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Geographic Information System (GIS)-Based Path Loss Model for Southern Nigeria

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Abstract
In this paper, Geographic Information System (GIS)-based Path loss models for three locations , namely Ughelli, Odeama Creek and Diebu creek in the Southern Nigeria have been achieved. The risk of manually going to the fields to take measurements of relevant link budget parameters has been drastically reduced by using GIS; and more accurate results with clear visualization from point of operation were also achieved. In this work, a program was written in Visual Basic for Applications (VBA) to automatically compute the path loss using Cost 231 Hata Model, and display it spatially on an administrative map and satellite imagery (Land Use/Land Cover) using ArcMap 9.0 Application. The outcome of this process was tested to be consistent with results of an earlier study managed in the Southern part of Nigeria. It also exhibits how the high quality visualization and spatial handling capabilities of GIS gives it a great improvement as a path loss modeling tool. The incorporation of GIS into existing path loss analysis applications will thereby be recommended for its accelerated and precise results due to its capability to visualize the terrain and other exceptional facets.

***Keywords**: Southern Nigeria, Geographic Information Systems, Path Loss, Cost 231 Hata, Model*

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I. Introduction

Radio propagation planning is of a great benefit in any region, as regards wireless network development. With the aid of different mechanisms which include scattering, diffraction and reflection wireless network can be propagated. The power reduction of Electromagnetic (EM) waves as it propagates through space is known as Path loss (Nwalozie et al, 2013). Path loss is simply the difference between the power transmitted and the power received (Obot, 2011). Path loss plays a key role in the planning of 4G network. It is the attenuation of EM waves as it propagates from one point to the other through space.

A Geographic Information System is a structure which comprises of hardware, software and procedures that promote the administration, capitalization, analysis, modeling, representation and display of geo-referenced data to solve complex problems regarding planning and management of resources (Biebuma and Omijeh, 2013). This system supersedes the regular mapping system. It can execute complex analytical functions and then present the results visually as maps, tables or graphs. These aid decision-makers to practically observe the subject or concerns before them and then select the best course of action. There are various dimensional applications in use such as ArcGIS, MapInfo etc. where the most outstanding of which is the ArcGIS, which originated from the Environmental System Research Institute (ESRI) in Redlands (Prasad and Iqbal, 1997).

II. Theoretical Review

Models have been postulated considering different factors including geographical terrain, frequency of operation over a given distance. They could be applicable to other environment other than the one that was predicted but most times, they become less accurate. Path loss is a decline in power density of any electromagnetic wave as it propagates through space. Path loss plays a major role in the design and analysis of the link budget of a telecommunication system. Free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption are some of the causes of Path loss. Terrain contours, environment, propagation medium, the distance between the transmitter and the receiver, the height and location of antennas also influence Path loss (Biebuma et al, 2014)

According to Neskovic (2000), modern approaches in modeling of mobile radio system and path loss have been undertaken on different environments. COST-231 Hata model devised as an extension to the Hata-Okumura model is an example of the models commonly used for the prediction of path loss in mobile wireless system (Sweeney, 2003). The COST-231 Hata model operates in the frequency band from 500 MHz to 2000 MHz. This model is commonly used for path loss prediction at this frequency band. This is because it is simple to use and readily available for correction factors (Omijeh and Iroegbu, 2018).

Omijeh and Edeh (2008) carried out a path loss modeling and analysis at Odeama creek/Soku, Ughelli/Afiesere, and Diebu Creek/Nun River, all in southern part of Nigeria. The study consists of propagation measurement taken in the frequency range of 1500-2500MHz, with the line-of sight (LOS) mode. The measurements performed in this study were then put into the COST-231 Hata propagation model, equally a matlab program was written base on this model, COST-231. The result obtained is seen in table 1.

