Original Research Article

Performance Evaluation of Radio Frequency Visualisation Tool for Wireless Communications: A UNIUYO Campus Case Study

.

ABSTRACT

This study was motivated by the challenge of evaluating radio frequency (RF) signal behaviour concerning transmitter and receiver positioning prior to deployment and during troubleshooting. This paper presented the development and testing of a MATLAB-based signal visualisation application to enhance RF signal analysis across various frequencies and terrains, specifically focusing on theUniversity of Uyo(UNIUYO) permanent site and selected locations in Uyo. The application featured three distinct tabs with specialised functions. The first tab integrated campus radio broadcasts at 144.5 MHz and visualised signals for mobile communication standards (2G, 3G, and 4G). The second tab offered a computation interface for selected radio propagation parameters and a tool for converting geographic coordinates from degrees, minutes, and seconds (DMS) to decimal degrees (DD). The third tab was dedicated to 5G testing and deployment. To determine the signal travel extent for each transmitter location, the Longley-Rice and Freespace propagation models were used to represent worst-case and best-case scenarios, respectively. The results, illustrated graphically, demonstrated the application's effectiveness and versatility in RF signal analysis and 5G deployment planning. The study explored two primary 5G deployment strategies: the standalone (SA) approach and the non-standalone (NSA) technique. The SA strategy employed mid-band frequency (3.5 GHz) point-to-multipoint stations within clusters. The applicationutilised up to 19 transmitters (one main transmitter and 18 repeaters) per cluster. Conversely, the NSA technique integrated 5G technology with the existing 4G infrastructure to enhance coverage. The findings offer valuable insights into optimising 5G deployment in terrains similar to those at the UNIUYO permanent site and Uyo in general.

Keywords: Visualisation, radio frequency, standalone, non-standalone, UNIUYO

1. INTRODUCTION

Radio waves are the primary wireless network transmission and communication method, with the longest wavelengths in the electromagnetic spectrum easily transmitted through space [1]. They are a fundamental component of modern wireless communication, with radio propagation describing the movement of these signals from one location to another [2]. War and Myint [3] identified three main types of electromagnetic wave propagation: Line of Sight (LoS) or free space propagation, ground wave propagation, and skywave or ionospheric propagation.

LoS propagation requires transmitting and receiving stations to be in direct view of each other without obstacles [4]. However, obstacles like trees, buildings, and weather can cause attenuations and signal loss, necessitating amplifiers and transmitters for long-distance communication [5]. Ground wave propagation follows the earth's contour and can bend due to the earth's magnetic field, while skywaves are transmitted to the ionosphere and reflected [6]. The ionosphere consists of layers of charged particles from 48.28 km to 402.34 km above the earth's surface.

The electromagnetic spectrum includes visible light and invisible waves like radio waves, microwaves, infrared radiation, ultraviolet rays, X-rays, and gamma rays. Visualising radio waves involves making the radiation patterns and coverage areas of transmitting antennas visible, often using specialised software [7], [8]. Signal strength measurements can identify areas of strong and weak signals, helping to optimise antenna positioning for the best coverage [6].

In this research, MATLAB antenna toolbox will be used to investigate radio frequency (RF) signal propagation and visualisation in selected sites. This will help determine the best type of antenna for each terrain, optimise antenna positioning, and identify areas with the best signal coverage with minimal obstruction. One site to be investigated is the University of Uyo (UNIUYO) permanent site, where the potential for deploying fifth-generation (5G) wireless technology (standalone and non-standalone) will be explored.

2. REVIEW OF RELATED LITERATURE

Thissection provides a comprehensive overview of previous research relevant to the topic of study.

Soe and Aye [3] created a new radio wave propagation model for indoor NLoS scenarios using a TP-LINK router. They modified the free space model to account for corridor conditions on each floor using ray tracing at a 2.4 GHz frequency range. This model estimated indoor signal strength values based on the geometrical plan, with MATLAB used for performance comparison across various frequencies. The results aimed to help wireless network designers optimise costs. However, the model was limited to indoor settings and did not address outdoor propagation over vast areas.

Gerasimov et al. [9] used a ray tracing approach for radio wave propagation in tunnels, particularly in structures larger than the transmission wavelength. Using image theory, they applied a multi-ray model to down-scaled experiments and field tests in a concrete pedestrian tunnel at 1, 2.4, and 10 GHz frequencies. They demonstrated how frequency, polarisation, tunnel dimensions, and dielectric properties affect wave propagation. The downside to the authors' submission was that the study was confined to tunnels and lacked radio wave visualisation.

Otani et al. [10] analysed indoor propagation characteristics using large-scale numerical electromagnetic simulation with the Finite Difference Time Domain (FDTD) technique at a 5 GHz frequency. Using a high-capacity computer system, they confirmed the validity of their simulations for RSSI and channel modelling, helping in designing wireless networks by determining access point numbers and locations. The gap identified in the research was that the study focused only on indoor propagation.

Ozgun [11] introduced a MATLAB-based tool, Geometrical Optics Uniform Theory of Diffraction (GO+UTD), with a user-friendly Graphical User Interface (GUI) for simulating electromagnetic wave propagation and diffraction over varied terrain using geometrical optics and the uniform diffraction theory. The tool was validated through numerical comparisons with the Parabolic Equation Toolbox (PETOOL). The study mainly addressed diffraction effects without signal visualisation.

Nazari and Ghobani [12] developed an algorithm for calculating and visualising a Three Dimension(3D) radar coverage area, considering environmental factors like wave refraction, surface reflection, and earth curvature. The algorithm was tested in Tehran, Iran. The study analysed ideal conditions without integrating an RF propagation model or including the 5G standard.

Mudzinga and Chawanda [13] reviewedHigh Frequency(HF) radio propagation prediction techniques and methods for estimating usable frequencies inspired by recent ionospheric prediction and modelling advances. The review did not test or simulate the techniques to verify their effectiveness.

Nagamoto and Omiya [14] conducted precise predictions of 28 GHz millimetre-wave indoor propagation characteristics using large-scale FDTD simulations. They used high-performance computing to provide detailed electromagnetic field distributions and validated their results against measured data. The focus was on indoor propagation, lacking outdoor signal visualisation.

Zreikat and Dordevic [15] analysed six path loss prediction models, findingStanford University Interim(SUI), Ericsson, and Empirical Hata models best for new mobile networks. They noted that SUI performed better in suburban environments, while Ericsson was better for urban settings at higher frequencies. The study did not visualise the extent of coverage of the models.

