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Suitable Propagation Models for 2.4 GHz Wireless Networks: Case Study of Gidan Kwano Campus, FUT MINNA

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Abstract: *In the last few decades, the use of Wireless Local Area Network (WLAN) popularly referred to as Wi-Fi (Wireless Fidelity) in communication system has been on the increase with the exponential usage of handheld cell phones, laptops, and palm-tops to mention but a few. However, WLAN faces a peculiar propagation issue which lies in its changing propagation environment and this affects the quality of service. Poor quality of service is experienced on WLAN of Gidan Kwano campus of Federal University of Technology (FUT), Minna, due to signal propagation impairment caused by the terrain and the structures within the campus. In this work, Received Signal Strength (RSS) measurement was conducted at varying radial distances away from the selected Access Points (APs) both in Line of Sight (LOS) and Non- Line of Sight (NLOS) situations. The path loss exponent (n) and standard deviation (σ) were estimated for the environment. For LOS and NLOS scenarios, the obtained path loss exponents were 2.31 dB and 3.2 dB respectively. The developed models were contrasted with the existing standard models and found to perform better based on the quantitative measures taken in the study area. This shows that the developed models can be utilised for accurate access point deployment within the Gidan Kwano Campus, FUT Minna and other environments with similar features.*

Keywords: *Wireless Local Area Network (WLAN), Path loss Model, Path Loss exponent, Path loss impairment, Access Points (APs).*

1. INTRODUCTION

Wireless Local Area Networks (WLANs) have recently gained prominence in various walks of life, including medical centres, retail, assembling, warehousing, and academic environment [1, 2]. These sectors have benefitted immensely by utilising hand-held gadgets and notebook computers for real time data transmission [3].

Wireless communication offers clients and associations numerous advantages, for example, compactness and adaptability, increased profitability, and lower cost of installation when compared to the wire line communication systems [4]. WLAN gadgets enable clients to move their cell phones from place to place without the requirement for wires. Less wiring implies more noteworthy adaptability and increased proficiency. Handheld gadgets, such as, Personal Digital Assistants (PDA) and mobile phones permit remote clients to synchronize individual databases and give access to network services, for example, remote email, web browsing, and other web administrations [5, 6].

However, as wireless signals move from a transmitter to a receiver, they get diffracted, scattered, and absorbed by the territory, trees, building, vehicles and individuals which constitute the environment of propagation [7, 8, 9, 10, 11, 12, 13]. The nearness of obstacles along the path of wireless signal may cause great signal attenuation more noteworthy than it would under free space condition [14, 15, 16]. Radio signal attenuation and path losses are greatly due to the terrain of propagation [17, 18, 19, 20]. Poor network planning is a factor responsible for WLAN poor quality of service [21, 22, 23, 24]. For accurate network planning, a good knowledge of propagation characteristics is of great importance [25, 26]. In the literature, empirical propagation models are most prevalently used for handling network planning issues. However, due to changes in the environment of propagation, the empirical models are not globally applicable [27]. Accordingly, it is important to determine the particular radio propagation characteristics that will be ideal for the environment under study while carrying out network planning [28]. The Gidan Kwano campus of FUT, Minna often times encounter poor quality of service arising from the signal propagation impairment. The accurate prediction of well-known propagation models is not suitable to evaluate the propagation characteristic of this campus due to the peculiarity of its terrain. This paper is geared toward developing a propagation model for the campus using received signal strength measurements from a selected access points within the campus.

2. METHODOLOGY

Many techniques and materials have been utilised in taking information from an access point (or a base station) [20, 25]. These techniques include radio frequency (RF) overview and drive test among others [4, 21, 22]. For this work, the technique for RF overview was utilised and this section describes the materials and strategies used to achieve this investigation. Figure 1 shows the summary of the methodology deployed.

