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Comparing Path-Loss and Empirical Models for Cellular Transmission Within And Outside Ilorin.

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Abstract
This work presents a comparative analysis of three empirical path-loss models with measured data for areas both within and around Ilorin in Kwara State (8.5^{0}N, 4.5^{0}E). The three models investigated are Hata-Okumura model, COST 231 Hata, and ECC-33 model. Downlink data was collected at an operating frequency of 900MHz using a 3-axis non-directional digital radio frequency(RF) meter to determine the electric field at various specified receiver distances. The test was carried out to investigate the effectiveness of the commonly used existing models for cellular transmission within the study area. Our results show that Hata-Okumura model gives a better fit while COST 231 Hata and the ECC-33 models over predict path-loss in the study area. Thus, the Hata-Okumura model gives better predictions and therefore recommended for path loss predictions in Kwara State.

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I. INTRODUCTION

The world has become a global village due to the ability to communicate and share information over a distance. The development of the electric telephone system (wired), which spanned many years has made communication easier and faster. Meanwhile, the introduction of the wireless telephone system, which is a major breakthrough, has added mobility and flexibility to communication. However, the wireless telephone system which comes in either fixed wireless telephone line or the Global System of Mobile Communication (GSM) has its own limitations which can be due to the equipment (antenna, cable, indoor- unit), facilities (location, mast, power supply) and the channel through which the information is sent. Some of these limitations are: multipath fading, attenuation, distortion, absorption and scattering of transmitted signals received over a long distance.

In effect,the G.S.M is particularly susceptible to different losses because it uses radio waves to transmit information through the local atmosphere – a generally highly dynamic region which exhibits spatio-temporal variations both in property and in composition. Similarly, to establish very long distance radio communication, transmission is through the ionosphere which is equally dynamic in nature (Agbo et.al.,2013; Bawa et.al.,2015; Oron et.al.,2013;Sethi et.al.,2012;Rashmi et. al., 2005).

The aforementioned losses which a radio signal experiences from transmitter to receiver are conventionally defined as Path-loss. The path-loss experienced by signals depends largely on the local characteristics of the environment (terrain, weather and population density) in which they propagate. Terrain refers to the physical features of the environment. These include hills and valleys, the presence of trees and vegetation, water bodies and man-made structures. All these features affect communication as they either reflect or absorb radio signals. Weather also has a significant effect on path-loss.Water droplets in the atmosphere absorb, refract and reflect signals with absorption and refraction being more dominant. This explains the poor network quality during the rainy season. On the other hand, dust and smoke particles in the atmosphere scatter incident waves. The population density of an area directly influences the number of man-made structures and their spatial distribution. These structures in turn provide surfaces for multiple reflection of radio waves. This leads to multipath fading.

Hence, there is the need for proper path-loss study for various environments. This should be done as part of the network planning while designing a communication network as inadequate knowledge of path-loss has led to poor communication network design.

This research work is aimed at studying path-loss in GSM signals in and around Ilorin, Kwara State, Nigeria. To achieve this, data obtained from direct measurement will be compared with various path-loss models.It is expected that this work will establish the suitability or otherwise of each model to Ilorin's terrain.

II. Path-loss Models

In planning a wireless telecommunication network, it is important to put every factor that can affect the propagation of signals into consideration (Edwards and Durkin, 1969). One of such factors is path-loss. Path-loss determines the various cell ranges and can be studied with the use of propagation models. Propagation models can be classified into 3. These are empirical models, semi-empirical models and deterministic models (Rakesh&Srivasta, 2012; Akinwole and Biebuma, 2013; Mollel&Kisangiri,2014; Singh, 2012).

Radio network planners can either develop their own models for different areas in a cellular network, or they can use the existing standard models which are generic in nature and are used for a whole area. The advantage of using a customized model is that it promises a greater level of accuracy, however, it is time consuming to construct (Nadir& Ahmad,2010; Akingbade&Olorunnibi, 2013). The standard models which are designed by calculating field data in different environments are easier and faster to use, but these models have limited accuracy. The models considered in this work are discussed below:

2.1.1 Hata-Okumura Propagation Model

The Hata model for urban area, also known as the Okumura-Hata model (Hata, 1981 and Neskovic et.al., 2000) is used for predicting path-loss in urban, suburban and open areas. This model takes the effect of diffraction, reflection and scattering caused by city structures into account. Hata's formulation is limited to certain ranges of input parameters and is applicable only over quasi-smooth terrain.