Table 1: **Path loss Results table for Sites under Study (Source: Omijeh and Edeh, 2008_)**

Link Name, Latitude, Longitude	MODE	Tx Power	Antenna Gain	Antenna Height	Cable type with Losses	Rain Attenuation	Path loss	Fade Margin	Rx Level
Caw Thome channel/Soku 04 33 39 N 007 00 00 E 04 39 29.40 N 006 36 35 E	LOS	32 dBm	46.5 dBi	103m/ 118m	LMR-600 Coax at 110m 14.29 dB	11.8 dB	164.4 dB	12 dBm	-68.0 dBm
Ughelli/Uzere 05 29 19 N 006 00 24 E 05 19 59 N 006 14 59 E	LOS	32 dBm	46.5 dBi	72m/ 68m	LMR-600 Coax at 78m 6.43 dB	13.4 dB	178.4 dB	13.7 dBm	-66.3 dBm
Kolocreek/Nun River 05 03 36 N 006 27 17.60 E 04 53 23 N 006 22 22 E	LOS	32 dBm	46.5 dBi	112m/ 118m	LMR-900 Coax at 120m 11.50 dB	17.5 dB	170.8 dB	11.2 dBm	-68.8 dBm

Review of COST 231 Hata Model

The COST 231 HATA model is used for readily obtaining the path loss in mobile wireless system. It is a revised version and an extension to the Hata-Okumura model (Hatat, 1980). The assigned frequency of operation is between the range of 500 MHz - 2000 MHz. There are also provisions for antenna factor corrections for flat environment (Baldassaro, 2002). It is often used to predict pathloss, this is due to its provision for correction factor and simplicity, the basic equation for path loss in dB (Rama, 2000).

$$PL=46.3+33.9\log(f)-13.82\log(h_b)-ah_m+(44.9-6.55\log(h_b)\ logd+C_n \quad (1)$$

Where, f is the frequency in MHz, d is the distance between AP and CPE antennas in km, and h_b is the AP antenna height above ground level in metres. C_n is 0dB for suburban and 3dB for urban region. ahm can be defined for urban region as

$$ah_m=3.20(\log(11.75_{hr}))2-4.97, for\ f>400MHz \quad (2)$$

And for sub-urban and rural environments,

$$\boldsymbol{ah_m=(1.1logf-0.7)_{hr}-(1.56logf-0.8)} \quad (3)$$

III. Design Methodology

In this design, the Cost 231-Hata Model was used (Sami, 2013) (Gupreet, 2013). Using Microsoft Access, a database to capture the parameters in the COST-231 Hata model and the geographic Coordinates of the transmitter and receiver stations was set up. A form to link to the database was created. The path loss was calculated using VBA code which was linked to a button in the form. The table was imported into Arc Catalog as a geo-database and displayed as an ESRI shape file on ArcMap. The points were joined and the calculated pathloss displayed. This was overlayed with administrative boundaries and satellite imagery (land use/ land cover). Results gotten were tested to be consistent with a previous research carried out (Omijeh and Edeh, 2008).

Mathematical Model

In carrying out Path loss analysis, COST-231 Hata Model equation was used to model the path loss using real data from the southern region.

$PL=46.3 + 33.9\log_{10}(f) – 13.82\log_{10}(h_b) - ah_m +(44.9 – 6.55\log_{10}(hb))\log_{10}d + C_m$ from equation 1

Where, f is the frequency in MHZ, d is the distance between the transmitting and the receiving antennas in km; h_b is the transmitting antenna height above ground level in meters. The parameter C_m is defined as 0 dB for suburban or open environments and 3 dB for urban environments. The parameter ah_m is define for urban environments,

$ah_m = 3.20 (\log_{10}(11.75h_r))^2 – 4.97$, for f > 400MHz from equation 2

for suburban or rural (flat) environments,

$ah_m = (1.1\log_{10}f – 0.7) h_r – (1.56\log_{10}f – 0.8)$ from equation 3

where, hr is the receiver antenna height above the ground level.

