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Analysis of Propagation Models for Base Station Antenna: A Case Study of Ado-Ekiti, Nigeria

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Abstract: *Path loss analysis using key parameters and mathematical models is essential for accurate characterization of a radio channel for a coverage area. It plays a fundamental role in predicting the radio coverage, path-loss, death zone and designing of an optimized fixed and mobile network systems. This paper analysed and compared two models, Okumura and Okumura Hata on the basis of variation in antenna height and operational frequency of a base transmitting station (BTS) in Ado-Ekiti, Nigeria. The result obtained shows that Okumura Hata model has a better signal strength delivery to destination with a less reduced path loss variation compared to Okumura model. Even though there is significant gain of about 12dB when Okumura model parameters was varied it is not better than the signal strength Okumura Hata model will deliver to a destination.*

Keywords: *antenna height, Okumura, Okumura Hata, path loss, signal strength.*

1. INTRODUCTION

Wireless communication is very important if not the most important means of communication in this 21st century because of usages in the day-to-day activities of human being ranging from telecommunication, terrestrial television, transportation (maritime and air), military and security [1]. Famoriji and Olasoji [2] stated that wireless communication could either be a point to point link or point to multi-point network through transmission of an electromagnetic wave which is received at the receiver station. These radio-waves which contain electro-magnetic field are to transfer information from one point (transmitter) to another (receiver).

The propagation of this radio waves signal as it moves from one point to another predict the path loss along the channel link between it and, also, the effective coverage area of the transmitter. Radio-waves can propagate in various modes depending on the path of the signal, the frequency of propagation, its electrical properties and the geographical topography of the earth. It should be noted that radio-wave signal strength reduces as the inverse of distance travelled from the transmitter and there can be additional attenuation from the medium if it has non-zero conductivity or by other loss mechanisms [3].

In reality as signal propagates, there exist a variety of propagation paths as the signal travels due to multipath effect and the received signal can be a complex convolution of the original signal transmitted. As a result of this the received signal can suffer from fading and delay spread. Furthermore, objects on propagation path, the distance between the transmitter and the receiver, and the height and location of antennas all affect propagation mechanism [4]. Therefore, it is imperative to keep reviewing the various propagation models available and to study the behaviours and properties of radio-waves in free space when they travel from one point to another.

As continued development of more mobile technologies such as 4G, LTE and WCDMA keep evolving , there are serious challenges that are occurring to propagation models in terms of planning, designing, implementing, testing and maintaining them in which there is need to understand the various propagation mechanisms and models available[5], test and use the best that fit in for the geographical area to be covered because some of these models have been around for a long time and practically are not deplorable to a large extent in this modern world. For example models such as Okumura and Okumura Hata was designed close to 60years ago, in reality the world have changed with more tall houses been build, more trees, atmospheric properties have change and so on. All these are factors which affect the models especially the propagation mechanism need to be study, analyse and prove if these propagation models are still reliable and applicable and if not come up with ideas on how to solve the arising issues of these models by coming up with new models which considered the models shortcomings [6,7,8].

The performance of the Okumura-Hata model in the 900 MHz band by [9], showed that the results of several measurement obtained in different regions of Egypt show significant errors in the Okumura-Hata model. Hence, that there is need for improvement by introducing correction factor to the Okumura-Hata model that suits the Egyptian 900 MHz cellular environment and this correction factor is based on signal strength received in different terrain, topography and population which brought about improvement in the received signal strength over the area of Egypt when implemented.