3. METHODOLOGY

Fig. 1 shows the flowchart describing the different stages in simulating the signal propagation parameters and visualisation.

3.1 Site Topography, Area, And Height Above Sea Level

The site topography was assessed with Google Maps, as presented in Fig. 2. Regarding the minimum area of coverage, the site measurement is approximately 2.4 km by 2 km; Uyo sits 45 m above sea level, and from the aerial view of Fig. 2, there is a spread of unevenness in the terrain of the selected study site. Data from the field study indicates a 5 m difference in elevation between East and West elevations.

3.2Transmitter and Receiver Site Selection, Antenna Distance, and Tilt Angle Determination

A transmitter usually consists of an RF circuit component and an antenna. The RF circuit provides the antenna with a signal and power. The essential characteristics of a transmitter include its output power, operating frequency, and antenna radiation pattern. The optimal location of the transmitter antenna is proposed to be around the centre of the circle, as shown in Fig. 3.

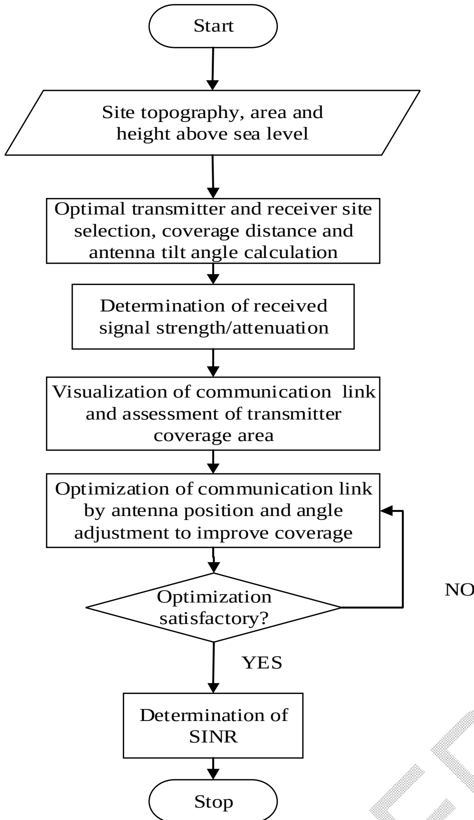
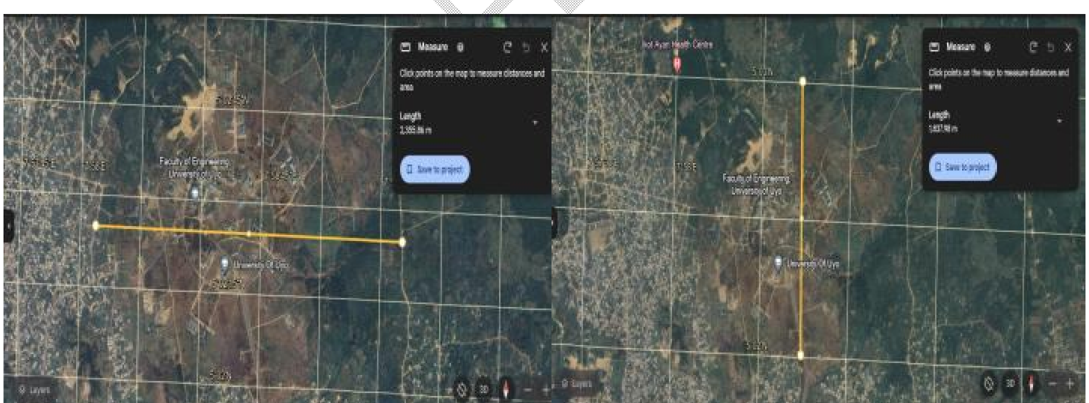


Fig. 1: Flowchart of research methodology



(a) **(b)**

Fig. 2: Google Earth site aerial view (a) minimum coverage length (b) minimum coverage width

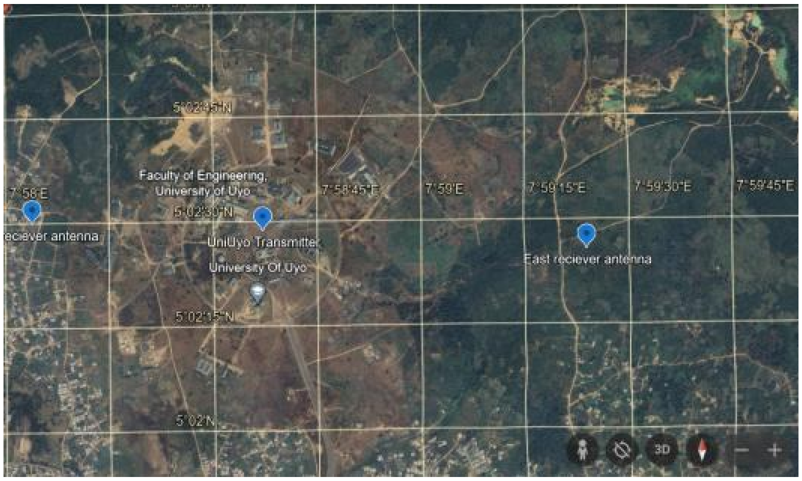


Fig. 3. Site aerial view showing antenna locations (Google Earth)

The transmit antenna location is approximately 1.4 km (1441 m) from the East receiver antenna and 1 km (1038 m) from the West receiver antenna. The positional attributes of the locations above are highlighted in Table 1.

Table 1: Transmitter and Receiver Antenna Positions in DMS

Antenna Site	Latitude	Longitude
Transmit antenna	$5^o02'28" N$	$7^o58'37" E$
East antenna	$5^o02'25" N$	$7^o59'23" E$
West antenna	$5^o02'29" N$	$7^o59'03" E$

The Latitude and Longitude in Table 1 was converted to decimal degrees (DD) as follows:
Retaining the degree part for the transmitter position, the minutes and seconds are converted to degrees as follows:

$$47\ minutes = \frac{02}{60}\ degree = 0.03333^o$$

$$4\ seconds = \frac{28}{3600}\ degree = 0.00777^o$$

$$minute + seconds = 0.04111^0$$

Thus, the complete latitude becomes 5.04111^0. This process was repeated for other antenna sites, and the computed values are presented in Table 2.

