Comparative Analysis of Propagation Pathloss and Channel Power of VHF and UHF Wireless Signals in Urban Environment

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Abstract: **The paths loss propagation model is an important tool in wireless network planning but inaccurate models normally leads to networks co-channels interference and a waste of power. Hence, it is important to investigate the radio path loss and the channel power behaviour for working out radio and LTE technology. In this work, a comparative analysis of path loss prediction models with measured data and channel power is presented. Three different propagation path loss models (Free space, Okumura and Egli) have been analyzed and compared with measured data. The experimental campaign took place in Ogbomoso, south western, Nigeria (8.1227°N, 4.2436°E) and the measured data were obtained at two frequency bands; 150 MHz (VHF) and 900 MHz (UHF). The results and statistical analysis revealed that, for the two frequency bands considered, Okumura model is in good agreement with measured path loss having root mean square errors (RMSE) 3.98 and 5.86 for VHF and UHF band respectively while free space and Egli overestimated the measured path loss. The RMSE values obtained are within the acceptable minimum standard limit, 6 dB for good radio signal propagation. It was also noted that, the channel power decreases with increase in distance. The mean channel power and the pathloss exponent obtained for 150 MHz are -72 dBm and 2.189 respectively while for 900 MHz it was -85 dBm and 2.650 respectively. These values will assist the communication engineers for proper planning in this environment.**

Key words: **Channel power, Path loss, radio signal, VHF, UHF.**

I. INTRODUCTION

Understanding the effects of varying conditions on radio propagation has many practical applications; from choosing frequencies for international shortwave broadcasters, to designing reliable mobile telephone systems, to radio navigation, to operation of radar systems [1] [2]. Precise estimation of radio propagation path loss is a major factor for the good design of mobile and radio systems. In terrestrial cellular radio systems, radio signals generally propagate by means of any or a combination of these three basic propagation mechanism: reflection, scattering and diffraction. Path loss is the difference (in dB) between the effective transmitted power and the received power and may or may not include the effects of the antenna gains but it is influenced by terrain contours, environments (urban, sub-urban and rural), vegetation and foliage. This loss is best characterized by a parameter known as pathloss exponent. Communication engineers are generally concern with the applications of mobile radio link parameter which consists of the pathloss exponent that indicates the rate at which a signal depreciates with increase in distance. A unique mean path loss exponent (n) is always assigned to each propagation environment which is established by means of the field work.

The distance between the base station (BS) and mobile station (MS) also affect the path loss. In radio system planning, it is absolutely necessary to estimate the propagation characteristics by measuring the signal strengths of a given environment. For measurement, characterization and analysis of modern telecommunication systems, the ability of spectrum analyzer to measure the received signal strengths and power over precise section of the spectrum in invaluable. Also, the quality of transmission, non-linearity and phase noise of a communication channel can be effectively measured using spectrum analyzer. By using different experimental results and by statistical data processing, many scholars have developed various models which permit the calculation of expected field strengths and path loss from a given transmitter at chosen receiver locations and made it clear that the propagation loss shows logarithmic behavior to the distance. Of all the studies, Okumura's report [4] is very practical, because it carefully arranges field strength and service area. Not onlyis the report used as comparison data with other authors' reports [4] [5], but also the propagation prediction methods in the report have become standard for planning in today's land mobile systems in Japan. Hence, the study presented here was embarked in order to measure and develop a coverage prediction tool of path loss and channel power for short to medium ranges (up to 5 km) in the very high frequency and ultrahigh frequency bands.

II. CLASSICAL EMPIRICAL PROPAGATION MODELS

Empirical propagation models are models that provides a first order estimate for a wide range of locations. A handful of empirical models are widely accepted for cellular communications, these models usually simply consists of computing a path loss exponent *n* from a set of field data, and deriving a model for path loss in decibel.