The report showed by [10], that the propagation models performed differently when their parameters are varied most especially the antenna height of the base station, in which there is less path-loss if the base station antenna height is very high most especially for urban environment and, also, that there is a little or no different when the operational frequency was varied across. All these point to the fact that deploring of propagation model to an area should be subjected to study, analyse and test to know the best fit

1.1 Okumura Model

Okumura model was formulated in the mid-1960s based on data collected from the city of Tokyo, Japan, [8] which took into account Tokyo city structure which has tall buildings and other characteristics of an urban environment. The model is used to calculate the path-loss of frequencies in the range of 150MHz – 1920MHz and distance of 1km-100km and base station height of 30m- 1000m. This model is based wholly on measured data and often used for network planning purposes to estimate the reliability of a network system or the level of interference that will occur to the radio waves. The model statistically analysis a large number of experimental measurements conducted by varying the various communication parameters such as the frequency, distance, height of both the transmitter and receiver antennas and the gains as well and so on. Okumura model is expected to predict path loss of a signal and does not take into consideration accuracy of geographical input of the area to be covered and are assumed robust since they are developed from large measure of data and not is suitable for studying radio wave behaviour over a short distance [11].

To determine path-loss using Okumura model, the free space path loss between the selected points of area to be covered is first determined and then attenuation value is added to it along with correction factors to account for the type of terrain of the area to be covered. The model is expressed as shown in (1)

$$\mathrm{L\ (dB)} = \mathrm{LF} + \mathrm{Amu\ (f,d)} - \mathrm{G(hte)} - \mathrm{G(hre)} - \mathrm{GArea} \quad (1)$$

Where,

L is the path loss in dB

L_F is the free space path-loss in dB

A_{mu} (f, d) is the median attenuation which is a function of frequency and distance.

G (h_{te}) is the base station antenna height gain factor

G (h_{re}) is the receiver/mobile antenna height gain factor

G_{Area} is the gain due to the type of environment

Furthermore, Okumura varies the various gains of the parameters as follows

$$G(hte) = 20\ log\left(\frac{hte}{200}\right) \qquad 1000\mathrm{m} > h\,\mathrm{te} > 30m \quad (2)$$

$$\mathrm{G(hre)} = 10\log\left(\frac{\mathrm{hre}}{3}\right) \quad \mathrm{hre} \leq 3\mathrm{m} \quad (3)$$

$$G(hre) = 20\log\left(\frac{\mathrm{hre}}{3}\right) 10\mathrm{m} > hre > 3m \quad (4)$$

The major problem with Okumura model is its slow response to changes in environment and terrain structure so it can be said not to be good for use in rural areas as these can still expand to become urban areas.

1.2 Okumura Hata Model

Okumura Hata is best known as an empirical model, which is developed from Okumura model and is valid from the range of 150MHz- 1500MHz and for link distance coverage of 1km-20km. Hata presented the urban area propagation loss as a standard formula and provide equation for other areas possible such as semi urban and rural areas. Hata model like that of Okumura predict path-loss of signal propagation and can be found in every possible Radio frequency propagation method used today. However, Hata model does not have path – specific correction, in the Okumura model, the effective antenna height of the transmitter is calculated as the height of the transmitter antenna above the average terrain. Using that approach measured data have shown several disadvantages to that approach for effective height of antenna calculation, but Hata model tends to average over extreme variations of the signal level due to sudden changes in terrain elevation [12]. The path loss equation for Okumura Hata model is expressed as shown in (5), (6) and (7)

$$Lurban(dB) = 69.55 + 26.16\log\ (f) - 13.82\log(\ h_{te}) - A(h_{re}) + (44.9 - 6.55\log h_{te})\log d \quad (5)$$

$$Lsub - urban(dB) = L(dB)urban - 2[\log(f/28)]^2 - 5.4 \quad (6)$$

$$Lrural(dB) = L(dB)urban - 4.78(\log f)^2 + 18.33\log f - 40.94 \quad (7)$$

Where,

F is the frequency in MHz from 150MHZ- 1500MHz

h_{te} is the effective height of transmitter base station(30m-200m)

h_{re} is the effective height of receiver base station(1m-10m)

d is the separation distance between transmitter and receiver(km)

A(h_{re}) is the correction factor for effective mobile antenna height which is a function of the size of the coverage area.