Algorithm

i. Declare all variables using the appropriate format/structure (PL, f, h_r, h_b, ah_m, C_m and coordinates both for receiving and transmitting stations
ii. Create a table in a database with the declared variables as the fields
iii. Create a form containing identical fields with the table created
iv. Link the table with the form
v. Input Cordinates and Station information
vi. Set values for the terrain (Urban, Suburban and Rural)
vii. Define the parameter ah_m for different terrain conditions, that is:
    Urban - $ah_m = 3.20 (\log_{10}(11.75h_r))^2 – 4.97$
    Surburban/Rural - $ah_m = (1.1\log_{10}f – 0.7) h_r – (1.56\log_{10}f – 0.8)$
viii. Define value of Cm for the different terrain conditions:
    Urban, $C_m = 3$, Suburban/Rural, $C_m = 0$
ix. Input other Parameters (f, h_r, h_b and d)
x. Compute Pathloss the Cost 231-Hata model showed below:
    $PL = 46.3 + 33.9 \log_{10}(f) – 13.82\log_{10}(h_b) - ah_m + (44.9 – 6.55\log_{10}(hb)) \log_{10} d + c_m$
xi. Output Computed value of Pathloss

Figure 1 shows the Flowchart for Path loss Analysis using Cost 231-Hata Model

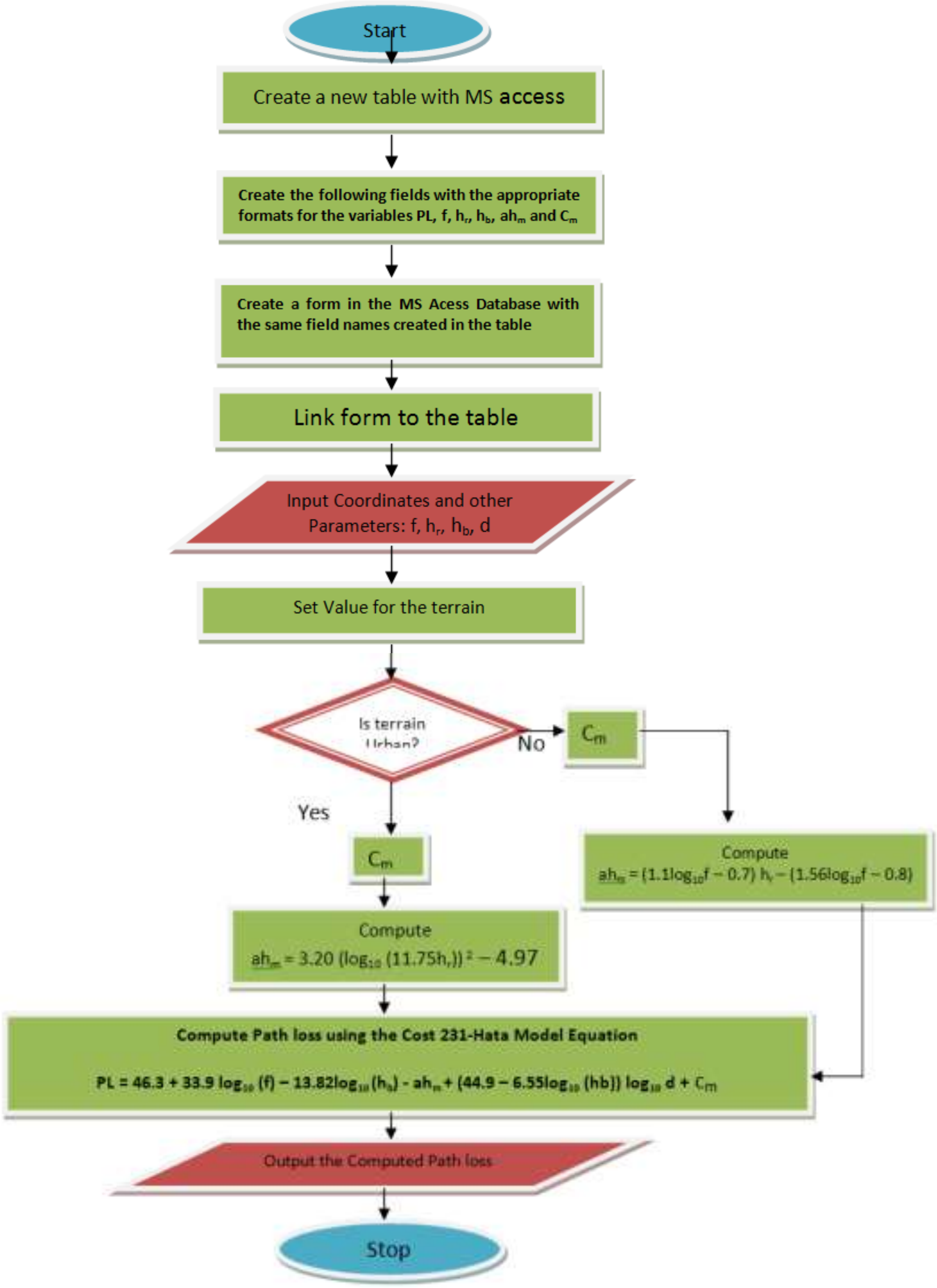

Fig1. Flowchart for Path loss Analysis using Cost 231-Hata Model

Fig 2 Path loss calculation application interface