Table 2: Antenna positions in decimal for transmitter and receivers

Antenna Site	Latitude	Longitude
Transmit antenna	5.041111	7.97694
East antenna	5.041389	7.96750
West antenna	5.040280	7.98972

The next step was to determine the appropriate transmit power to be used. The transmit power to be adopted for the proposed Frequency Modulation (FM) station, according to the International Telecommunication Union Radiocommunication Sector (ITU-R) standard, must cover twice the specified range; this is done to accommodate cable losses, signal attenuation, shadowing, and other miscellaneous losses. Since campus radio is categorised under Low-Power FM (LPFM) service, a transmitter with Effective Radiated Power (ERP) of 100 W (0.1 kW) is proposed for the University Campus (permanent site). The peculiarities of LPFM transmitters are summarised in Table 3.

Table 3: Characteristics of LPFM transmitters

Parameter	Value
Service Range	$\approx 5.6\ km$
ERP	$1 - 100\ W$
Antenna Height	$\leq 30\ m$

Source: ITR-R (2011)

To verify the measurements obtained from Google Maps and compute the minimum population reach of transmitted signal from the radio, [16] suggested some expressions vital to the measurement evaluation. The population distance of the transmission, d_{pt} is computed using Equation (1).

$$d_{pt} = \sqrt{2hR} \tag{1}$$

where h is the height of the transmitter antenna, and R is the earth's radius (6400 km).

According to the Nigerian Communication Commission (NCC) guideline, base station antennas within residential areas must not exceed 25 m high. They should maintain a minimum of 10 m setback from the fence where necessary [17]. This regulation given by NCC, which is exclusive to wireless telecommunication base stations in residential areas, also stipulates that for towers located in commercial or industrial areas, a maximum height of 150 m with a clearance of 50 m from the nearest structure be maintained and should not be sited at a minimum of 15 km from the closest airport or helicopter helipad. Following the regulation and considering the study site terrain, a maximum antenna height (h) of 25 m was selected. Thus;

$$d_{pt} = \sqrt{2 \times 25 \times 6.4 \times 10^6}$$

$$= 17889\ m = 17.888\ km$$

Area of reach (A_r) is evaluated using Equation (2) as follows.

$$A_r = \pi {d_{pt}}^2 \tag{2}$$

$$= 3.142 \times 17.889^2$$

$$= 1005\ km^2$$

Taking an average population density (P_d) on campus to be 500 per square kilometre. Therefore, the minimum population reach (P_r) is computed using Equation (3).

$$P_r = A_r \times P_d \tag{3}$$

$$= 1005 \times 500$$

$$= 502500$$

$$= 0.50\ million$$

Accordingly, the antenna tilt angle is computed using the [18] expression in Equation (4).

$$Tilt\ Angle, \theta_t = \left(\frac{H_t - H_r}{d_r}\right) \tag{4}$$

where H_t is the height of the transmit antenna, H_r is the optimal height of the receiver antenna, d_r is the separating distance between the transmitter and the receiver.

Interestingly, the expression $\frac{H_t - H_r}{d_r}$ is the bandwidth of the transmitted signal which shows that antenna tilt angle is simply obtained by taking the inverse tangent of the bandwidth of the transmitted signal.

$$\text{Bandwidth} = \frac{25 - 0.8}{1441}$$

$$= 0.01679$$

Hence, the antenna tilt angle for the transmit antenna facing Water Works (South Core) is computed as follows:

$Tilt\ Angle, \theta_t = tan^{-1}(0.01679) = 0.96^0$

While the $Tilt\ Angle, \theta_t$ for the transmit antenna facing animal farm using the same set of parameters at a distance of 1038 m is calculated to be 1.34^0.

3.3DeterminationReceived Signal Strength

The pathloss is first computed using Equation 5 to effectively estimate the received signal strength.

$$L_p = 32.44 + 20R_{(km)} + 20f_{(MHz)} \quad (5)$$

where $R_{(km)}$ is the distance between the transmit antenna and receive antenna, $f_{(MHz)}$ is the radio transmission frequency (144.5 MHz).

The chosen frequency is tentative and can easily be adjusted to any suitable frequency. The pathloss for the link between the transmitter site and the Eastern receive antenna is evaluated for 1.4 km.

$$L_{East\ antenna} = 32.44 + 20(1.4) + 20(144.5)$$
$$= 78.56\ dB$$

The pathloss for the link between transmitter site and West receive antenna is computed as follows.

$$L_{West\ antenna} = 32.44 + 20(1.1) + 20(144.5)$$
$$= 76.47\ dB$$

Similarly, assuming that all power available at the transmitter is converted to radio wave with no losses, Equation (6) is used in computing the field strength, E_{fs}[16].

$$E_{fs} = \frac{\sqrt{30P_t}}{d} \quad (6)$$

where P_t is the transmitter power in watts 100 W, and d is the coverage distance in km.

For the antenna facing East, d = 1.4 km, thus;

$$E_{fs\_SC} = \frac{\sqrt{30\times100}}{1.4}$$
$$\approx 39\ \mu\frac{V}{m}$$
$$\approx 16\ dB\mu\frac{V}{m}$$

And for that facing West:

$$E_{fs\_NC} = \frac{\sqrt{30\times100}}{1.1}$$
$$\approx 50\ \mu\frac{V}{m}$$
$$\approx 17\ dB\mu\frac{V}{m}$$

For the test case scenario with a 100 W (20 dBW) transmit power (P_t), six-element director Yagi Uda antenna with a gain of 10.2 dB is employed at the transmitter, and assuming the minimum receiver antenna gain to be unity gain (0 dB) for mobile phone receivers (since most students may likely listen through their smartphones), the received signal strength (P_r) is computed using Equation (7) as follows.

$$P_r = P_t + G_t + G_r - L_p \quad (7)$$

For East receive antenna:

$$= 20 + 10.2 + 0 - 78.56$$
$$= -48.36\ dB$$
$$= -78.36\ dBm$$

For West receive antenna:

$$= 20 + 10.2 + 0 - 76.47$$
$$= -46.27\ dB$$
$$= -76.27\ dBm$$

In the next section, the computed parameters will be implemented in a MATLAB application using the MATLAB app designer interface to visualise the antenna radiation pattern, coverage distance, propagation link, and received signal strength. During the MATLAB implementation, an attempt is made to evaluate the entire setup with other established outdoor propagation models considering obstructions along the transmission path. Also, the visualisation of transmitted signals using fifth-generation (5G) mobile communication standards is equally presented based on selected site clusters around Uyo, the Akwa Ibom State capital.