A (h_{re}) for a small or medium-sized city

$$A(h_{re})\ dB = (1.1\log(f) - 0.7)\ h_{re} - (1.56\log(f) - 0.8) \quad (8)$$

A (h_{re}) for large city

$$A(h_{re})\ dB = (8.29\ (\log 1.54\ h_{re})^2 - 1.1 \text{ for } f \leq 300\mathrm{MHz} \quad (9)$$

$$A(h_{re})\ dB = (3.2\ (\log 11.75\ h_{re})^2 - 4.97) \text{ for } f \geq 300\mathrm{MHz} \quad (10)$$

The major limitation Okumura Hata model has is that it does not provide coverage to the whole range of frequencies which Okumura model covered.

2. RESEARCH METHODOLOGY

Using the given Okumura propagation prediction and the Garea factor which are value due to the type of environment (rural, urban) the signal is propagating are obtainable on Okumura curve which is available in graphical form. The geographical environment of Ado Ekiti, Ekiti State, Nigeria which is located in latitude 7°37′16″N and longitude 5°13′17″E with its longest North-South extent is about 16km and the longest East-West stretch is about 20km [13] and can be said to be small or medium sized city based on the environment with little high rise buildings structures in the environment that can causes multipath of signals. Figure 1 shows the map of Ado Ekiti, Nigeria.

Figure 1: Map of Ado – Ekiti (source Google Earth)

Using the parameters acquired from the location (Ado Ekiti) together with the parameters provided by the Okumura model graphs [14] as shown in figure 2 and 3.