2.1 Free Space Pathloss

As the electromagnetic waves travel through open space they are attenuated. This attenuation is described as Free-space Loss. This loss is often expressed as a function of frequency

(f) and distance (d), and a scaling constant. Hence, longer distance and higher frequency means greater attenuation. Free-space loss can be calculated thus [6]

$$P_{FSL} = 32.45 + 20\log\left({}^{f}/_{f_o}\right) + 20\log\left({}^{d}/_{d_o}\right) \qquad (1)$$

where the frequency, f_o = 1 MHz and distance, d_o = 1 km, *f* is the frequency of the emitted signal (MHz) and *d* is the distance between the transmitter and receiver

2.2 Egli Model

The Egli's model is a terrain model for radio frequency propagation. Egli model predicts the total path loss for point-to-point link and the model is suitable for cellular communications scenarios where the transmission has to go over an irregular terrain. The Egli's model is given as [7]

$$PL(dB) = G_b G_m \left(\frac{h_b h_m}{d^2}\right)^2 \left(\frac{40}{f}\right)^2 \qquad (2)$$

where G_b is the gain of the base station antenna, G_m is the gain of the mobile station antenna, h_b is he height of the base station antenna in meters h_m is the height of the mobile station antenna in meters, *d* is the distance between the base station and mobile station antennas in meters and *f* is the transmission frequency in MHz.

2.3 Okumura Model

Okumura is one of the most frequently used macroscopic propagation model. It is used for finding out path loss in the frequency range of 150 MHz to 1920 MHz for distances of 1 to 100 km and base station antenna heights ranging from 30 m to 100 m. this model is wholly based on measured data. Okumura's model assumes that the path loss between the transmitter (TX) and the receiver (RX) in the terrestrial propagation environment can be expressed as [8] [9]

$$L_{50}(dB) = L_{FS} + A_{mu} - G_{hb} - G_{hm} - G_{Area} \qquad (3)$$

where L_{50} (dB) is the median value (i.e. 50th percentile) of path loss, L_{FS} is the free space loss, and can be calculated using equation (1), A_{mu} is the median attenuation relative to free space, G_{hb} is the base station antenna height gain factor, G_{hm} is the mobile antenna height gain factor, and G_{Area} is the gain or correction factor due to the type of environment. G_{hm} and G_{hb} are calculated using these simple formulae:

$$G_{hb} = 20log\left({}^{h_b}/_{200}\right) \quad 1000\,m > h_b > 30\,m \qquad (4)$$

$$G_{hb} = 10log\left({}^{h_b}/_{200}\right) h_b < 30\,m \qquad (5)$$

$$G_{hm} = 10log\left({}^{h_m}/_{3}\right) h_m < 3\,m \qquad (6)$$

$$G_{hm} = 20log\left({}^{h_m}/_{3}\right) \quad 10\,m > h_m > 3\,m \qquad (7)$$

2.4 Channel power

The channel power of radio signal measured in a spectrum analyzer is the process of integrating Fast Fourier transform (FFT) bins over the specified channel bandwidth. The FFT size define the number of bins used for dividing the window into equal strips or bin. Hence, a bin in a spectrum sample and define the frequency resolution of the windows. The power within a channel bandwidth could be determine based on the spectrum measured as [10]

$$P_{ch} = 10log_{10}\left[\left(\frac{B_s}{RBW}\right)\left(\frac{1}{N}\right)\sum_{i=1}^{N} 10^{\left(\frac{p_t}{10}\right)}\right] \qquad (8)$$

whereP_{ch} is the power in the channel (dBm), Bs is the specified bandwidth or channel bandwidth (Hz), RBW is the resolution bandwidth (Hz), N is the number of data points in the summation.