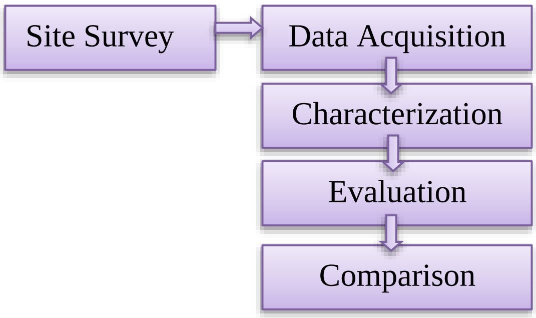

Figure 1: Summary of the methodology

2.1 Study Area Description

The Gidan Kwano campus of Federal University of Technology (F.U.T) Minna is situated in Minna, the Niger state capital, Nigeria. It lies on Longitude 6.50E and Latitude 9.70N. The campus is moderately sized with complex terrain because of the presence of tall structures, classrooms and trees within it. The attenuation of the Wi-Fi signal within the campus is attributed to numerous reflections, absorption and diffractions off rooftops, trees, cars and so on. Figure 2 is the aerial view of the campus as captured from the Google Earth, showing the locations of the access points and the measurement routes.

Figure 2: Google Earth view of F.U.T Minna, Gidan Kwano campus showing the buildings on which the Access Points were mounted and the measurement routes.

The access points (APs) utilised for this work are referenced with respect to the campus building they were mounted on, in particular, ITS Wi-Fi, LIB. Wi-Fi, SEM Wi-Fi, SEET2 Wi-Fi, PTDF Wi-Fi, AGRIC-AP, CON-Wi-Fi, SICT Wi-Fi, ABE Wi-Fi, and SET Wi-Fi. These APs were picked as a result of accessibility of their hardware specifications and configuration.

2.2 Radio Frequency Site Survey

An RF site survey is the initial phase in the deployment of a wireless network and the most important development to guarantee wanted operation. A site study is a step-by-step process by which the surveyor thinks about the facility to understand the RF behaviour, finds RF coverage areas and decides the appropriate placement of wireless devices. RF site survey was led utilising apparatus that enables data to be gathered from an access point, example of such data is the received signal strength indicator.

2.3 Surveying Tools

In carrying out the site survey, Air Check Wi-Fi Tester 2.4GHz and 5.0GHz was utilised to capture wireless packets from an ad-hoc or infrastructure network setup utilising an access point. The specifications of the software and hardware equipment utilised for this study are given in Figure 3.

Figure 3: Surveying tools for the study

1) Software specifications:
i. Microsoft windows 8 Pro.
ii. Matlab version R2014a
iii. Inssider software

2) Hardware specifications:
a: Air Check Wi-Fi Tester 2.4GHz and 5.0GHz
b: Laptop
i. Vendor: Hp
ii. Model: Note book 15
iii. CPU Speed: 2.7GHz
iv. Memory: 2GHz
v. Wireless Card: Intel PRO/Wireless 2200BG
c: IEEE 802.11b/g Access Point
i. Vendor: Mikrotik RB Metal G52SHPacn
ii. Range: $\approx 183m = 600ft$
iii. Transmitter reference Power: *1W*
iv. Bands: *2.4GHz* to *2.4835GHz*
v. Transmission speed-Wi-Fi 2.4GHz: 150Mb/s
d: Global Positioning System (GPS)
i. Vendor: Magellan
ii. Model: Explorist 500
e: 25-foot measuring tape.

2.4 Data Collection Methods

An Hp laptop with a Network Interface Card (NIC) installed and running on Microsoft Windows 8 Pro with Inssider software was utilised to obtain RSSI information at varying radial distance from the chosen APs on the campus. The following privacy guidelines were observed during data collection:

1) The Inssider software did not attempt gaining access to the network.
2) The Inssider software sees all the access points publicly communicating their Service Set Identifier (SSID).

Ten (10) APs were chosen on the Campus at distinctive areas. The chosen APs were from a similar vendor and with similar specifications utilising IEEE 802.11 b/g standard. At each AP, straight ways were stamped out at various bearings from the AP to the laptop. On every one of these ways, test points were physically estimated at a 10m interval utilizing a measuring tape estimating to a 100m stamp from the AP.

1) Line of Sight (LOS) data collection procedure scenario: In a LOS environment, the receiving antenna is detectable to the transmitting antenna with an exceptionally minimal obstacle. The origins of attenuations are essentially from the movement of individuals and vehicles over the path of signal transmission. This is so since the human body is made of around 70 percent water, hence, it ingests some amount of signal accordingly causing loss of strength of the signal being transmitted. Signal information with relating separations from the APs were measured, and at each measured separation, a few estimation of RSSI were gathered. The APs in a LOS environment situation are: FUT Wi-Fi (ITS), FUTLIB. Wi-Fi, SEM MBB Wi-Fi, SEET2-Wi-Fi and GOOGLE Wi-Fi (PTDF).