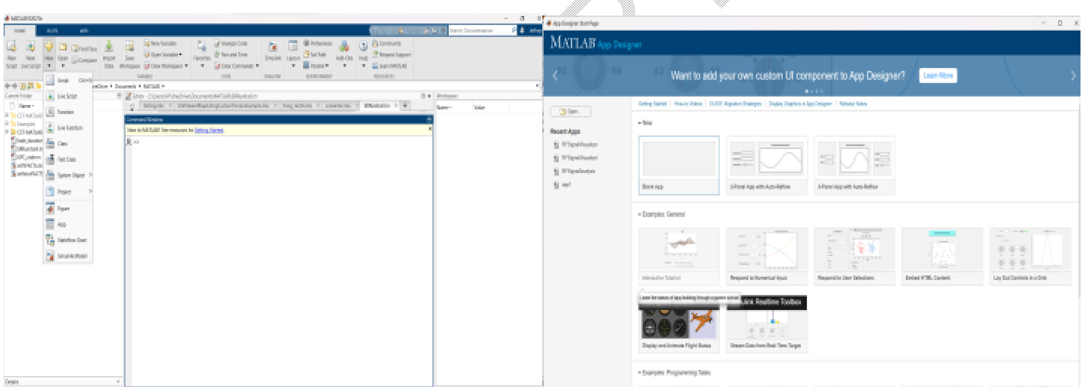
3.4DeterminationReceived Signal Strength

Parameters such as longitude and latitude sourced from Google Earth (presented in Tables 1 and 2) and used to measure the area of the site, and other computed parameters such as the population of reach, minimum population reach, pathloss as well as received signal strength were used to create a MATLAB application to automate the entire process of RF signal visualisation along with parameter computation.

3.4.1 MATLAB application design procedure

Installing a MATLAB program on the computer is fundamental to building a MATLAB application. After that, the following steps are applicable:

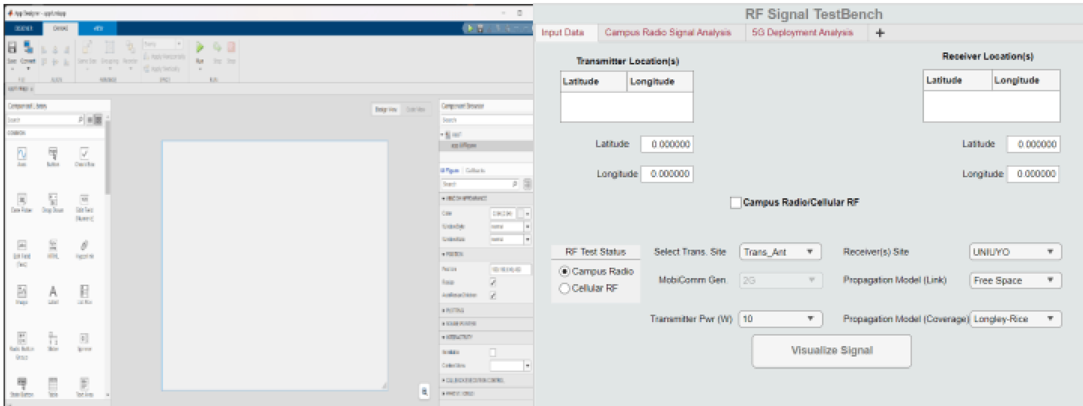
i. Launch MATLAB
ii. On the Home tab, as presented in Fig. 4 (a), click the dropdown on 'New' and select 'App.'
iii. Several templates on the MATLAB App Designer interface, from which 'Blank App' is selected, are shown in Fig. 4 (b).



(a) (b)

Fig. 4: MATLAB interface (a) Workspace (b) Designer interface

iv. From the 'App Designer' interface, various components to choose from are displayed on the left-hand side of the 'Component Library' as illustrated in Fig. 5 (a).
v. The working area for designing the app interface is the Canvas. The desired component for the app interface design (such as Tab, Edit Field, Check box, Label, Radio Button, and Table) is selected from the component library, placed on the Canvas, and renamed as applicable, as illustrated in Fig. 5 (b).



(a) **(b)**

Fig. 5: MATLAB App Designer (a) Canvas (b) Proposed input data interface

vi. The MATLAB Designer interface offers two options that can be interchangeably used, namely, Design View and Code View. Each component placed on the Canvas in Design View is further programmed in Code View to behave in a predefined manner to achieve the required response, as depicted in Fig. 6.

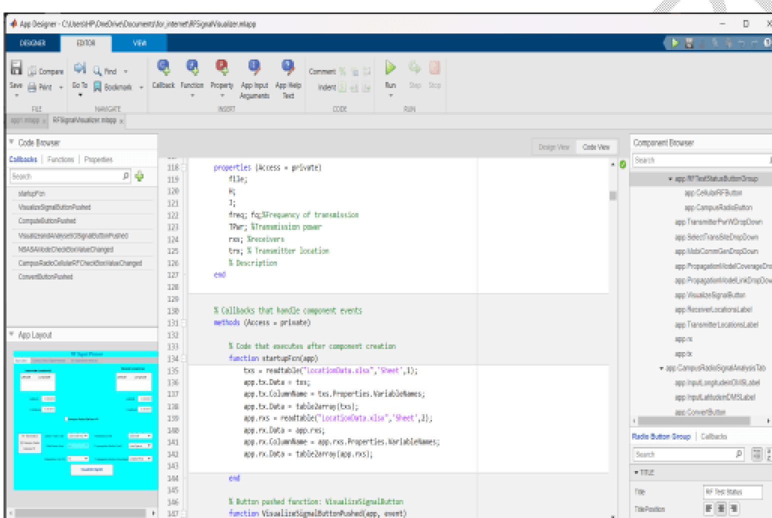
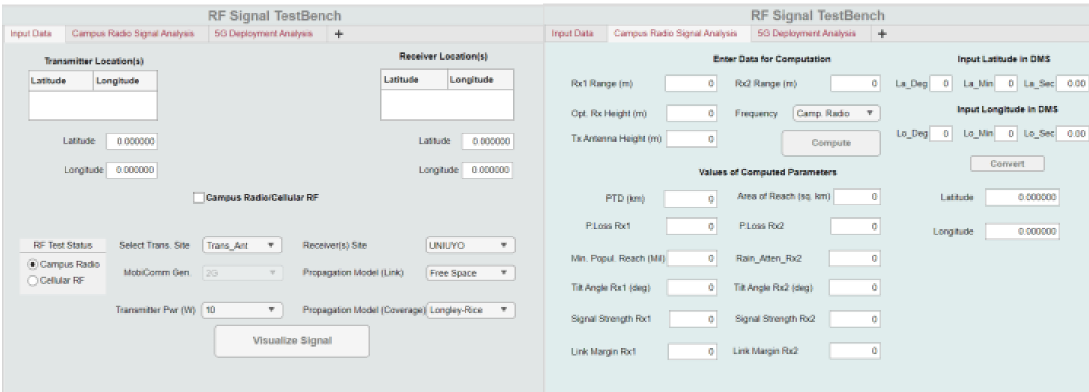


Fig. 6: MATLAB App Designer showing the canvas in Code View

The proposed MATLAB application features three tabs: Input Data, Radio Signal Analysis, and 5G Deployment Analysis. The Input Data tab primarily includes fields for entering positional data for the transmitter and receiver sites, which are imported from an Excel sheet titled ‘LocationData,’ along with the transmitter power and frequency. Additionally, this tab provides options for selecting the propagation model (either Free Space or Longley-Rice). It allows users to view the radio broadcast signal coverage, as shown in Fig. 7 (a).