Table 2: Pathloss results for Different stations with GIS application

Link Name, Latitude, Longitude	MODE	Tx Power	Antenna Gain	Antenna Height	Distance	Cable type With Losses	Path loss	Fade Margin	Rx Level
Odeama creek /Soku 04 33 39 N 007 00 00 E 04 39 29.40 N 006 36 35 E	LOS	32 dBm	46.5 dBi	103m/ 118m	22.6km	LMR-600 Coax at 110m 14.29 dB	152.6 dB	12 dBm	-68.0 dBm
Ughelli / Afiesere 05 29 19 N 006 00 24 E 05 19 59 N 006 14 59 E	LOS	32 dBm	46.5 dBi	72m/68m	31.84km	LMR-600 Coax at 78m 6.43 dB	165 dB	13.7 dBm	-66.3 dBm
Diebu creek / Nun River 05 03 36 N 006 27 17.60 E	LOS	32 dBm	46.5 dBi	112m/ 118m		LMR-900 Coax at 120m 11.50 dB	153.3dB	11.2 dBm	-68.8 dBm
04 53 23 N 006 22 22 E					25.4km				

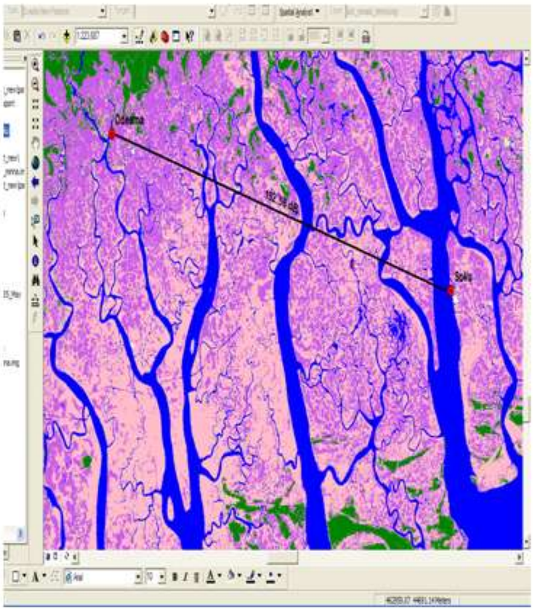

Fig 3 Odeama creek /Soku displayed on land use on administrative boundaries.

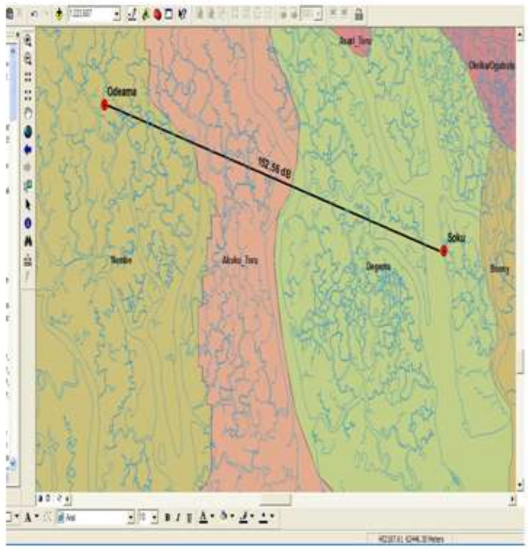

Fig 4 Odeama creek/Soku stations displayed land cover showing the legend.

IV. Results And Discussion

Figure 2 shows a screen capture of the form view of the path loss calculation interface.

With a previous research done, the program was tested and the results were compared with the output of the application. The summary of results obtained when GIS was applied in path loss analysis as contained in this work is shown in table 2.