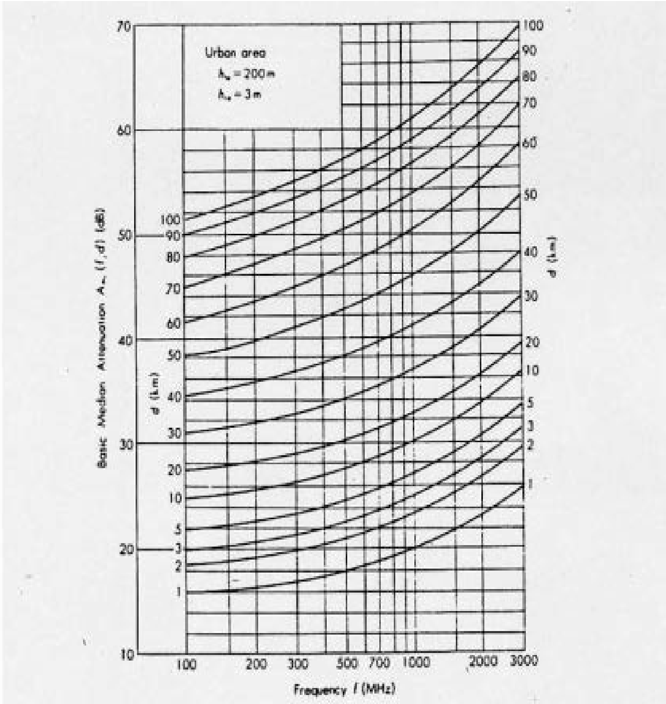

Figure 2: Median attenuation graph

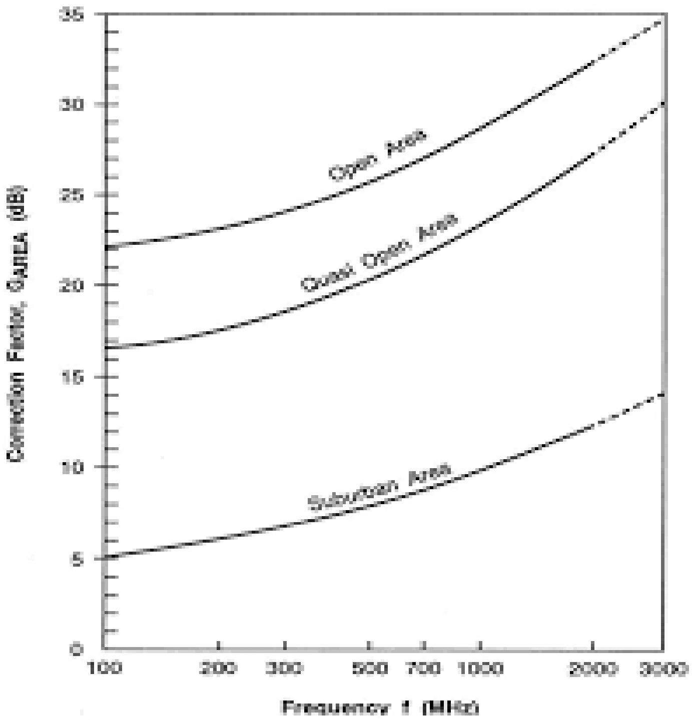

Figure 3: G_{area} factor for geographical area

Also, the average antenna height was chosen based on physical inspection of about twenty base stations all around the city and other parameters derived from the Okumura graph in figure 2 and figure 3.

Table 1: Simulation parameters

Parameters	Values
Operating Frequency for Mobile Networks	900MHz - 1800MHz
Maximum Distance in Ado Ekiti	20km
Average Transmitter Antenna Height for the City	30m-60m
Receiver Antenna Height	3 m
Median Attenuation	32.4dB
Correction Factor	8.8 dB in suburban

3. RESULTS AND DISCUSSION

When calculated and simulated using the Okumura model, the path-loss of this signal with properties in table 1, the graphical result is shown in figure 4

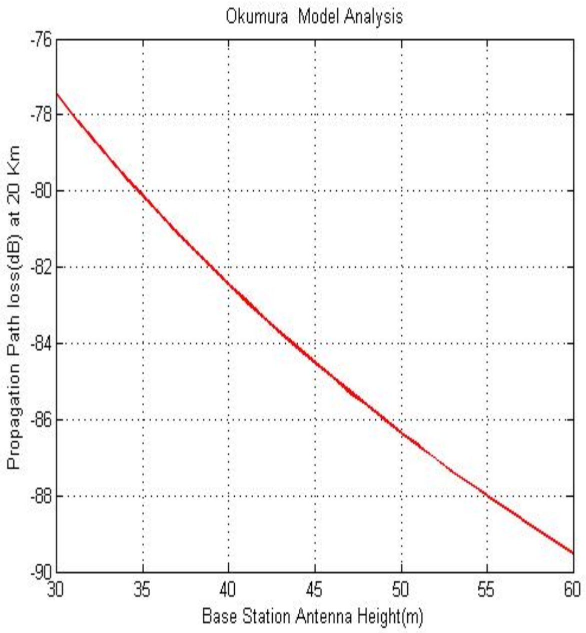

Figure 4: Path-loss for Okumura Model for Base Station Variation

There is significant change of about 12db in the path-loss as the transmitter antenna height increases from 30 metres to 60 metres which therefore causes a ten-fold increase in signal strength due to antenna height variation for the city.

The Operational frequency of the signal when range between the 900MHz -1800MHz, A plot of the path-loss against operational frequency range is shown in figure 5.