Hata's model for the urban area is given as:

$$L_u = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + A_a \quad (1)$$

$$a(h_m) = (1.1\log_{10}(f) - 0.7)h_m - (1.56\log_{10}(f) - 0.8) \quad (2)$$

For Suburb: $L_{su} = L_u - 2\{\log_{10}(\frac{f}{28})\}^2 - 5.4$ ....(3)

For Open Country: $L_{oc} - 4.7\{\log_{10}(f)\}^2 + 18.33\log_{10}(f) - 40.94$ ....(4)

L_u= urban path-loss

$L_{su} =$ suburban path − loss

L_{oc} = open country path-loss

F=frequency (150MHz or 1500MHz)

h_b= base station height (30m-200m)

h_m= mobile station height (1m-10m)

d= distance (1km-20km)

A_a= area correction factor

$a(h_m)$= mobile antenna height correction factor.

The mobile antenna height correction factor is computed for a small or medium sized city as:

$a(h_m) = (1.1\log(f) - 0.7)(h_m) - (1.56\log(f) - 0.8$..........................(5)

For a large city, it is given as

$a(h_m) = 8.29(\log(1.54h_m))^2 - 1.1$ (for $f \leq 200$MHz)...................................(6)

or

$a(h_m) = 3.2(\log(11.75))^2 - 4.97$ (for $f \geq 400$MHz)..(7)

The area correction factor for the suburban area is calculated as

$A_a = 5.4 + 2(\log(\frac{f}{28}))^2$....................................(8)

For open areas, it is calculated as:

$A_a = 4.78\log(f)^2 - 18.33\log f + 40.94$.............(9) (Hata,1980)

Hata implementation of the Okumura model is applied in almost every radio frequency propagation analysis tool (Deme et.al., 2013). However, care should be taken in its use because the propagation is largely specific to Japan's propagation environment. In addition, terms like "small city", "large city" and "suburban area" are not clearly defined and can be interpreted differently by people with different backgrounds. Therefore, in practice, the area adjustment factor should be obtained from the measurement data while optimizing propagation model. Also, in the original Okumura model, the effective antenna height of the transmitter is calculated as the height of the transmit antenna above the average terrain. Measurements have shown several disadvantages to that approach for effective antenna calculations. In particular, Hata's model tends to average over extreme variations of the signal level due to sudden changes in terrain elevation. To circumvent the problem, some prediction tools examine alternative methods for calculating the effective antenna height (Deme et.al.,2013 ; Akingbade& Olorunnibi,2013).

2.1.2 Cost-231 Propagation Model

This model uses the Height Above Average Terrain (HAAT) along each radial direction to determine the attenuation and has been put to the test at 940MHz to predict the channel path-loss over a distance of up to 5km from transmitter to receiver with a transmitter height of 60m and a receiver height of 3m.

The model is expressed in terms of the following parameters:

Carrier frequency (f) = 500-2000MHz
Antenna height (h_t) = 30-200m
Receiver height (h_r) = 1-10m
Transmission distance (d) = 1-20km
Path-loss is expressed as:

$PL = 48.5 + 35.9\log(f) - 14.84\log(h_t) - ah_r(45.8 + 6.58\log(h_t))\log d + C_r$......(27)
(Rakesh&Srivatsa,2013).

$ah_r = 3.25(\log(11.80h_r))2 - 4.81$ (antenna height correction factor)...............(10)

$C_r = 0$ for medium cities and suburban areas.
3 for metropolitan areas.

2.1.3 ECC-33 MODEL

The path loss model presented by the Electronic Communication Committee is referred to as the ECC-33 model (Bruno et.al. 2011).

The path loss is defined as:

$L = A_{fs} + A_{bm} - G_b - G_r$................................(11) (Mollel and Kisangiri,2014).

Where $A_{fs} = 92.4 + 20\log d + 20\log f$ (free space attenuation)..............(12)

$A_{bm} = 20.41 + 9.83\log d + 7.89\log f + 9.56\log(f)^2$ (basic median path loss)......(13).