The second tab includes a section dedicated to automating previously conducted calculations to determine population transmission distance, coverage area, minimum population within reach, antenna tilt angle, pathloss, received signal strength, and link margin. These calculations are performed by inputting necessary parameters such as receiver range, optimal receiver height, and transmitter height. Additionally, the interface offers a feature for converting longitude and latitude from DMS to decimal format, as shown in Fig. 7 (b).

Figure 8 shows the third tab of the proposed MATLAB application for the visualisation of 5G signal coverage on selected sites in Uyo with an option for inputting desired longitude and latitude (in decimal format) using a different number of transmitter clusters; a transmitter cluster consists of a single transmitter and a select number of repeaters.



(a) **(b)**

Fig. 7: MATLAB App Designer (a) Input Data tab (b) Radio Signal Analysis tab

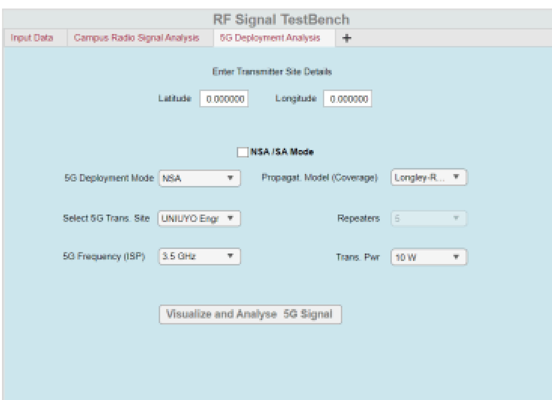


Fig. 8: 5G Deployment Analysis tab on MATLAB application interface

4. RESULTS AND DISCUSSION

In this section, the results of the simulation of the RF signal testbench is presented along with its application in the test deployment of fifth-generation (5G) mobile wireless communication in both standalone (SA) and non-standalone (NSA) mode on the UNIUYO campus and other selected sites. The 5G deployment strategy will be based on the mid-band frequency (3.5 GHz) point-to-multipoint stations in a cluster using a maximum of 19 transmitters (one transmitter and 18 repeaters) per cluster.

4.1MATLAB Application Development

Longitude and latitude data sourced from Google Earth (as shown in Tables 1 and 2) and utilised in the previous chapter to determine site areas and other parameters—such as population reach, minimum population coverage, pathloss, and received signal strength—were employed to develop a MATLAB-based application for automating RF signal visualisation and parameter calculation.

The proposed MATLAB application is organised into three tabs: Input Data, Campus Radio Signal Analysis with a location DMS to DD converter, and 5G Deployment Analysis. The Input Data tab lets users load the transmitter and receiver location details into the app. It also provides an interface for visualising signal coverage for campus radio broadcasts and mobile communication (2G, 3G, and 4G) deployments in selected areas. This tab also facilitates the adjustment of transmitter power and the selection of propagation models (either Free Space or Longley-Rice) via a dropdown menu. It is important to note that the study locations are pre-programmed to load automatically when the app is launched.

Additionally, a toggle switch (Cellular RF) enables users to change the configuration parameters to those specific to mobile radio communication, differing from the campus radio broadcast settings. The app displays campus radio analysis by default, but users can switch to mobile communication by selecting the Cellular RF checkbox, as illustrated in Fig. 9. The second tab is a placeholder for automating the calculations in Chapter Three to ascertain population transmission distance, area of reach, minimum population of reach, antenna tilt angle, pathloss, received signal strength, and also compute link margin. These terms were calculated by entering the required parameters, such as receiver range, optimal receiver height, and transmitter height, as illustrated in Fig. 10. Also, the conversion of longitude and latitude from DMS and DD is done on the Campus Radio Signal Analysis tab.

The third tab, which is the 5G deployment tab as seen in Fig. 11, consists of two deployment modes for 5G signal Viz: SA and NSA with similar configurations as is obtainable with the input tab like site locations, propagation model, and transmitter power (limited to 40W). For SA, different numbers of repeaters (a maximum of 19 repeaters in a cluster) were equally included for various deployment scenarios. Note that by default, the NSA deployment mode is displayed; use the SA Mode checkbox to select standalone mode when needed.