It is clear that that Odeama creek and Soku (a built up area) are separated basically by Tall Mangrove forest, from the legend. This alongside other attenuation factors explains the high value of path loss calculated, thus the received signal will be low if measures are not taken to improve signal quality. This leads to a better understanding than when it is merely described with words. Preliminary planning can therefore be done based on this analysis, even before going to do real field survey.

The Odeama creek/Soku stations displayed on administrative boundaries and river layer is shown in Figure 4 above. This is necessary for the planner to know the administrative delineations so that plans can be made towards complying with the respective state and local government statutory requirements.

The Ughelli/Afiesere stations are shown in Figure 5 and the computed path loss displayed on land use land cover. It is clear that Ughelli and Afiesere are separated by heavy forests which include palm, rubber etc. using the legend in fig 3. This alongside other attenuation factors explains the high value of path loss calculated, thus the received signal will be low if measures are not taken to improve signal quality.

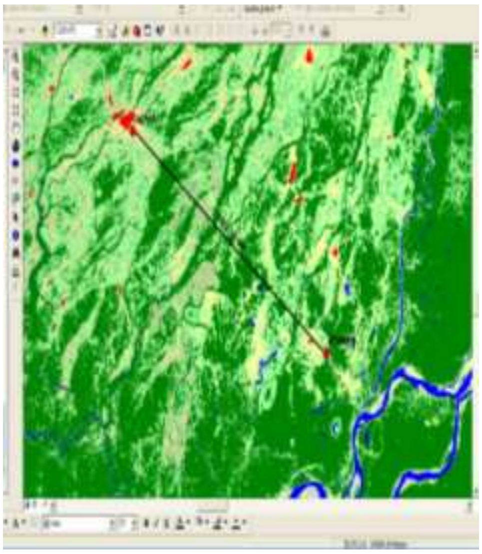

Fig 5: Ughelli/Afiesere stations displayed on LULC Calculated

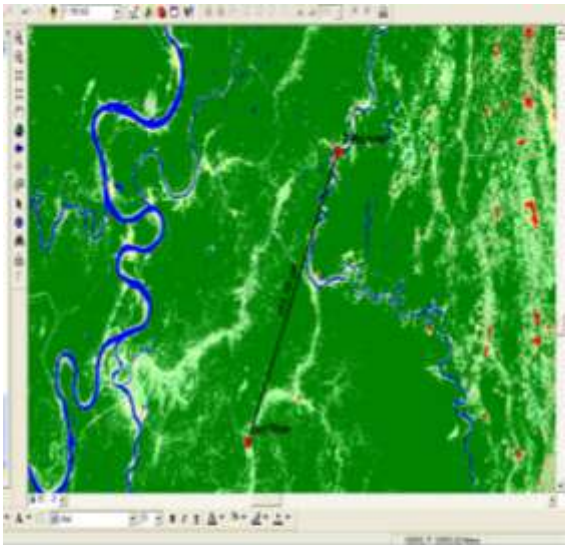

Fig 6 Diebu creek/Nun River stations and pathloss displayed on land use land cover.

From fig 6, it is clear that Diebu Creek and Nun River are separated by mangrove and forests. This alongside other attenuation factors explains the high value of pathloss calculated, thus the received signal will be low if measures are not taken to improve signal quality.

V. Conclusion

In this work, the Geographic Information Systems (GIS) has been used to obtain accurate values of some relevant link budget parameters used in path loss analysis model. GIS-based path loss models independently can result in an accurate analysis, however it depends on descriptions of terrain and other geographical parameters which are very essential. Therefore, the planner in the office, with no physical contact with the field, may not be supplied with the necessary visually aided information of the terrain description, distance between transmit and receiving stations and other geographical parameters. With the aid of the tool customized for this purpose called Geographic Information Systems, the visual and spatial handling capabilities brought an extra edge into the study of path loss analysis. In this paper , this tool was used to achieve the same result at an higher speed but with a benefit of allowing the planner to visualize the terrain parameters from his display system while making accurate decisions. With this, certain other analysis such as Proximity, Network and Overlay can be used to further simplify the work of the telecommunications engineer.

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