2) Non-Line of Sight (NLOS) data collection procedure scenario: For NLOS condition, there were no visual observable pathway between the receiving and the transmitting antennas. The radio transmission way is mostly or completely impeded by the nearness of physical obstructions, for example, tall structures, trees, slopes, individuals, vehicles and so on. These interference bodies weaken the signal strength by method of absorption, reflection, scattering and diffraction. RSSI values were gathered from five (5) APs on the campus at estimated separations from the APs in a NLOS domain situation. The APs in a NLOS situation are: FUTAGRIC-AP, CON-FUT Wi-Fi, GOOGLE Wi-Fi (SICT), ABE-Wi-Fi and GOOGLE WIFI (SET).

Data were gathered between the hours of 10 am and 12 pm and between 2 pm and 4 pm from Monday through Friday. The movement of individuals and vehicles is reduced at these hours of the day being the lecture hours. This is aimed at reducing the attenuation caused by individuals and car movement. There is an interior antenna situated behind the laptop screen, so the laptop screen was directed toward the apex sky keeping in mind the end goal to improve the probability that the direct beams signal path falls on the beam width of the antenna.

3. RESULTS AND DISCUSSION

In the study of wireless data communication networks, the path loss exponent is the principal parameter of interest [4]. The path loss exponent relies greatly upon the environment of propagation. High path loss exponent symbolizes how quick the signal strength drops with respect to the distance between the transmitter and the receiver [10, 23]. Therefore, in carrying out signal propagation modelling for a given study area, the path loss exponent for such study area has to be determined. This section shows results, discussion and analysis of information gathered on RSSI from the environment of propagation.

3.1 Presentation of results

The ranges of the signal strength measurements and the corresponding signal quality from Inssider software is presented in Table 1 based on the standard [4]. The measurement surveyed signal strength obtained for some of the APs in LOS and NLOS are presented in Tables 2 and 3 respectively.

Table 1: Standard definition of signal quality in terms of RSSI [4]

Received Signal Strength in dBm	**Signal quality**
$-60 < RSSI \leq -20$	Excellent signal
$-75 < RSSI \leq -60$	Good signals
$-85 < RSSI \leq -75$	Low signal
$-90 < RSSI \leq -85$	Very Low signal
$-108 < RSSI \leq -90$	No signal

Table 2: Mean RSSI for LOS environment scenario

d(m)	Mean RSSI FUT Wi-Fi (ITS)	Mean RSSI FUT_LIB. Wi-Fi	Mean RSSI SEM MBB Wi-Fi	Mean RSSI SEET2 Wi-Fi (ITS)	Mean RSSI GOOGLE Wi-Fi (PTDF)
1	-14.03	-14.03	-14.03	-14.03	-14.03
10	-41.65	-42.70	-43.45	-42.35	-42.75
20	-42.35	-44.45	-45.85	-46.40	-43.90
30	-43.25	-42.65	-46.75	-44.35	-45.80
40	-42.85	-44.35	-47.50	-47.10	-48.65
50	-48.05	-47.40	-45.90	-54.90	-47.55
60	-53.75	-51.30	-53.05	-57.85	-53.65
70	-52.90	-52.85	-56.95	-56.75	-62.25
80	-56.55	-54.70	-54.85	-62.50	-52.60
90	-61.80	-52.40	-65.75	-65.00	-65.40
100	-67.85	-60.25	-63.55	-66.75	-69.40

Table 3: Mean RSSI For NLOS environment scenario

d (m)	Mean RSSI FUT AGRIC-AP	Mean RSSI CON-FUT Wi-Fi	Mean RSSI GOOGLE Wi-Fi (SICT)	Mean RSSI ABE-WIFI	Mean RSSI GOOGLE WIFI (SET)
1	-14.03	-14.03	-14.03	-14.03	-14.03
10	-54.10	-52.60	-48.85	-50.80	-48.35
20	-57.15	-57.85	-52.50	-55.40	-54.50
30	-62.25	-56.80	-55.75	-59.65	-57.20
40	-68.60	-58.50	-62.90	-61.50	-56.95
50	-65.65	-66.20	-70.25	-59.05	-59.95
60	-67.75	-62.35	-67.30	-63.20	-66.45
70	-74.20	-83.85	-66.60	-71.10	-70.45
80	-73.30	-81.40	-74.85	-69.00	-75.85
90	-86.25	-85.70	-81.90	-79.15	-79.85
100	-84.90	-87.80	-79.85	-84.05	-78.95