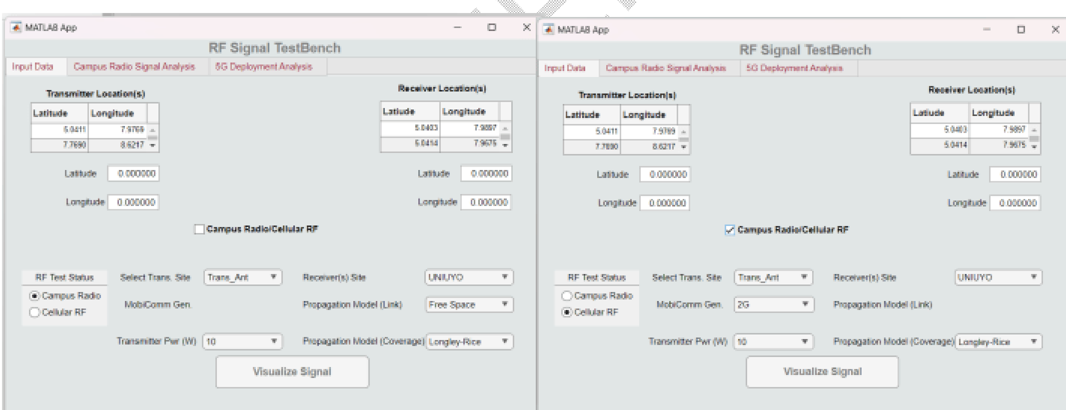


Fig. 9: MATLAB App Designer Input Data tab (a) Campus radio (b) Cellular RF

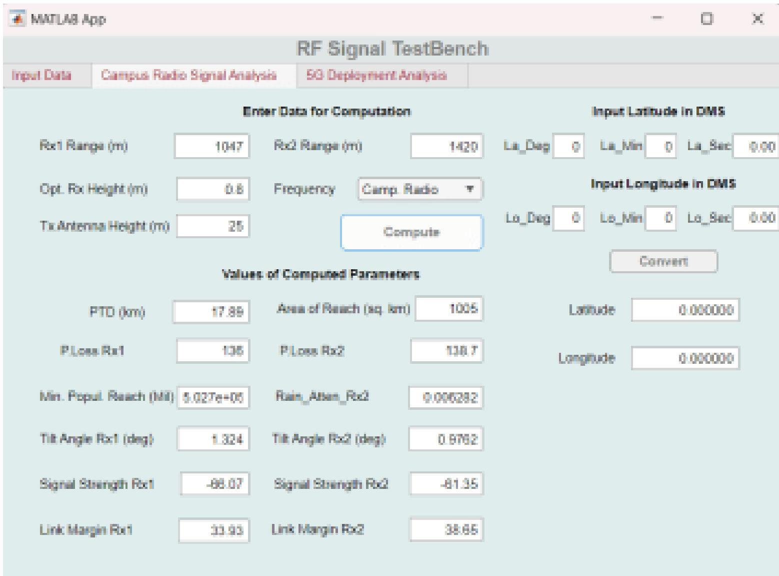


Fig. 10: Radio signal analysis tab

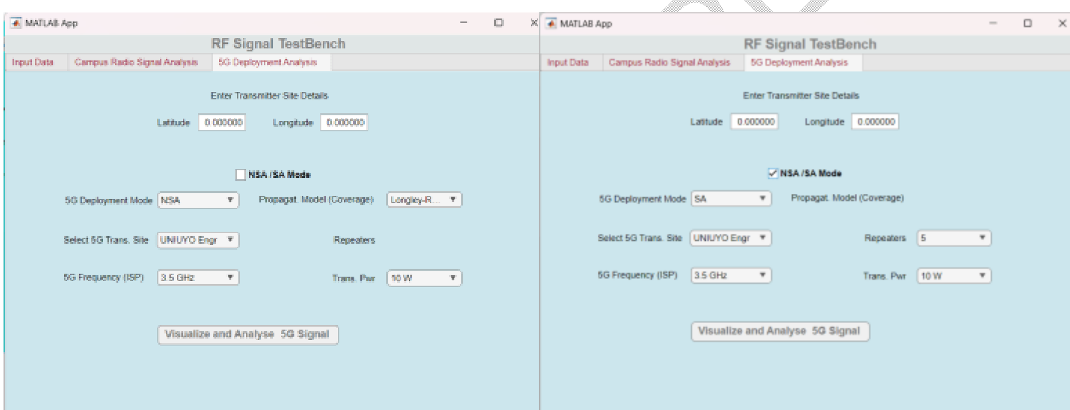


Fig. 11: 5G deployment analysis tab on MATLAB application interface (a) NSA mode (b) SA mode

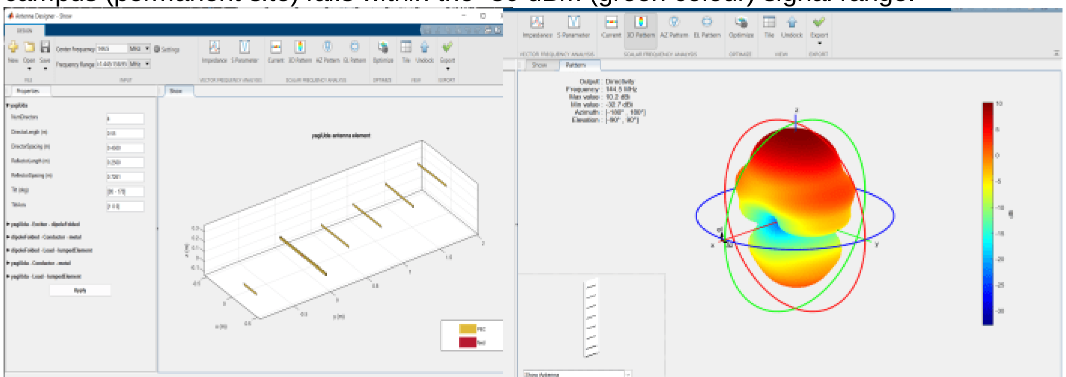
4.2MATLAB Application Output

A Yagi Uda antenna used at the transmitter for the campus radio RF test was first designed in MATLAB using Antenna Designer Toolbox at a Very High Frequency (VHF) of 144.5 MHz, which equally doubles as the broadcast frequency as shown in Fig. 12 (a) with its 3D radiation pattern(nearly omnidirectional) of the designed antenna illustrated in Fig. 12 (b). A surrogate optimisation technique was applied to the antenna to ensure it maximises its front directivity, resulting in a maximum isotropic gain of 10.2 dBi and a front-back lobe. A total of two antennas were adopted, each facing an individual receiver position at the computed tilt angles.

4.2.1 Campus radio signal coverage map

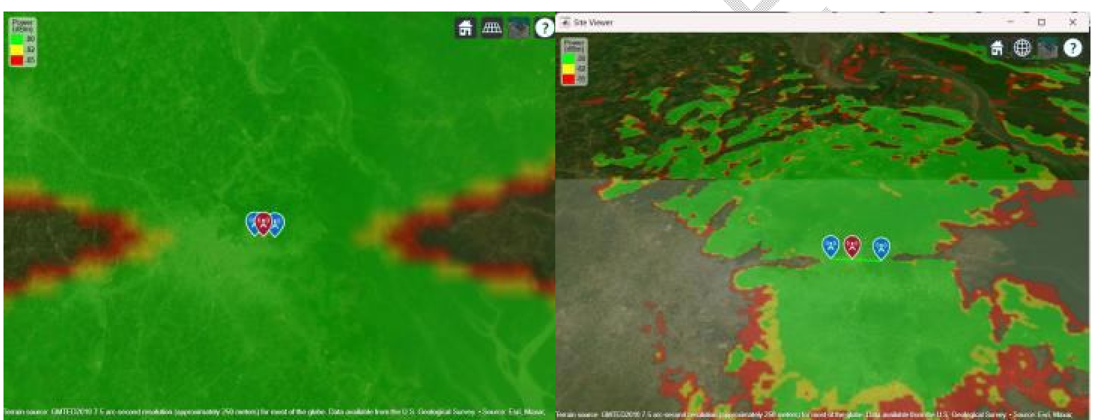
The developed MATLAB application is a valuable tool for selecting the optimal transmitter position when siting a radio station on the UNIUYO campus (permanent site) or any other location. It facilitates the investigation of RF signal propagation using both Free

Space and Longley-Rice models, representing the best and worst-case scenarios. This application simplifies planning decisions by providing instant signal visualisation at the click of a button, as demonstrated in Fig. 13. According to these figures, the entire UNIUYO campus (permanent site) falls within the -80 dBm (green colour) signal range.



