*, Vol 40, No. 4, pp. 721–730, Nov. 1991.

[21] Toledo, A. F., Turkmani, A.M.D. and Parsons, J. D. "Estimating coverage of radio transmission into and within buildings at 900, 1800, and 2300 MHz," *IEEE Personal Communications Magazine*, pp. 40–47, April 1998.

[22] Toledo, A. F. and Turkmani, A.M.D. "Propagation into and within buildings at 900, 1800, and 2300 MHz," Proc. *IEEE Vehicular Technology Conference,* pp. 633-636, May 1992.

[23] Seidel, S. Y. and Rappaport, T.S. "914 MHz path loss prediction models for indoor wireless communications in multi Floor buildings," *IEEE Transactions on Antennas and Propagation*", pp. 207–217, Feb. 1992.

[24] Cox, D. C. "910 MHz urban mobile radio propagation: Multipath characteristics in New York City," *IEEE Transactions on Communication.*, Vol. COM-21, No. 11, pp. 1188–1194, Nov. 1973.

[25] Berg, J.E., Bownds, R. and Lotse, F. "Path loss and fading models for microcells at 900 MHz," *Vehicular Technology Conference. Rec.,* pp. 666–671, May 1992.

[26] Goldsmith, A. J. and Greenstein, L.J. "A measurement-based model for predicting coverage areas of urban microcells," *IEEE J. Selected Areas Communication*., Vol. SAC-11, No. 7, pp. 1013–1023, Sept. 1993.

[27] Gudmundson, M. "Correlation model for shadow fading in mobile radio systems," *Electronics Letters*., Vol. 27, pp. 2145–2146, Nov. 7, 1991.

[28] Goldsmith A. J., Greenstein, L.J. and Foschini, G.J. "Error statistics of real-time power measurements in cellular channels with multipath and shadowing," *IEEE Transactions on Vehicular Technology*, Vol. 43, No. 3, pp. 439-446, Aug. 1994.

[29] Motley, A.J. and Keenan, J.M.P. "Personal communication radio coverage in buildings at 900 MHz and 1700 MHz," *Electronic Letters*, pp. 763–764, June 1988.

[30] Hoppe, R., Wolfle, G. and Landstorfer, F.M. "Measurement of building penetration loss and propagation models for radio transmission into buildings," *Proc. IEEE Vehicular Technology Conference,* pp. 2298–2302, April 1999.