2.5 Pathloss exponent (n)

Path loss exponent is a parameter used to characterize how fast the signal attenuates with respect to the communication distance [11]. The average large-scale for an arbitrary transmitter and receiver separation is expressed as a function of distance by using a pathloss exponent is given as

$$P_L(d)\alpha\left(\frac{d}{d_o}\right)^n \qquad (9)$$

$$\hat{P}_L(d) = \hat{P}_L(d_o) + 10n\log\left(\frac{d}{d_o}\right) \qquad (10)$$

where*n* is the pathloss exponent which indicates the rate at which the pathloss increases with distance, d_o is the closed-in reference distance, *d* is the distance between TX and RX. The bars in equation (10) denote the average of all possible path loss values for a given value of *d.* when plotted on a log-log scale. Aremu*et.al.,* (2017) obtained the path loss exponent, *n* for Ogbomoso at microwave frequency band (2.5 GHz and 3 GHz), the average value of *n* obtained were 2.925 and 3.150 respectively. The observed values are in good agreement with international standard range for urban cellular radio[12]. It was also affirmed that, the value of *n* depends on the specific propagation environment. Table 1 shows the lists of typical and standard values pathloss exponents obtained in various mobile radio environments [13]

Table 1: Pathloss exponents for different environments

Environment	*n*
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In-building LOS	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

III. MEASUREMENT CAMPAIGN AND METHODOLOGY

The outdoor measurement campaign was conducted at YOACOen-route Takie/Caretaker axis in Ogbomoso, South western, Nigeria. The radio signal strengths measurement were carried out at two frequency bands using the transmitter RRC300 with known characteristics of antennas and standing wave ratio. This transmitter is capable of transmitting VHF and UHF radio signals. A radio frequency hand held spectrum analyzer which was connected to PC was used as the receiver synchronously captured the transmitted signal and channel power. The receiver provides accuracy to within 0.99 dB and sensitivity to better than -120 dBm with the frequency ranges between 15 to 2700 MHz. A digital distance wheel meter and GPS receiver were used to measure the separation distance between the transmitter and receiver. Figures 1 and 2 shows the snapshot of RF explorer channel power meter during the course of measurement.

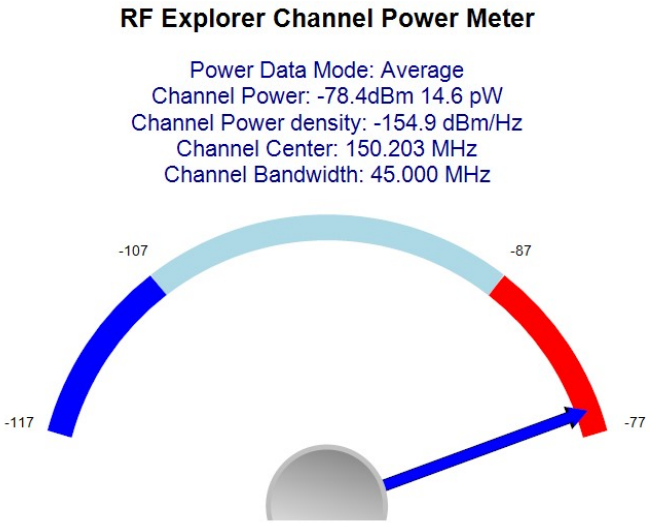
Simulation of path loss with distance for the three models namely; free space, Egli and Okumura models were obtained using equations (1) (2) (3) while MATLAB R2018b software was used for data analysis. In this study, three statistical analyzed tools namely; the prediction error, root mean square error, RMSE (μ), and spread-correlation root mean square error (SC-RMSE) were employed. Statistics were applied to test the performance of fit for the proposed model with respect to measured data. The prediction error ε, [14] which is the difference between the measured path loss (Pm) and model's predicted path loss Pp is shown in (9). The root mean square error is computed as shown in (10). The spread correlated error SC-RMSE is used to extract the impact of dispersion from the overall error which has the effect of reducing the error associated with a noisy link with standard deviation, σ is compute as [10];

$$\varepsilon = P_m - P_p \tag{9}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_m - P_p\right)^2} \tag{10}$$