(a) (b)

Fig. 12: MATLAB Antenna Designer Toolbox (a) Yagi Uda antenna (b) 3D radiation pattern



(a) (b)

Fig. 13: Proposed campus radio coverage map using (a) Free Space model (b) Longley-Rice model

Subsequently, links are established between the two receivers and the transmitter to measure the received power strength at each location. The Free Space model was first applied, representing the best-case scenario for a communication link. The results, displayed in Fig. 14, show that with receiver sensitivity set between -75 dBm and -105 dBm, the received power remained consistent at -59.4 dBm for the link between the transmitter and the East receiver (Fig. 14 (a)) and at -59.7 dBm for the link between the transmitter and the West receiver (Fig. 14 (b)). The slight difference in received power between the two receivers is primarily due to the transmitter's range, given the ideal conditions assumed in the Free Space model.

(a) **(b)**

Fig. 14: Free space link between transmitter and receivers (a) East receiver (b) West receiver

By maintaining the same receiver sensitivity and using a more practical model like the Longley-Rice propagation model, which accounts for terrain features and obstacles along the transmission path, a slightly different result was obtained, as shown in Fig. 15. The received power dropped from -59.4 dBm to -61.9 dBm for the link between the transmitter and the East receiver, as depicted in Fig. 15 (a), and from -59.7 dBm to -77 dBm for the link between the transmitter and the West receiver, as illustrated in Fig. 15 (b). These results, summarised in Table 3, suggest that there are more obstacles between the transmitter and the West receiver than between the transmitter and the East receiver.

Fig. 15: Longley-Rice link between transmitter and receivers (a) East receiver (a) West receiver

Table 3: Free Space and Longley-Rice Models Applied to UNIUYO Radio Links

Model/Receiver	East Receiver	West Receiver
Free Space	-59.4 dBm	-59.7 dBm
Longley-Rice	-61.9 dBm	-77 dBm

4.2.2 Automated parameter computation

The results of computed parameters are presented in Fig. 16 (a). Most parameters manually computed in the previous chapter correspond with values observed in Fig. 16 (a).

4.2.3 5G deployment analysis

The MATLAB application developed was also used to test the hypothetical deployment of 5G in mid-band frequency. Figs. 16 (b), 17 (a), and (b) show the input interface and graphical representation of a standalone (SA) and non-standalone macro-cell test environment with a transmitter cluster where 5G signals were deployed on the UNIUYO campus. The selected site was the UNIUYO permanent site, with the main transmitter positioned behind the administrative building and flanked by 18 repeaters.

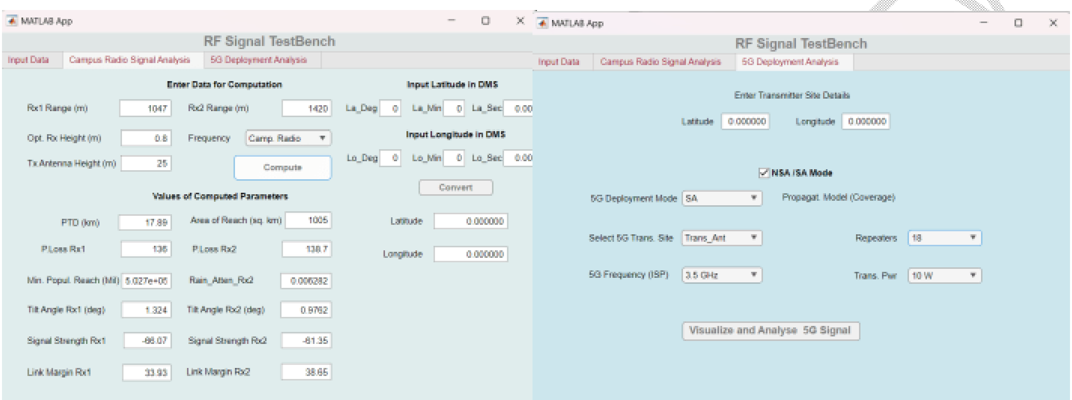


Fig. 16: MATLAB application interface (a) Computed parameters (b) 5G deployment tab

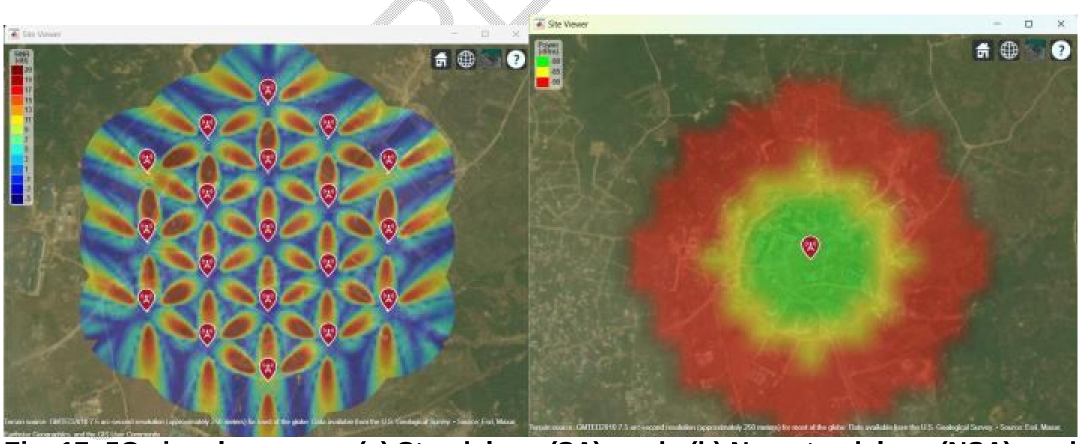


Fig. 17: 5G signal coverage (a) Standalone (SA) mode (b) Non-standalone (NSA) mode

The density of the transmitter employed to deploy 5G (SA mode) was borne out of the need to counter known peculiarities of 5G signals, especially given their inability to travel far due to increased frequency.