$G_b = \log(\frac{h_b}{200})(13.958 + 5.8(\log d)^2)$ (base station height gain factor)................(14)

for medium city environments :

$G_r = 42.57 + 13.7\log f(\log(h_r) - 0.585)$ (receiver height gain factor)................(15)

for large city environments:

$G_r = 0.759h_r - 1.862$.............................(16)

The medium city model is more appropriate for European cities whereas the large city environment should only be used for cities having tall buildings (Bruno et.al. 2011; Mollel and Kisangiri, 2014).

III. Materials and Methods

This study was carried out within Ilorin which is the capital of Kwara state, Nigeria and along the Ilorin-Eiyenkorin-Ogbomoso road.

Twenty different base stations located both within the city center and around the outskirts of Ilorin metropolis were considered for the study. The locations were selected due to the spatial distribution of masts. Their various locations are shown in table 1. A general feature observed in the outskirts is the scarcity of houses and other man-made structures. This is so because the communities along the road are sparsely populated. Also, there are no tall structures as the buildings are usually less than 30m in height. These two features qualify the study areas to be classified as suburban areas. On the other hand, the presence of houses and other man-made structures within the metropolis qualifies it to be regarded as urban areas.

Primary method of data collection which involves direct measurement and observation was employed in the study. Readings were taken at the base of each selected base station, and subsequent readings were recorded further away from the mast at an interval of 200m.

Mast No.	Location
1	8° 23' N, 4° 27'E
2	8° 21' N, 4° 26'E
3	8° 19' N, 4° 24'E
4	8° 18' N, 4° 23'E
5	8° 17' N, 4° 21'E
6	8° 16' N, 4° 19'E
7	8° 15' N, 4° 18'E

8	8° 12' N, 4° 18'E
9	8° 11' N, 4° 16'E
10	8° 25' N, 4° 36'E
11	8° 24' N, 4° 37'E
12	8° 22' N, 4° 42'E
13	8° 14' N, 4° 48'E
14	8° 23' N, 4° 40'E
15	8° 19' N, 4° 44'E
16	8° 19' N, 4° 45'E
17	8° 16' N, 4° 47'E
18	8° 14' N, 4° 52'E
19	8° 13' N, 4° 53'E
20	8° 11' N, 4° 55'E

Table 1 showing the GPS coordinates of the masts studied.

A Tenmars TM-196 field strength meter was used for the measurements, and the measured quantity is the electric field. The meter is a broad band device for measurement in the high frequency range. It is a 3-axis non-directional (isotropic) digital processing meter and its range of measurement is from 10 MHz to 8 GHz.

The RF meter measures the value of electric field strength (E) and convert it into magnetic field (H) and the power density (S).The meter can measure field strength along different axes (X,Y and Z) separately, and can also measure in all the axes at the same time when set to the triaxial mode of operation.For this work, the electric field at the point of observation was measured in milli-volts per meter (mv/m) and converted to Received Signal Level (R.S.L) in decibel-meter (dbm). Hence, path-loss is calculated as:

$\mathrm{R.S.Latthebaseofmast\ (dbm) - R.S.Latdistance(d)\ frommast\ (dbm)}$.............(17)

Coordinates of the selected base stations and those of the measurement points were obtained with the aid of a global positioning system (GPS) software installed on a hand-held phone – TecnoCamon C8. Global positioning system (GPS) is a device that receives signals for the purpose of determining the correct location of any object on the earth surface. GPS devices provide information about latitude, longitude and elevation (altitude) of a location. Measurements were taken over a distance of up to 10km from the base of each mast. The base of the mast was taken as the initial point, and measurements were taken at an interval of 200meters from the last measurement point. Distance covered was determined using the Haversine formula. This calculates the great-circle distance between two points – that is, the shortest distance over the earth's surface as the crow flies between the base station and the various measurement points.

The Haversine formula is given as:

$a = \sin^2(\Delta\varphi/2) + \cos\varphi_1 \times \cos\varphi_2 \ \mathrm{x} \sin^2(\Delta\theta/2)$........................(18)

$c = 2 \times \mathrm{arctan2}(\sqrt{a}\sqrt{(1-a)})$..(19)

$d = R \times c$..(20)

Where:

φ = latitude (degrees)

θ = longitude (degrees)

R = earth's radius (mean radius = 6,371km).