3.2 Computation of path loss exponent using Log distance path loss propagation model.

$$P_L(d)[dB] = P_L(d_0)[dB] + 10n log(d/d_0) \quad (1)$$

$$P_L(d)[dB] = P_T - RSSI(dBm) \quad (2)$$

$$P_T = 10 * Log(P_t / W_m) \quad (3)$$

Where $P_L(d)$ is the Path Loss at distance d, $P_L(d_0)$ is the Path Loss at reference distance $1m$, P_T is the transmitter power in dBm, P_t is the reference transmitter power of $1W$ *and* W_m *equals* $10^{-3}W$. RSSI are the measured data against distance at the various locations.

With reference to (3) for P_t equals One Watt and Wm equals 10^{-3} *Watt*,

$$P_T = 10 * Log(1/10^{-3})$$

$P_T = 30$ *dBm*

Substituting $P_T = 30$ *dBm* in equation (2) gives,

$$P_L(d)[dB] = 30 - RSSI(dBm) \quad (4)$$

With reference to (4) at reference distance of 1m away from the access point, RSSI is -14.03dBm. From which $P_L(d_0)$ is solved to be 44.03dB. Hence (1) becomes,

$$P_L(d)[dB] = 44.03 + 10n\log(d) \quad (5)$$

The path lose exponent for both LOS and NLOS were obtained using (5). The standard deviation (σ) and Sum of Square Error (SSE) of the developed models from the established standard model were computed by applying (6) and (7) utilizing MATLAB tool.

$$\sigma = \sqrt{\sum_{i=1}^{M}(y_i - \bar{y})^2 / M} \quad (6)$$

$$SSE = \sqrt{\sum_{i=1}^{M}(y_i - \bar{y})^2} \quad (7)$$

Where y_i is the measured path loss at a particular interval, $\bar{y}$ is the developed model path loss and M is the data length. Table 4 and 5 show the mean path loss exponents for LOS and NLOS scenarios respectively.

Table 4: The Mean Path Loss Exponent for LOS

Location	**Mean Path Loss Exponent(n)**
FUT Wi-Fi(ITS)	2.24
FUT_LIB Wi-Fi	2.16
SEM MBB Wi-Fi	2.34
SEET2 Wi-Fi	2.44
GOOGLE Wi-Fi(PTDF)	2.36

Table 5: The Mean Path Loss Exponents for NLOS

Location	**Mean Path Loss Exponent(n)**
FUTAGRIC-AP	3.36
CON-FUT Wi-Fi	3.34
GOOGLE Wi-Fi(SICT)	3.14
ABE Wi-Fi	3.11
GOOGLE Wi-Fi (SET)	3.07

Table 6 gives the summary of the path loss exponents for both LOS and NLOS scenarios.

Table 6: Summary of the Path Loss Exponent for both LOS and NLOS Scenarios

Environment	**Mean Path Loss Exponent(n)**
LOS	2.31
NLOS	3.20

(8) and (9) are the derived mean path loss models for LOS and NLOS scenarios.

$$P_L(d)_{(LOS)}[dB] = 44.03 + 23.1\log(d/d_o) \quad (8)$$

$$P_L(d)_{(NLOS)}[dB] = 44.03 + 32\log(d/d_o) \quad (9)$$

3.3 Discussion of results

Path loss exponent is the most imperative model parameter obtained from the analysis. This parameter gives noteworthy knowledge into how wireless signals attenuate with respect to the distance between the access point and the mobile users. In the analysis, it was gathered that the path loss exponent for NLOS scenario was higher when compared to that of the LOS environment. This shows that the signal strength for NLOS scenario decreases faster due to the presence of obstructions along the path of propagation than for LOS scenario.