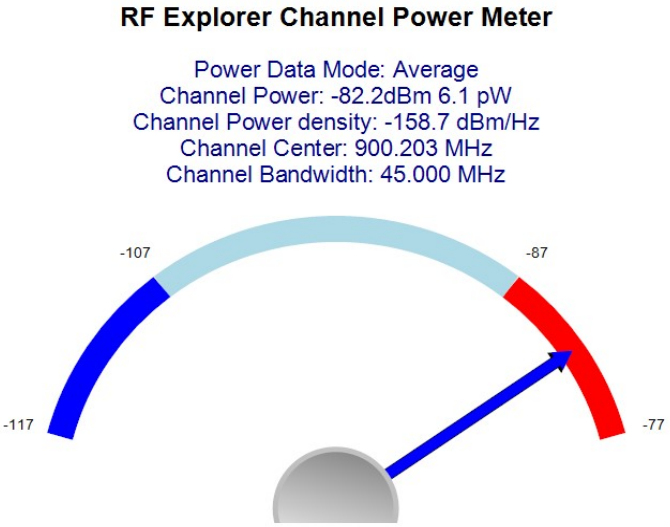
$$SC - RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(P_m - P_p\right)^2 - \sigma} \tag{11}$$

In this work, n was determined using equation (10) by linearization of the measured path loss using the standard equation of a straight line. This was carried out by plotting the received powers (in dBm) against the logarithm of distance. A straight line was drawn along the received powers and the slope of the line was determined.


RF Explorer Channel Power Meter

Power Data Mode: Average
Channel Power: -78.4dBm 14.6 pW
Channel Power density: -154.9 dBm/Hz
Channel Center: 150.203 MHz
Channel Bandwidth: 45.000 MHz

Figure 1: Snapshot of the RF explorer channel power meter at 150 MHz


RF Explorer Channel Power Meter

Power Data Mode: Average
Channel Power: -82.2dBm 6.1 pW
Channel Power density: -158.7 dBm/Hz
Channel Center: 900.203 MHz
Channel Bandwidth: 45.000 MHz

Figure 2: Snapshot of the RF explorer channel power meter at 900 MHz

IV. RESULTS AND DISCUSSION

Figure 3 and 4 depicts the comparison of measured and the empirical path loss models as a function of distance for Yoaco via Takie square itinerary up to 5 km at VHF and UHF bands. Generally, it was noted that, the radio path loss increases with increasing in separation distance between the transmitter and the receiver. The frequency 150 MHz suffered low path loss with an average value 89.6 dBm while the 900 MHz suffered more path loss with mean value 112.4 dBm as shown in Figure 5. The results and statistical analysis revealed that, for the two frequency bands considered, Okumura model is in good agreement with measured path loss having root mean square errors (RMSE) 3.98 and 5.86 for VHF and UHF band respectively while free space and Egli overestimated the path loss. The values obtained were within the acceptable standard limit, 6 dB for good radio signal propagation. From the measured data, the pathloss exponent (n) obtained for VHF was 2.189 while that of UHF was 2.650.