IV. Result

Globacom Masts (Mast 1-Mast 5)

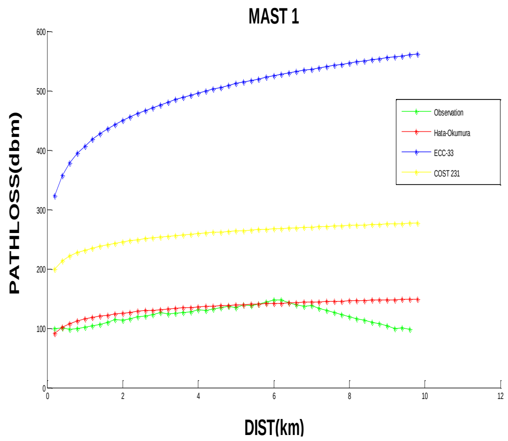


Fig.4.1 Comparison of models with observation for BTS 1.

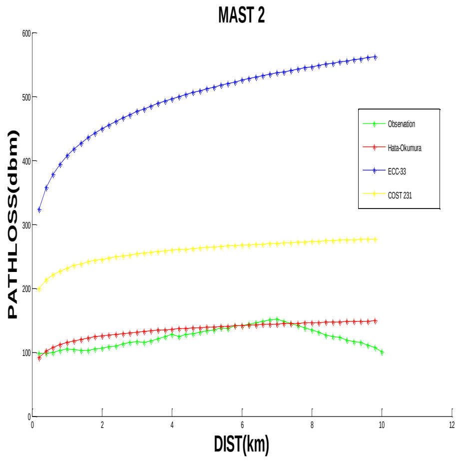


Fig.4.2 Comparison of models with observation for BTS 2.

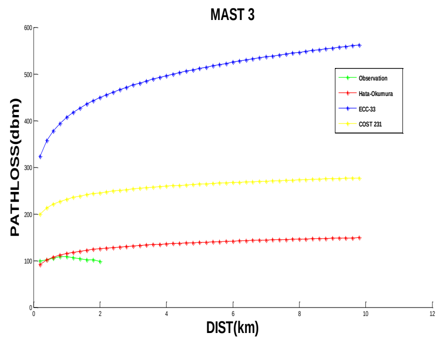


Fig.4.3 Comparison of models with observation for BTS 3.

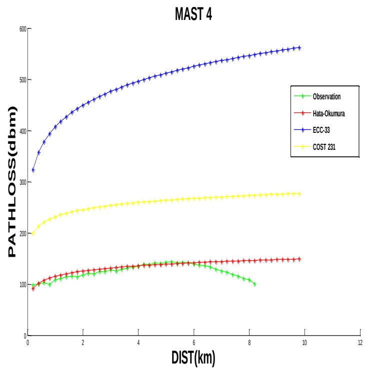


Fig.4.4Comparison of models with observation for BTS 4.

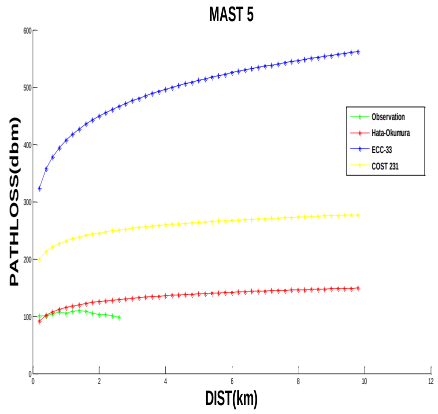


Fig.4.5 Comparison of models with observation forBTS 5.

MTN Masts(Mast 6-Mast 13)

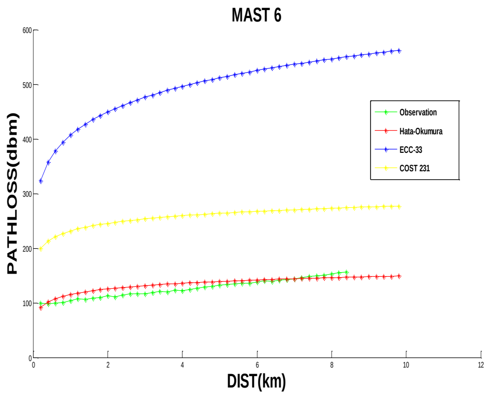


Fig.4.6 Comparison of models with observation for BTS 6.