3.4 Comparison with existing standard models

Propagation path loss exponents gotten from the empirical measurements were contrasted with that of the free space, Hata and COST-231 model (refer Table 7 and Table 8 and depicted in Figure 4 and 5). Obviously, the path loss exponents from the empirical measurements as contrasted with the free space loss appeared to be higher, and this was seen to be caused by extra losses from environment of propagation which attenuates the signal quicker than in free space. The standard deviation (σ) and Sum of Squared Error (SSE) of the developed models from the field measurements and established models were the parameters used to evaluate the models quality. In this analysis (refer Table 9 and 10), the standard deviation of the measured LOS path loss and the developed model LOS path loss was 2.81 dB as opposed to 5.60 dB of the measured LOS path loss and Free Space Loss. Also, the standard deviation of the measured NLOS path loss and the developed NLOS model was 3.23 dB while that of Hata model and the measured NLOS path loss was 7.04 dB. The SSE of the measured LOS path loss and the developed model LOS path loss was 8.87 dB while that of the free space model and the measured LOS path loss was 17.71 dB. The measured NLOS path loss and the developed model NLOS SSE was 10.20 dB while that of Hata model and the measured NLOS path loss was 22.26 dB.

Table 7: Comparison between measured data, developed model and free space loss

d (m)	**Measured data [PL_{LOS}]**	**PL (d) [LOS] For n=2.31**	**PL (d) [FSL] For n=2.0**
10	71.95	67.13	64.03
20	75.90	74.08	70.05
30	73.80	78.15	73.57
40	75.95	81.03	76.07
50	83.30	83.27	78.01
60	86.25	85.11	79.60
70	84.40	86.65	80.93
80	88.50	87.99	82.09
90	89.80	89.17	83.11
100	90.85	90.23	84.03

Table 8: Comparison between measured data, developed model, Hata model and Cost-231 model

d (m)	**Measured data [PL_{NLOS}]**	**P L (dB) [NLOS] for n=3.20**	**PL(dB) Hata Model**	**COST-231 MODEL**
10	83.60	76.03	72.46	59.83
20	89.10	85.66	81.44	68.81
30	92.25	91.30	86.69	74.06
40	98.45	95.29	90.42	77.79
50	97.70	98.39	93.31	80.68
60	98.25	100.93	95.67	83.04
70	105.30	103.07	97.67	85.04
80	103.15	104.93	99.40	86.77
90	108.75	106.57	100.92	88.29
100	109.90	108.03	102.29	89.65

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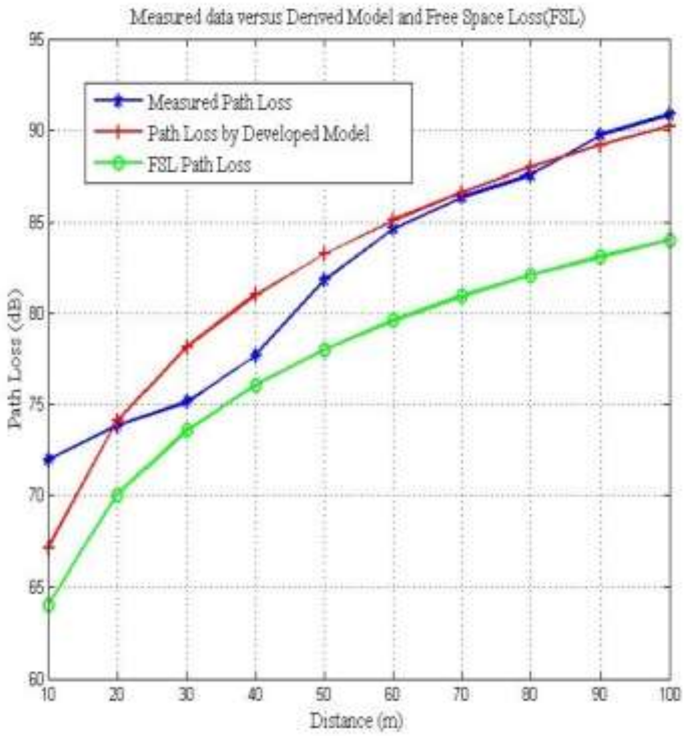

Figure 4**:** Comparison of the measured data with the derived model and Free Space Loss (FSL).

