Indian journal of
Engineering

Signal propagation curve for digital television broadcast network in Nigeria

Igbonoba Ezekiel Endurance Chukwuemeke[1], Bankole Adesola Temitope[2]

To Cite:
Igbonoba EEC, Bankole AT. Signal propagation curve for digital television broadcast network in Nigeria. *Indian Journal of Engineering*, 2023, 20, e10ije1010
doi: https://doi.org/10.54905/disssi/v20i53/e10ije1010

Author Affiliation:
[1]Computer engineering department, University of Benin, Edo state, Nigeria; Email: igbonoba2000@live.com
[2]Computer engineering department, Ahmadu Bello University, Zaria, Kaduna state, Nigeria; Email: atbankole@abu.edu.ng

Peer-Review History
Received: 02 March 2023
Reviewed & Revised: 04/March/2023 to 25/March/2023
Accepted: 29 March 2023
Published: 31 March 2023

Peer-Review Model
External peer-review was done through double-blind method.

Indian Journal of Engineering
pISSN 2319–7757; eISSN 2319–7765

DISCOVERY
SCIENTIFIC SOCIETY

ABSTRACT

In order to create a signal propagation curve that will show signal degradation and describe the spread of digital signal strength for radio scientists and engineers, this study analyses the signal propagation curve of the digital terrestrial television broadcasting (DTTB) network in Jos, Plateau State, Nigeria. The goal of the study was to create a DTTB propagation curve for the Nigerian DTTB broadcast network's planning and execution. Received signal strength (RSS) was used as the primary measured parameter throughout the study in a measurement-based performance analysis. In route A, the signal strength declined to little over half of its starting value, according to the result analysis, however in route B, the decrease was not quite as great. The results of this research will help radio scientists and engineers better understand radio wave propagation, channel estimate and equipment design on the UHF band. In path loss computation and modeling, this can also assist in forecasting the power received or lost at a specific distance from the transmitter.

Keywords: Digital Terrestrial Television Broadcasting (DTTB), Digital video broadcasting-Terrestrial - Second Generation (DVB-T2), Electromagnetic Spectrum, Electromagnetic waves, Received Signal Strength (RSS), Signal Propagation Curve

1. INTRODUCTION

Theoretical background

An important factor in the theory of radio wave propagation and the design of radio equipment is the propagation curve, which is the fluctuation of a radio signal's electric field intensity with respect to distance (Ayayi and Owolabi, 1979). Predicting the Received Signal Strength (RSS) from distant sites is helpful (Zeinab et al., 2013). The transmitter power, the kind of signal path (rural or urban) and the topography of the locations involved all affect how the propagation curve is designed and implemented (Bothias, 1987; Kenedy and Bernard, 1992). Planning radio propagation and designing equipment employ it (Collin, 1985). The VHF/UHF propagation curves, which were published by the (CCIR, 1986), have been used for international planning since 1963. The graphs show the decline in field strength with increasing distance for a variety of transmitting antenna heights, where the latter is defined as the antenna's height above the mean terrain elevation within a range of 3 to 15 kilometers (Ajewole et al., 2014; Akinbolati et al., 2015; Akinbolati et al., 2016).

The DTTB signal is sent over the UHF broadcast band using a space wave that travels in a straight line from the transmitter through the troposphere. As a result, the signal picked up at distant sites may be the direct transmitted wave, the reflected wave, or the diffracted wave (Ajewole et al., 2014). This is because terrestrial objects have an impact on the propagation path (Akinbolati et al., 2015). Transmitter output power, also known as effective isotropic power of the transmitter (EIRP), transmitting antenna height, and the structure of the signal path are additional variables that affect the quality of the signal received from the transmitter on the UHF band (Akinbolati et al., 2016). Others include the separation between the transmitter and the receiver, the height of the receiver, the antenna's gain, and the calibre of the receiver (Akinbolati et al., 2016). Moreover, there is the signal attenuation produced by foliage (Ajewole et al., 2013) and precipitation (Ajewole et al., 2014) on digital TV signals. The goal of this effort was to create a DTTB propagation curve for the development and construction of a DTTB broadcast network in Jos and the surrounding areas of Nigeria's Plateau State.