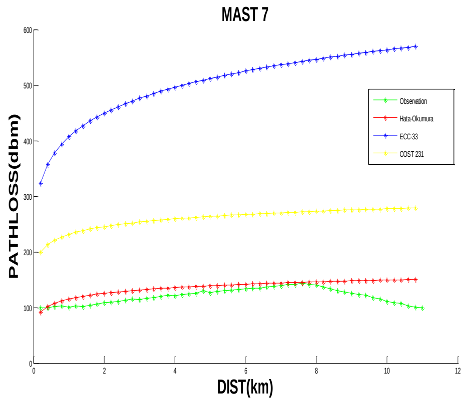


Fig.4.7Comparison of models with observation for BTS 7

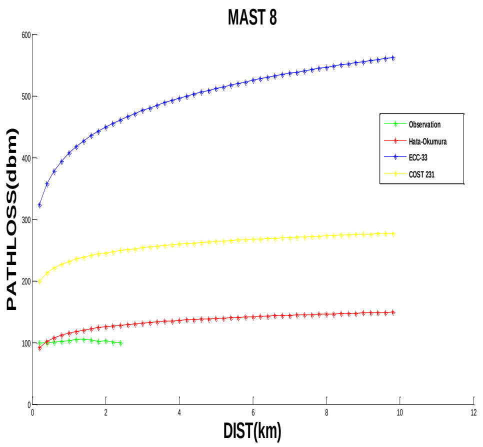


Fig.4.8Comparison of models with observation for BTS 8

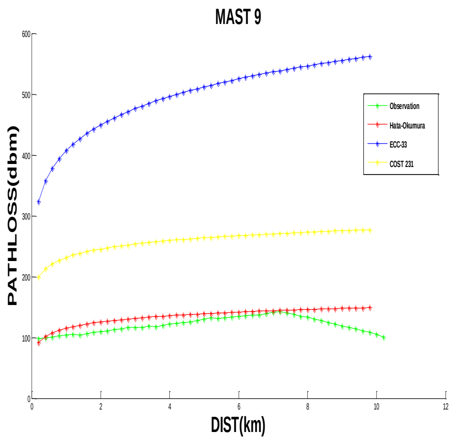


Fig.4.9 Comparison of models with observation for BTS 9.

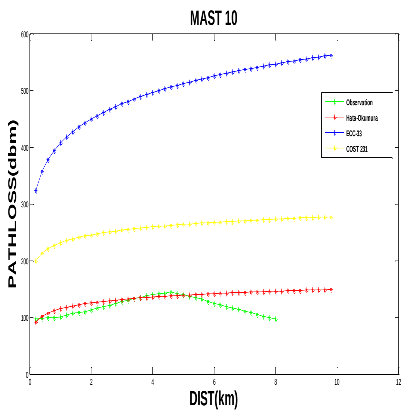


Fig.4.10 Comparison of models with observation for BTS 10.

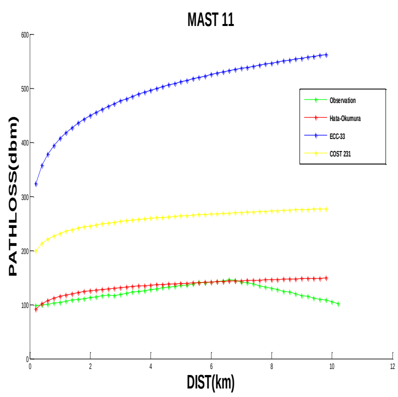


Fig.4.11 Comparison of models with observation for BTS 11.

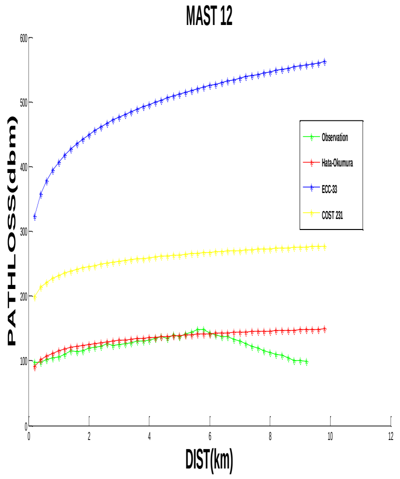


Fig.4.12Comparison of models with observation for BTS 12.