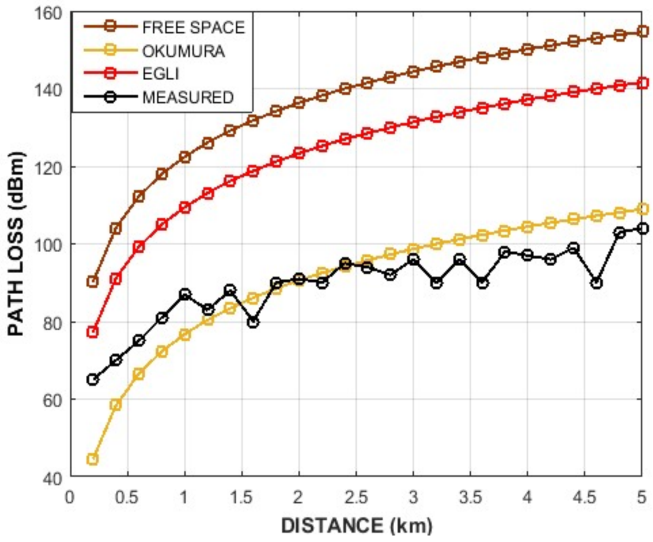


Figure 3: Comparison of measured and predicted path loss models at 150 MHz

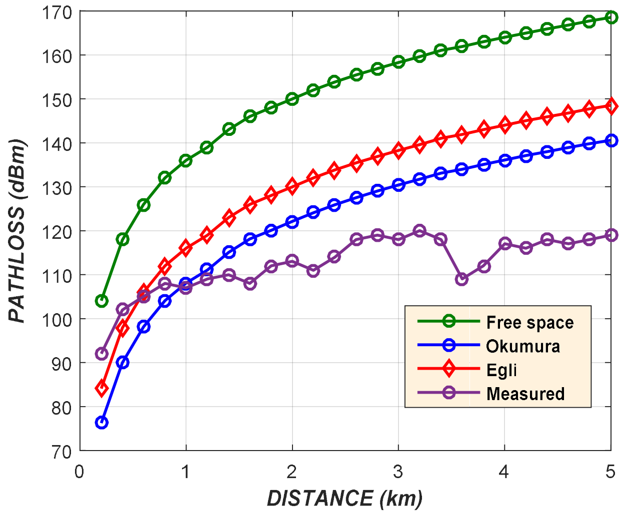


Figure 4: Comparison of measured and predicted path loss models at 900 MHz

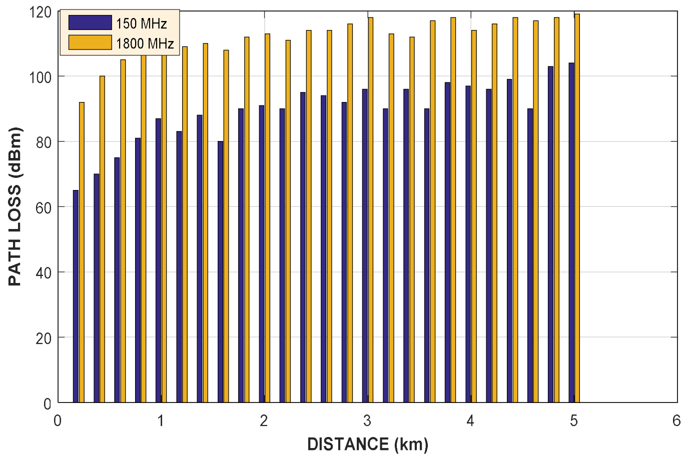


Figure 5: Comparison between measured propagation pathloss at 150 and 900 MHz

Figures 6 and 7 shows the prediction error against the distance. It was noted that path loss predicts a closer fit to the measured results as expected. Compared with the measured data, Okumura model shows large prediction errors for each spot of measurement. It was also found that the FSPL and Egli models both shows similar prediction error results but FSPL shows lowest prediction error. This implies that, Okumura model is in good agreement with measured data for each point of measurement.

Figures 8 and 9 shows the SC-RMSE against the distance for the three models considered at 150 MHz and 900 MHz frequencies. It was observed that, Okumura model gives the best result along the itinerary, this indicates that, for a good path loss prediction, Okumura model would perform better for the VHF and UHF frequencies band in this environment. Interestingly, the SC-RMSE for the three models follows the path loss pattern of the terrain profile obtained during the measurement.