This technological advancement is significant in path loss calculation and modeling because it can forecast the power received or lost at a specific distance from the transmitter. The published papers (Akinbolati et al., 2016; Ayekomilogbon et al., 2013; Ayeni et al., 2015) are among those that have demonstrated the importance of path loss modeling in coverage estimate. Moreover, choosing broadcast station coverage areas has a considerable impact on the socioeconomic well-being of the local population (Akinbolati et al., 2015), making it a useful scientific feedback mechanism. The study's results would be helpful for radio wave propagation and reception on DTTB network channels in the study area specifically, as well as in other environments of a similar nature generally. It is helpful in predicting coverage regions and path losses and effective path loss prediction is a crucial component of a well-designed mobile system (Nisirat et al., 2011). Every radio signal's pattern of propagation in relation to interactions with terrain characteristics along its path of transmission can be seen in propagation curves. The ITU-R has urged scientists and engineers in their different parts of the world to conduct research on propagation curves (ITU-R, 1995).

Key performance indicators for DTTB signals propagation curve

Electromagnetic spectrum

The electromagnetic (EM) spectrum is the range of all potential frequencies of electromagnetic radiation, including radio waves, X-rays, infrared light and visible light. Table 1 presents the various electromagnetic spectrum frequencies and their intended uses.

Table 1 Electromagnetic Spectrum and their Applications (Akinbolati et al., 2017)

S/n	Electromagnetic spectrum calibration		
	Frequency (Hz)	Band	Application
1.	3-30K	Very Low Frequency (VLF)	Audio Telephone, Navigation Employs and Ground wave propagation.
2.	30-300K	Low Frequency (LF)	Navigation aids, Radio beachers telephone.
3.	300-3M	Medium Frequency (MF)	AM broadcast, civil defense.
4.	3-300M	High Frequency (HF)	Amateur radio, Mobile radio and Military communication.
5.	30-300M	Very High Frequency (HF)	VVHF, TV, FM, air traffic police/navy communications.
6.	300M-3G	Ultra-High Frequency (UHF)	UHF, TV, Radio space telemetry.

Received signal strength

The strength of a signal received is measured at the antenna of the receiver and is known as the received signal strength (RSS). The decibel-miliwatts (dBm) of the radio environment, the distance between the transmitter and the receiver and the broadcast power all play a role in determining RSS (Xi et al., 2016). Changes in the propagation path between the transmitter and receiver are what cause the fluctuations in signal strength. Radio transmissions are actually subject to a number of constraints, including the issues with fading and shadowing, multipath and environmental factors like temperature and humidity. Hence, the signal quality and strength should be assessed in order to provide a dependable data transmission (Houssaini et al., 2018).

The average received signal intensity at any location in a mobile radio channel decays as the square of the power law of the separation distance between a transmitter and receiver, which is based on the inverse square law, according to propagation measurements (Nkordeh et al., 2016). (Nkordeh et al., 2016) Provides an approximation of the average received power Pr at a distance d from the emitting antenna.

$$P_r = P_0 \left(\frac{d}{d_0}\right)^{-n} \quad (1)$$

$$P_r(dBm) = P_0(dBm) - 10\, n \log \left(\frac{d}{d_0}\right) \quad (2)$$

where, n is the path loss exponent and P_o is the power received at a close-in reference point in the far field region of the antenna at a short distance d_o from the transmitting antenna. These are some elements that could impact RSS in a real wireless system:

- Path loss on a large scale caused by the distance between transmitter and receiver.
- The effect of large objects in the channel between the transmitter and receiver is known as medium scale fading or shadowing.
- Small-scale fading is the result of the addition of multipath waves at the receiver, either constructively or destructively, as it moves on the order of a wavelength.
- Temporal fading, due to the movement of people and objects in the environment.
- Interference, due to the transmission of other signals in the same band.
- Thermal noise.
- Changes in transmit power, due to battery, temperature, or other changes in the transmitter hardware.
- Changes in the RSS measuring circuit in the receiver, again, due to battery, temperature, or other changes in the receiver hardware.