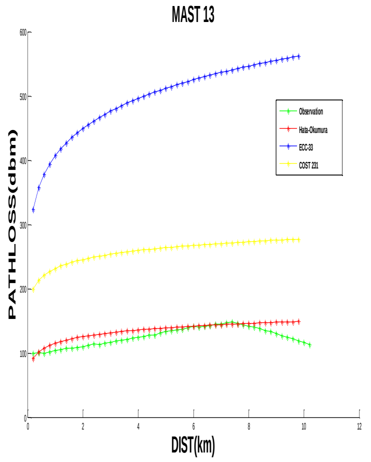


Fig.4.13 Comparison of models with observation for BTS 13.

ETISALAT MASTS (Masts 14-MAST18)

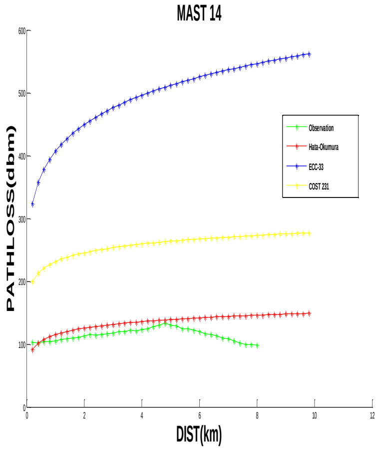


Fig.4.14 Comparison of models with observation for BTS 14.

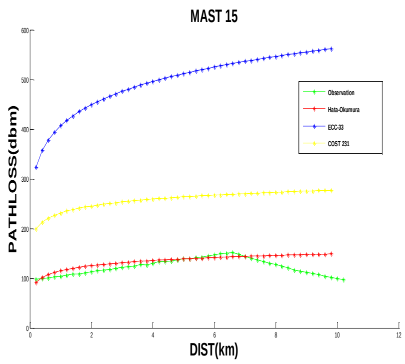


Fig.4.15Comparison of models with observation for BTS 15

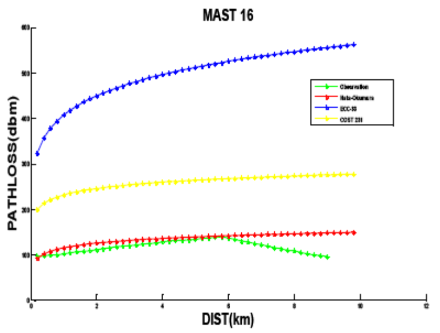


Fig.4.16 Comparison of models with observation for BTS 16.

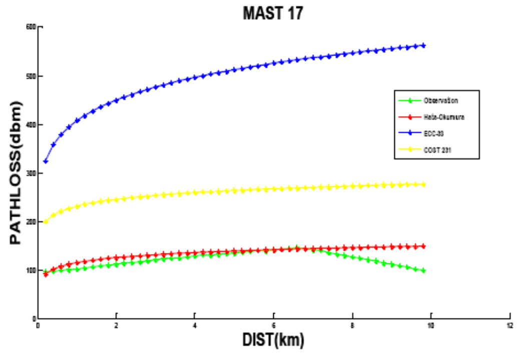
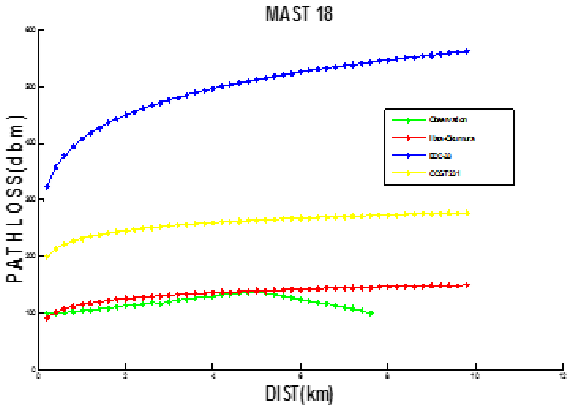
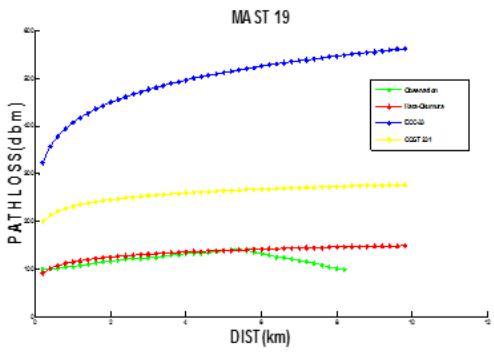


Fig.4.17 Comparison of models with observation for BTS 17.