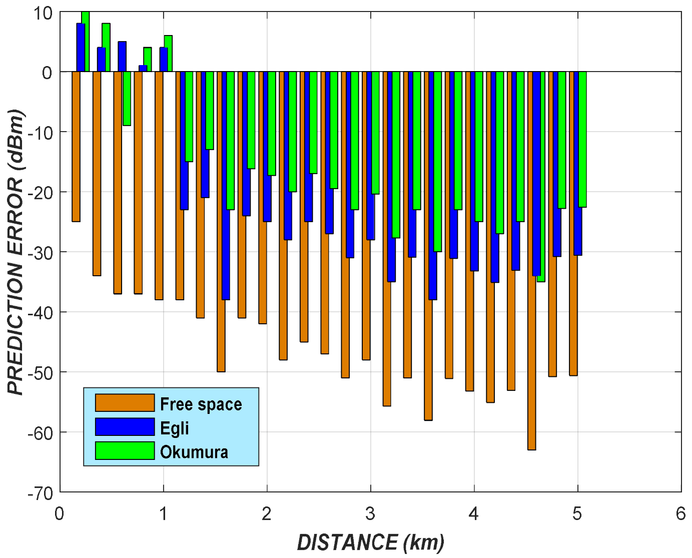


Figure 6: Pathloss prediction errors for different models at 150 MHz

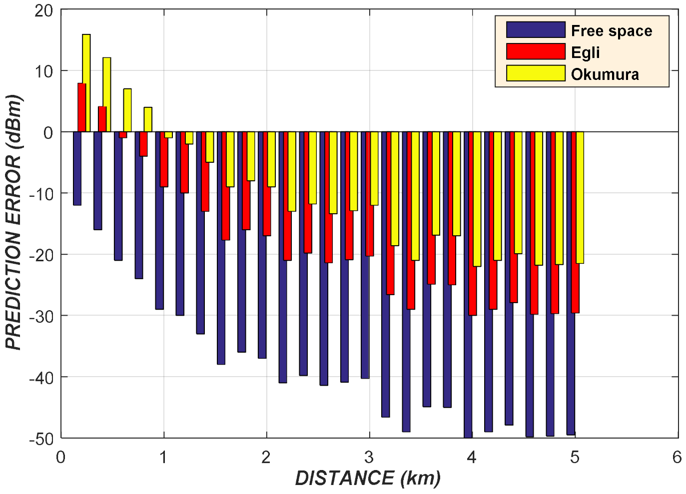


Figure 7: Pathloss prediction errors for different models at 900 MHz

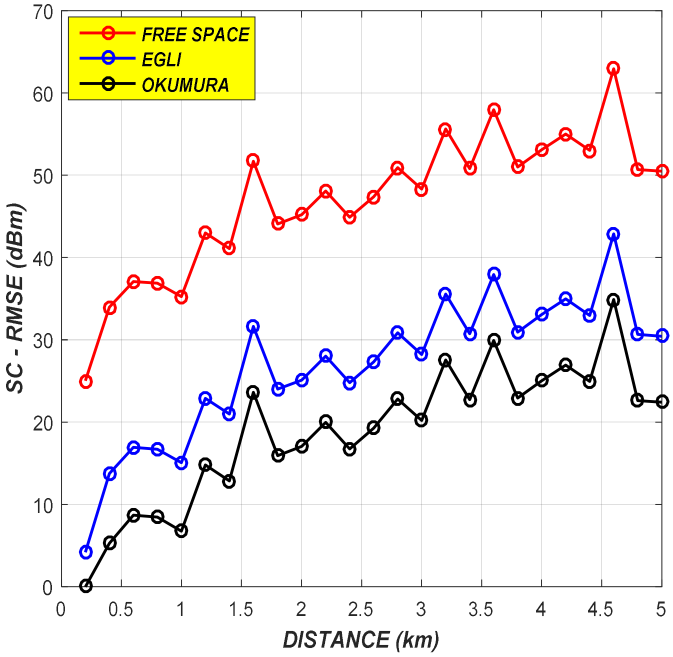


Figure 8: Spread correlated errors for the empirical models at 150 MHz

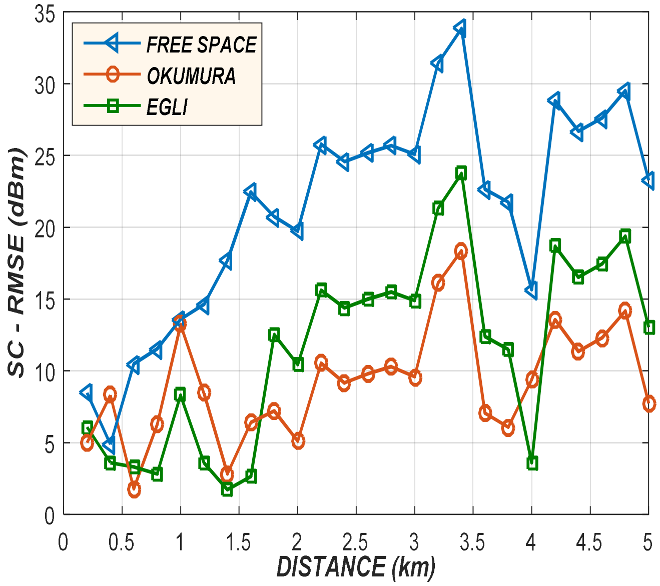


Figure 9: Spread correlated errors for the empirical models at 900 MHz

Figures.10 and 11 shows the channel power levels of the received signal along the path considered the values were obtained at every 0.2 km up to 5.0 km. It was noted that the channel power decreases with increasing in separation distance between transmitter and receiver, the mean channel power for 150 MHz (VHF) was found to be -72 dBm while that of 900 MHz (UHF) was -85 dBm. The study also revealed that, line of sight (LOS) and non-line-of-sight (NLOS) links appear throughout the distance covered and the received power level remained at the spectrum analyzer's threshold from 4.4 km up to 5.0 km