The total area occupied by the UNIUYO campus determined through Google map was approximately 5 km^2 which, from analysis and with the correct transmitter placement, required a single antenna centrally positioned to have adequate coverage at sub-1 GHz frequencies (campus radio). However, with increasing frequency, multiple repeaters became necessary for even signal spread on the UNIUYO campus, especially in SA 5G mode.

During the study, a transmitter site (behind the administrative office, UNIUYO permanent site) and two receiver sites (East and West receivers) were test sites used for radio broadcasts at 144.5 MHz. These sites were selected based on the observed extremes of the study site. Different transmitter locations were experimented with, and the position that showed much-improved signal coverage and received signal strength was at the convocation field, as presented in the study.

In terms of the 5G signal deployment on campus, aside from using the midband frequency, NSA mode can equally be adopted to leverage the already existing 4G towers on campus at sub-6 GHz frequencies. This will also drastically minimise the number of transmitters required to achieve maximum coverage of the entire campus, though at a reduced data throughput compared to the SA mode earlier presented.

In comparison to past works, the work put forward by [3] and [10] was specifically designed for indoor RF signal deployment, whereas the method discussed in this report targets outdoor radio propagation. In contrast, [9] developed a model for studying radio wave propagation in tunnels.Ozgun[11] focused primarily on the diffraction effects of electromagnetic waves over varying terrain but did not incorporate signal visualisation. Meanwhile, the platform presented in this study offers visualisation of signals over multidimensional terrain.

4. CONCLUSION

This study explored the interaction between the terrain of UNIUYO's permanent site and selected Uyo locations with radio frequency signals across various frequencies. A MATLAB-based RF signal visualiser application was developed using the App Designer interface, one of MATLAB's toolboxes. The results indicate that the study's objectives were successfully met, as demonstrated by the various figures. The SA 5G deployment strategy utilised mid-band frequency (3.5 GHz) with point-to-multipoint stations in clusters, employing up to 19 transmitters (one transmitter and 18 repeaters) per cluster. In contrast, the NSA technique extended the reach of 5G technology by layering it onto the existing 4G infrastructure.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

REFERENCES

[1] V. Armoogum, K. M. S. Soyjaudah, N. Mohamudally, and T. Gogarty, "*Propagation Models and their Applications in Digital Television Broadcast Network Design and Implementation*,"Trends in Telecommunications Technologies. InTech, 165-184, 2010.

[2] Electronics Notes, "What is Radio Propagation: RF Propagation," *Electronic-Notes*, 2021. https://www.electronics-notes.com/articles/antennas-propagation/propagation-overview/basics.php (accessed Mar. 27, 2022).

[3] T. soe War and A. Myint, “Development of Radio Wave Propagation Model in Indoor Non-Line-of-Sight (NLOS) Scenario,” *Int. J. Comput.*, vol. 4523, 2015.

[4] C. Ghobadi, P. R. Shepherd, and S. R. Pennock, “Line-of-sight propagation on IEEE Technology Navigator,” 2021. https://technav.ieee.org/topic/line-of-sight-propagation (accessed Apr. 01, 2022).

[5] J. Milanović, S. Rimac-Drlje, and I. Majerski, “Radio wave propagation mechanisms and empirical models for fixed wireless access systems,” *Teh. Vjesn.*, vol. 17, no. 1, pp. 43–52, 2010.

[6] Y. Singh, “Comparison of Okumura, Hata and COST-231 Models on the Basis of Path Loss and Signal Strength,” *Int. J. Comput. Appl.*, vol. 59, no. 11, pp. 37–41, 2012, doi: 10.5120/9594-4216.

[7] J. Hagedorn, K. Sayrafian, K. Y. Yazdandoost, and J. Terrill, “A 4D immersive platform to visualise RF propagation in BAN,” *8th Eur. Conf. Antennas Propagation, EuCAP 2014*, no. EuCAP, pp. 3366–3367, 2014, doi: 10.1109/EuCAP.2014.6902549.

[8] IEEE, “IEEE Recommended Practice for Antenna Measurements,” *IEEE Std 149-2021 (Revision IEEE Std 149-1977)*, pp. 1–207, 2022, Accessed: Oct. 08, 2023. [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9714428

[9] J. Gerasimov *et al.*, “Scaled modeling and measurement for studying radio wave propagation in tunnels,” *Electron.*, vol. 10, no. 1, pp. 1–13, 2021, doi: 10.3390/electronics10010053.

[10] H. Otani, S. Yamaguchi, S. Yonezawa, and M. Omiya, “A large-scale numerical simulation of indoor radio wave propagation for a wireless LAN system,” *ICCEM 2015 - 2015 IEEE Int. Conf. Comput. Electromagn.*, pp. 312–314, Mar. 2015, doi: 10.1109/COMPEM.2015.7052645.

[11] O. Ozgun, “New Software Tool (GO+UTD) for Visualisation of Wave Propagation [Testing Ourselves],” *IEEE Antennas Propag. Mag.*, vol. 58, no. 3, pp. 91–103, Jun. 2016, doi: 10.1109/MAP.2016.2541600.

[12] M. E. Nazari and A. Ghorbani, “Predicting a Three-Dimensional Radar Coverage Area,” *IEEE Antennas Propag. Mag.*, no. February, 2016.

[13] C. Mudzingwa and A. Chewanda, “Radio Propagation Prediction for HF Communications,” *Communications*, vol. 6, no. 1, pp. 5–12, 2018.

[14] S. Nagamoto and M. Omiya, “Highly Precise Prediction of 28 GHz Indoor Radio Wave Propagation Characteristics in an Office Environment for Design of 5G Wireless Networks,” in *2020 IEEE Region 10 Conference (TENCON)*, 2020, pp. 113–116.

[15] A. I. Zreikat and Milan Dordevic, “Performance Analysis of Path loss Prediction Models in Wireless Mobile Networks in Different Propagation Environments,” in *Proceedings of the 3rd World Congress on Electrical Engineering and Computer Systems and Science (EECSS’17)*, 2017, pp. 1–11.

[16] J. C. Mbagwu, U. C. Ozuomba, Z. L. Abubakar, and J. O. Ozuomba, “Design, Construction and Testing of JP Mini Radio Broadcast Transmitter and Audio Console,” *Int. J. Innov. Res. Electron. Commun.*, vol. 7, no. 2, 2020, doi:

10.20431/2349-4050.0702003.

[17] NCC, “Guidelines on Technical Specifications for the Installation of Telecommunications Masts and Towers Issued This 9Th Day of April , 2009,” 2009.

[18] Proxim, “Proxim Wireless - Calculations: Antenna Downtilt,” 2013. http://www.proxim.com/products/knowledge-center/calculations/calculations-antenna-downtilt