Airtel Masts (Mast 19- Mast 20)



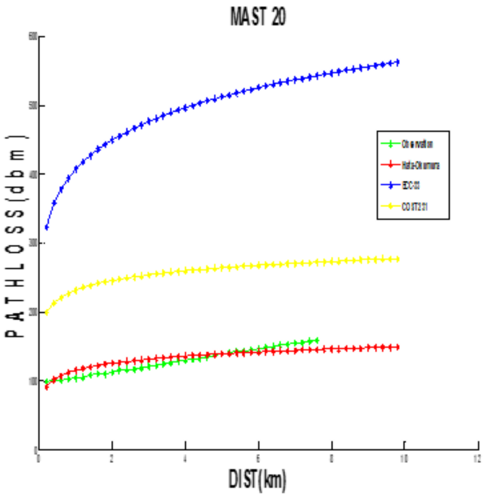


Fig.4.20 Comparison of models with observation for BTS 20.

Fig.4.19 Comparison of models with observation for BTS 19

MEAN PLOTS

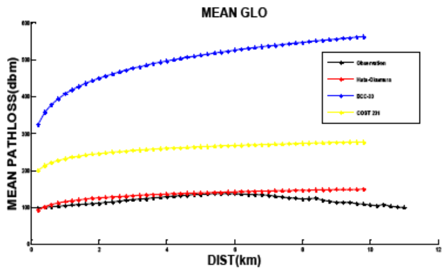


Fig.4.21 Comparison of models with mean for Globacom BTS.

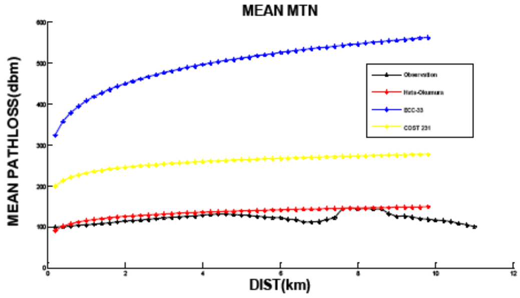


Fig.4.22 Comparison of models with mean for MTN BTS.

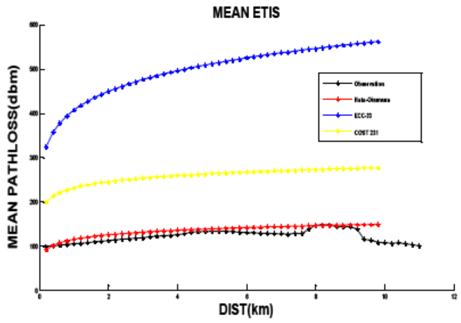


Fig.4.23 Comparison of models with mean for Etisalat BTS.

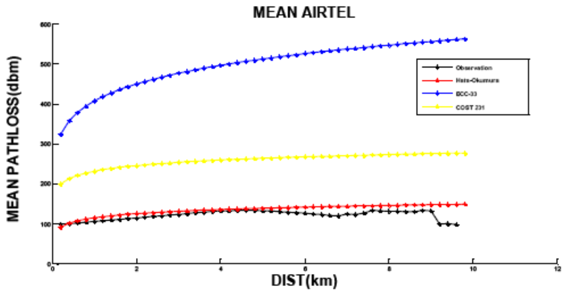


Fig.4.24 Comparison of models with mean for Airtel BTS.

The results shown in table 4.1 to table 4.8 above are presented and discussed based on the network provider. In a general sense, it can be observed that measured path-loss increases as distance between the mast and the mobile receiver increases. For Globacom masts (BTS1-BTS 4), path-loss ranges from a minimum of 100dbm at the base of all the masts to a maximum of 180dbm at a distance of 8.2km away from mast 4.

In mobile cellular telephony, mobile subscribers within a defined geographical location are grouped into one cell and they are served by a cell tower within the same region. Such cells are uniquely identified by a cell ID. Since subscribers are mobile, they are expected to cross from one cell to another within the same network. Thus, in order for subscribers to maintain access to the network, there must be a transfer from the mast of its current cell to the mast of the neighboring cell. This process is called handing over, and the point at which this occurs between the two masts is called the handing-over point. As mentioned earlier, signal strength reduces with distance from the mast due to attenuation and equipment losses. Hence, for practical purposes, the handing-over point is identified as the point at which signal strength starts to increase gradually after an initial steady reduction with distance. The cell ID of the serving cell is also noticed to change to that of the new cell at this point.