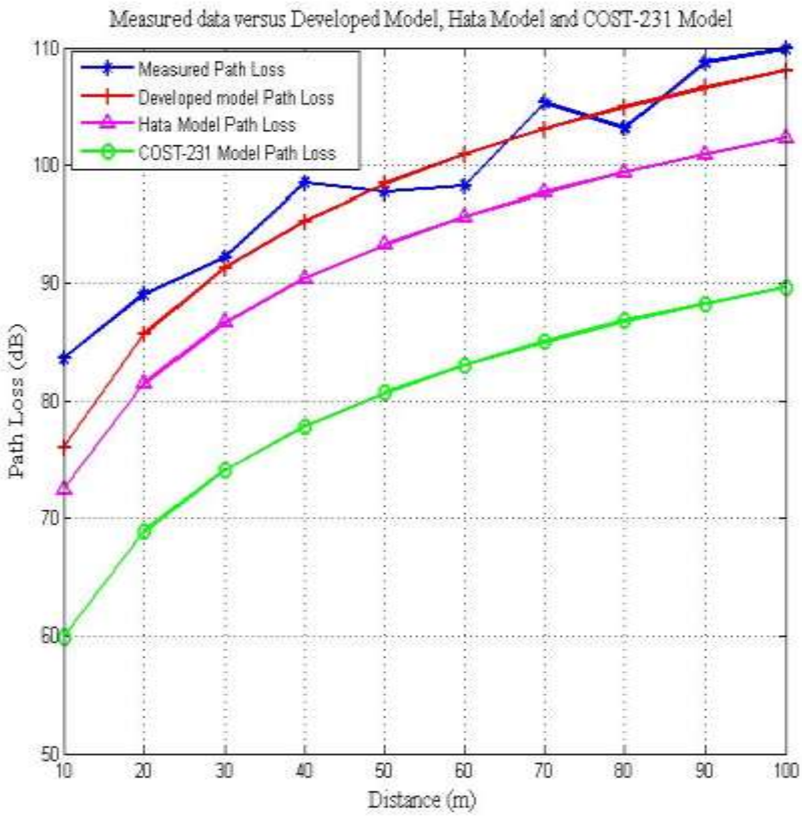

Figure 5: Comparison of the measured data with the derived model, Hata Model and COST-231 Model.

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Table 9: LOS Model validation

Measured LOS Path Loss versus Developed model LOS Path Loss standard deviation	Measured LOS Path Loss versus FSL model standard deviation	Measured LOS Path Loss versus Developed model LOS Sum of square error	Measured LOS Path Loss versus FSL Sum of square error
2.81 dB	5.60 dB	8.87 dB	17.71 dB

Table 10: NLOS Model validation

Measured NLOS Path Loss versus Developed model NLOS Path Loss standard deviation	Measured NLOS Path Loss versus Hata model standard deviation	Measured NLOS Path Loss versus Developed model NLOS Sum of square error	Measured NLOS Path Loss versus Hata model Sum of square error
3.23 dB	7.04 dB	10.20 dB	22.26 dB

4. CONCLUSION

The fundamental target of this work was to develop suitable propagation models capable of enhancing the quality of services rendered by WLAN networks of Gidan Kwano campus, FUT Minna. This was actualised by taking in succession the Received Signal Strength (RSS) measurements of some selected access points both in LOS and NLOS scenarios within the campus. It was seen in the cause of this work that the nearness of obstacles along radio transmission path influences the quality of the transmitted signal. The RSS fluctuates fundamentally at the various locations of measurement due to these obstructions resulting in the attenuation of the received signal. It is exceptionally essential to determine RSS at various locations where WLAN network is to be deployed. Diverse estimations of RSS for each area indicate whether such area receives good signal strength or not. Propagation path loss exponents were obtained for the selected access point both in LOS and NLOS showing the extent to which the signal strength attenuates with distance. The NLOS path loss exponents were seen to be higher than those acquired for LOS condition. This perception demonstrates that the nearness of obstructions along the transmitting antenna truly has effect on the quality of radio frequency signal resulting in multipath effect which weakens the signal strength in NLOS condition. In view of the empirical data gathered, propagation models were developed for both NLOS and LOS conditions. As contribution to knowledge, the developed models were contrasted with the established standard models from which a standard deviation of 2.81 dB was obtained comparing the measured LOS Path Loss and the developed model LOS as opposed to 5.60 dB of the measured LOS Path Loss and the Free Space model. Also, the measured NLOS Path Loss and the developed model NLOS standard deviation gives 3.23 dB as opposed to 7.04 dB of the measured NLOS Path Loss and Hata model. This demonstrates that the developed models can effectively be utilised for proper access point deployment at Gidan Kwano Campus, FUT Minna to accomplish maximum network coverage and excellent quality of service. The developed models are restricted for use in Gidan Kwano campus, FUT Minna and other environment with similar features due to the peculiarity of environmental factors to wireless signal propagation.

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