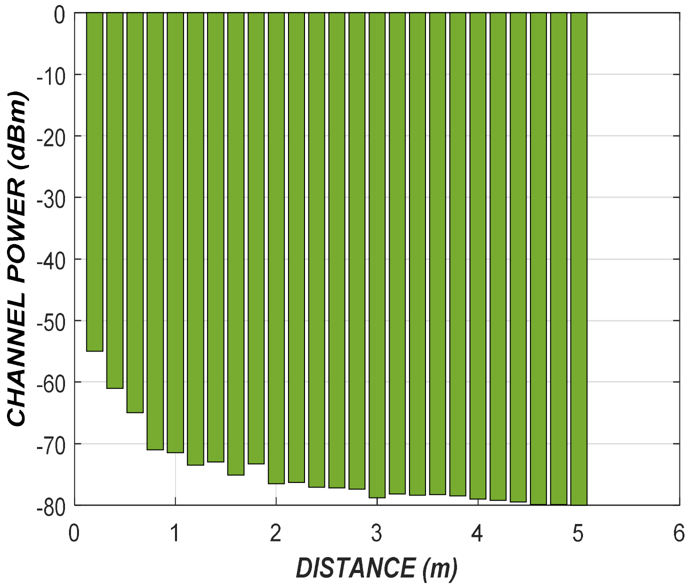


Figure 10: Graphical representation of channel power for each spot of measurement at 150 MHz

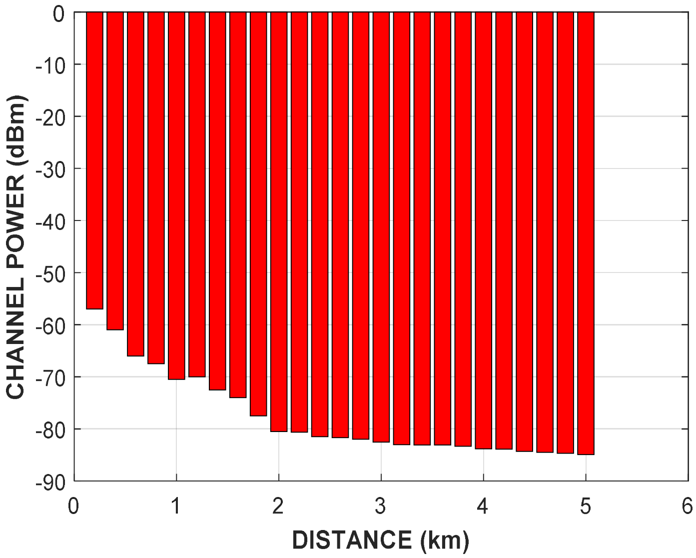


Figure 11: Graphical representation of channel power for each spot of measurement at 900 MHz

V. CONCLUSION

The outdoor measurement of propagation path loss and channel power of a radio signal for urban environment VHF (150 MHz) and UHF (900 MHz) propagation has been investigated. The measured path loss was compared with three empirical propagation path loss models namely; free space, Egli and Okumura. At the end of the comparative analysis using different path loss predictive models, the results and statistical analysis revealed that, for the two frequency bands considered, Okumura model was in good agreement with measured path loss having root mean square errors (RMSE) 3.98 and 5.86 for VHF and UHF band respectively while free space and Egli models over-estimated the measured path loss.