For the Globacom masts that were studied, the average handing-over point is 5.67km. This implies that a subscriber would travel an average distance of 5.67km before being handed over to the neighboring cell.

For MTN masts (BTS6-BTS13), the minimum path-loss is 100dbm at 0m away from all the masts while maximum path-loss value of 156dbm is recorded at a distance of 8.4km away from mast 6. The average cell radius is measured at about 4.95km.

For Etisalat masts (BTS14-BTS18), path-loss ranges from a minimum of 99dbm at the base of mast 17 to a maximum of 134dbm at a distance of 7.2km away from mast 15. In this case, the average handing-over point is 5km. In line with the earlier discussion on handing-over point, this implies that the average Etisalat cell has a cell radius of about 5km.

Lastly, for Airtel masts (BTS19-BTS20), the minimum path-loss is 98dbm at the base of mast 19 while maximum path-loss value of 159dbm is recorded at a distance of 7.4km away from mast 20. The average cell radius is measured at about 5.1km.

V. Discussion

In comparing path-loss across all networks, it can be seen that Airtel has the lowest minimum value compared to other networks. On the other hand, Globacom has the highest value for path-loss given as 180dbm. From our study, it is evident that Etisalat has the least path-loss compared to other networks (99dbm-134dbm). Thus, radio signals from Etisalat masts would have a slightly wider range compared to those from other networks.

As said earlier, path-loss was observed to increase with an increase in distance in all the masts under study. However, the increase was not 'smooth' as crests and troughs were observed. This can be partly attributed to the undulating nature of the terrain over which the measurements were made and varying features along the measurement path. As distance from the mast increases, if the road is uphill, an increase in the measured electric field strength is observed. This directly translates into an increase in the received signal level. Consequently, there would be a reduction in path-loss. The reverse of this is observed if the measurement path is downhill. In this case, there is a decrease in the measured electric field strength, which directly implies an increase in path-loss. This is in agreement with the works of Nadir & Ahmad (2010).

According to Mollel and Kisangiri (2014), the crests and troughs observed can also be attributed to loss factors. These factors are brought about by the presence of structures, trees and vegetation along the signal path. Such loss factors include diffraction, shadowing, reflection and absorption, free-space loss, aperture to medium coupling loss. The reduction in the received signal level, which directly means an increase in path-loss with distance is in agreement with the inverse square law (Adegboyega et.al.,2014). The inverse square law states that the intensity of any wave is inversely proportional to the square of the distance away from the source of the wave (Young et.al., 2008).

In a general sense, cell radius, and in essence, the handing-over point is one of the indicators of network coverage for a cellular network. For optimum network coverage, factors such as subscriber population density and topography are put into consideration during the network planning stage to determine the radius for each cell. This has to be carefully done in order to ensure that cells overlap at their boundaries and there are no "dead zones". In this study, MTN was found to have the lowest cell radius at 4.95km while Globacom has the highest radius at 5.67km.

In all the plots from figure 4.1 to figure 4.20, it is evident that both ECC-33 and COST-231 overestimated path-loss in the terrain under study. The ECC-33 model over-estimated path-loss the most, followed by the COST 231 model. However, the Hata-Okumura model gives the path-loss estimation closest to observation, and so, it provides the best fit to observation as shown in the figures above. Furthermore, in the plots for most of the mast, both observation and Hata-Okumura are seen to overlap at multiple points. This result is similar to that obtained by Deme et. al. (2013) in Maiduguri. In that work, the applicability of the Hata-Okumura model to path-loss prediction in Maiduguri was tested and it was observed that the model performed well in that terrain.

So also, from figure 4.21 to figure 4.24, the mean path-loss for all the networks is compared against the models. As was observed for each mast, the ECC-33 model over-predicted path-loss the most followed by the COST 231 model. The Hata-Okumura model provides the best prediction. It is observed that both the Hata-Okumura model and observation values for all the networks coincide at multiple points. This shows that the Hata-Okumura exhibits the highest correlation with the mean observation. Of all the networks, the mean observation for Globacom coincides with the Hata-Okumura model more than any other network.

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