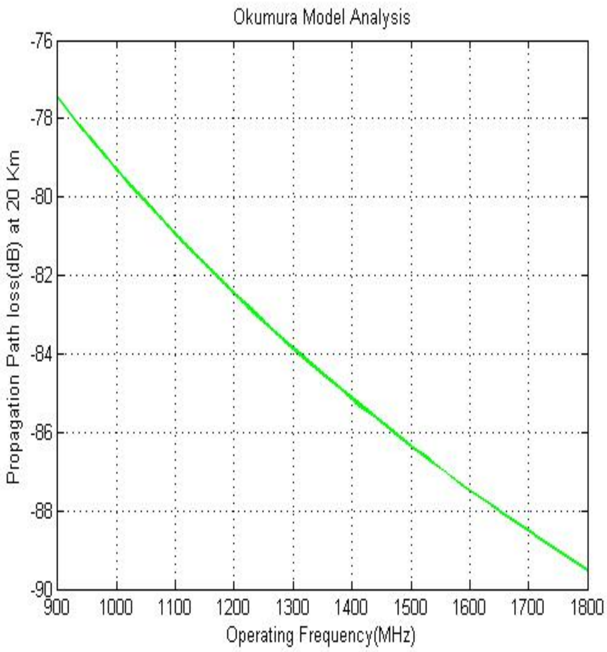

Figure 5: Path-loss for Okumura Model for Operational Frequency Variation

Using the same parameters in table 1 to simulate for Okumura Hata model, the path-loss of the signal is shown in figure 6.

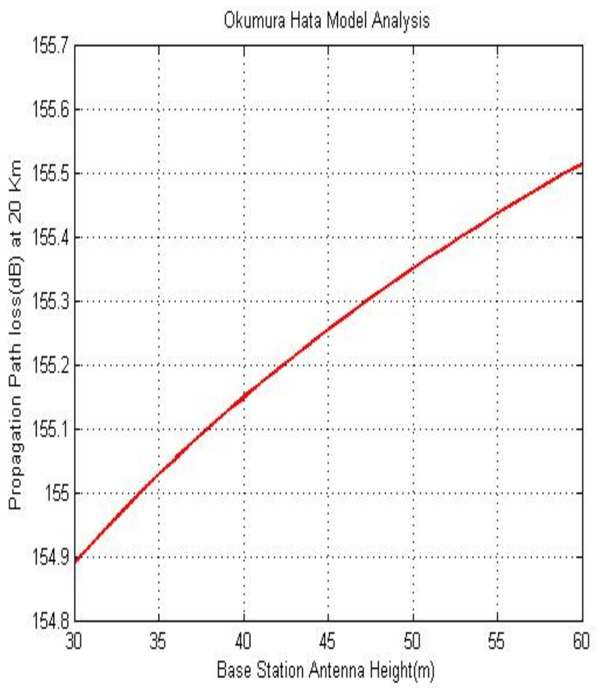

Figure 6: Path-loss for Okumura Hata Model for Base Station Variation

There is negligible path-loss changes of 0.6dB from (154.9dB- 155.5dB) as the base station antenna height is been varied within 30 metres – 60 metres average for the city. A plot of the path-loss against operational frequency range is shown in figure 7.