The results showed that Okumura's model is the most accurate and reliable path loss prediction model for the two frequency bands considered in this environment, since their RMSE values obtained are smaller than the acceptable minimum RMSE value of 6 dB for good signal propagation. It was also noted that, the channel power decreases with increase in distance. The mean channel power and the pathloss exponent obtained for 150 MHz are -72 dBm and 2.189 respectively while for 900 MHz it was -85 dBm and 2.650 respectively. These values will assist the communication engineers for proper planning in this environment. Hence, the recommended path loss prediction model at VHF and UHF bands for this environment is Okumura model.

REFERENCES

[1]. Westman H. P (1968), *Reference Data for Radio Engineers, Fifth Edition*, 1968, Howard W. Sams and Co., ISBN 0-672-20678-1, Library of Congress Card No. 43-14665 page 26-1

[2]. Demetrius T Paris and F. Kenneth Hurd (1969): *Basic Electromagnetic Theory*, McGraw Hill, New York 1969 ISBN 0-07-048470-8, Chapter 8

[3]. Rapparot, T.S.,.(2002) "Wireless Communications", Second Edition, Pearson Publication, India, pp 30 - 25

[4]. Kumari, M., Yadav, T., Yadav, P. (2011) "Comparative study of pathloss models in different environments," *International Journal of Engineering Science andTechnology (IJEST)*, vol. 3, No. 4, pp. 2945-2949.

[5]. Shalangwa, D. A., Singh, S.K (2010) "Measurement and modeling of path loss for GSM900 in sub urbanEnvironment over Irregular terrain," *International Journal of Computer Science and Network Security (IJCSNS)*, vol.10, No.8, pp. 268-274.

[6]. Sharma, S. (2007). Wireless and Cellular Communications, Second Edition, S. K. Kataria& Sons, New Delhi, Pp.20-96.

[7]. Mardeni, R. and Prey, L. Y. (2010). The Opti-mization of Okumuras Model for Code Division Multiple Access (CDMA) System in Malaysia, European Journal of Scientific Research, Vol. 45, Number 4, , pp. 508-528.

[8]. Rappaport, T.S (2002). Wireless Communications. Second edition, Pearson Publication, India. Pp. 57-176

[9]. Iskander, M. F. and Yun, Z. (2002) Propagation Prediction Models for Wireless Communication Systems, IEEE Transaction on Microwave Theory and Techniques, Vol. 50, Number 3, 2002, pp. 662-673.

[10]. Uwe, R.V., Glucio, L.S., Leni, J.M., Pedro, V.G.C., Leonardo, H.G. (2017). "Experimetnal Evaluation of the Mobile Radio Channel Capacity in the 2.48 GHz Band". Journal of Microwaves, Optoelectonics and Electromagnetic Applications. Vol. 16, no.2. pp 245-250.

[11]. Ghassemzadeh, S.S., Jana, R., Rice, C.W., Turin , W., Tarokh, V. (2002) "A statistical Pathloss model for in-home UWB channels". Ultra-Wideband Systems and Technologies, 2002. Digest of Papers, 2002 IEEE Conference. vol. 8. Pp 59-64.

[12]. Aremu, O.A., Adelek,J.T., Odepidan, K.O., Kolawole, T. (2017). "Estimation and Modelling of Radio Signal Attenuation using Pathloss Exponent at Microwave Band" Internatinal Journal of Trend in Research and Development . vol. 4 (3). Pp. 337-340.

[13]. Rappaport, T.S (1996). "Wireless Communications: Principles and Practice". Prentice Hall PTR, Upper Saddle River, New Jersey.

[14]. Nasir F. Adeseko A.A and Yunusa A.A. (2013). On the study of empirical path loss models for accurate prediction of TV signal for secondary users. Progress in Electromagnetics Research B. 49, 155-17