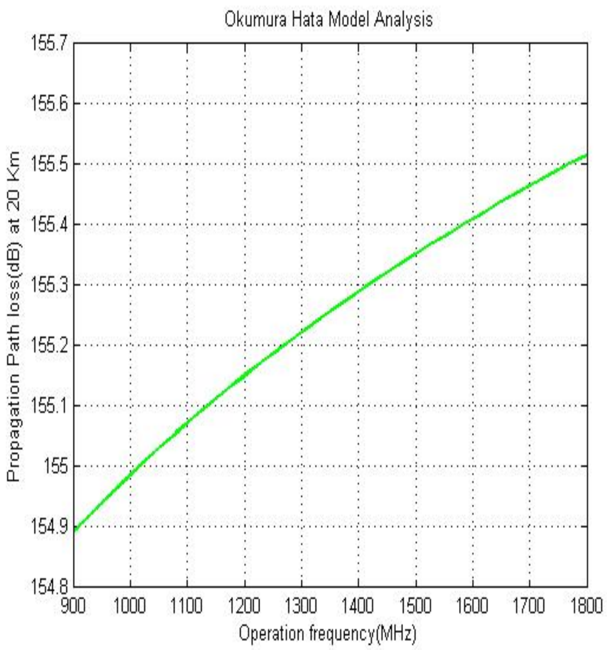

Figure 7: Path-loss for Okumura Hata Model for Operational Frequency Variation

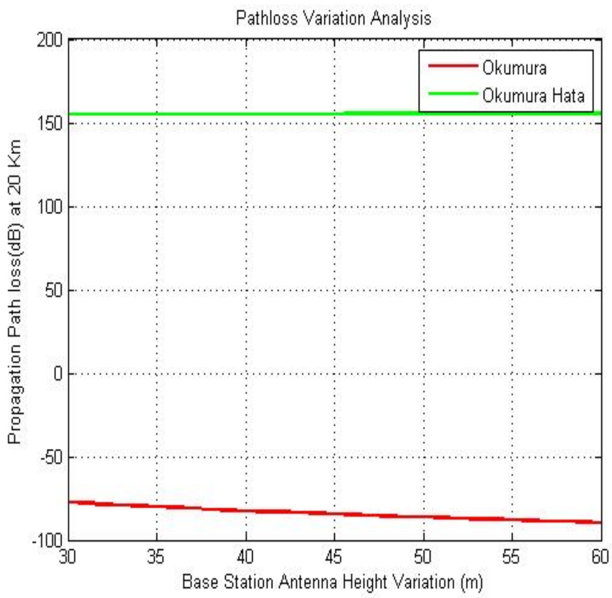

Figure 8: Comparison of both models on Base Station Variation

3.1 Comparison of Okumura Hata and Okumura Models on the Basis of Base Station Antenna Height

From figure 8, there is less path-loss of the signal for Okumura Hata model due to change in base station antenna height as compared to Okumura model which make the signal of Okumura Hata model to reach better distance and more effective coverage.

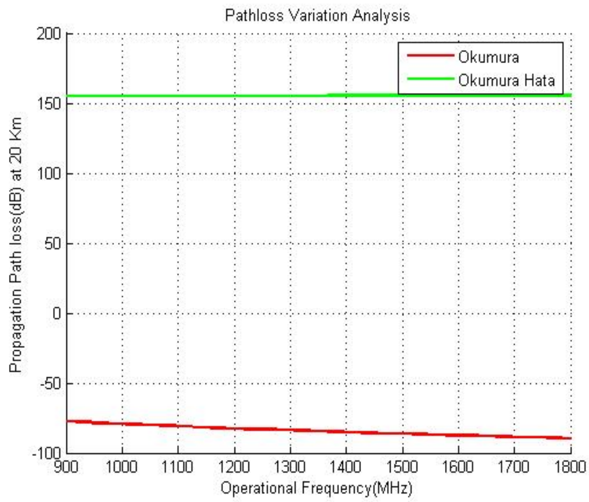

Figure 9: Comparison of both models on Operational Frequency Variation

3.2 Comparison of Okumura Hata and Okumura Models on the Basis of Operational Frequency

As shown in figure 9, there is again less loss of signal as it travels across the channel for Okumura Hata model compared to Okumura Model.

4. CONCLUSIONS

There is path-loss improvement for Okumura model compare to Okumura Hata model with respect to base station antenna height and operational frequency variation but the signal strength of Okumura Hata will still be the best for the city considering the path-loss that will have to be account for if the two models are used to transmit signals of the same power to the same location because there is little loss on transmitted signal power for Okumura Hata.

There is a very little change to the path-loss in varying the transmitter antenna height or the operational frequency for the Okumura Hata model, therefore it is advisable to keep the base station antenna not too high so as to reduce cost of rigging and also make it more accessible for maintenance or repair if the need arises.

Since there is a variation of about 12dB in signal strength for Okumura model when the discussed parameters where varied for the city, it is therefore not advisable to consider such for use in network planning because a more larger signal power will have to be transmit compared to Okumura Hata model to cover up for the loss of over 90percent that will occur on such signal before it get to the receiver hence the receiver antenna sensitivity will have to be large.

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