The first three of these factors are static when the transmitter and receiver are stationary in an unchanged environment. The factors 4–8 may contribute to dynamic changes in measured RSS even in stationary conditions (Luo et al., 2018). A simple treatment of RSS measurements with uncorrelated lognormal distributed perturbations is widely acknowledged in the literature and typically used in practical systems (Goldsmith, 2005; Pahlavan and Levesque, 2005; Zekavat and Buehrer, 2011) because it is difficult to pinpoint every influencing factor. Specifically, in research, antenna gains, transmitting power, free space path loss and lognormal white noise are used to mimic RSS. Any uncertainty can be modelled using a random term in this way, which may contain more effects than just thermal noise. These guidelines provide a straight forward approach for describing RSS and simplify its mathematical form. However, they are only possible if the PSD of the noise is roughly distributed uniformly across the unbounded bandwidth. The perturbations can no longer be regarded as being uncorrelated if significant variations are seen if the PSD actually contains those (Luo et al., 2018).

Electromagnetic waves

Transverse waves include electromagnetic waves. The propagation direction is parallel to the electric and magnetic fields. They convey the wave's magnetic and electric energy. The magnetic and electric fields are synchronized (Akinbolati et al., 2018). They are perpendicular to one another and their amplitudes are connected by:

$$\bar{B_o} = \frac{K}{\omega} E_0 = \frac{1}{C} E_0 \quad (3)$$

where k is the propagation constant, ω is the angular frequency of the wave, c is the speed of light in space and E_o is the magnitude of the electric field intensity.

In general, for a sinusoidal wave, the variation of the electric field Intensity in space and time is represented as;

$$\bar{E}(r,t) = \frac{1}{C} \bar{E_0} e^{i\,(k.r-\omega t)} n^{\wedge} \quad (4)$$

and the magnetic field strength

$$\overline{B}(r,t) = \frac{1}{C} \overline{E_0} e^{i(k.r-\omega t).(k^{\wedge}\, x\, n^{\wedge})} \quad (5)$$

where k is the propagation vector, $n^{\wedge}$ is a unit vector in the direction of propagation of the wave called the polarization vector and r is the space coordinate.

The ratio of the electric field intensity to the magnetic field intensity is definedas

$$\frac{|E|}{|H|} = \frac{E_x}{H_y} = \sqrt{\frac{\mu_O}{E_O}} = Z_O \quad (6)$$

Where, Z_O is the wave impedance or characteristic impedance of the wave in free space Z_O = 337Ω

Power density

Radiated power per unit area is referred to as power density, also known as the Inverse Square Law (Akinbolati et al., 2018). It is directly proportional to the transmitted power and inversely proportional to the square of the source's distance (Akinbolati et al., 2018). In other words, if the distance to a transmitter is doubled, the power density of the wave that is transmitted at the new location is cut in half (Akinbolati et al., 2016) The inverse square law, which is applicable to all types of radiation in free space, is this.

Therefore,

$$P_d \propto \frac{P_t}{r^2} \quad (7)$$

$$P_d = \frac{P_t}{4\pi r^2} \quad (8)$$

where, P_d is the power density at a distance r (m), from the transmitter, $P_{t(w)}$ is the transmitted power.

At distance r from the transmitter, the electric field strength is represented as;

$$|E| = \sqrt{\frac{30\ P_t}{r}} \quad (9)$$

|E| is in Volt/meter, r, is in meters and P_t is the power transmitted in watts.

When the gain of the transmitting antenna is considered, then |E| becomes:

$$|E| = \sqrt{\frac{30 P_t G_t}{r}} \quad (10)$$

The transmitting antenna's gain, G_t, is expressed in dB. By extrapolating from equation (10), it is evident that the electric field strength value of a radio signal received far from the transmitter is inversely proportional to that distance. This establishes a solid foundation for the mathematical modeling of the field strength and the line of sight (distance, r), which would be based on the data collection of the relevant parameters in the study areas.

2. MATERIALS AND METHODS

Materials and measuring procedure

An E8000A series spectrum analyzer, a DTT receiver (set-up-box), a receiving antenna, smart phone-enabled Google Earth map software, a personal computer (PC) system, a television, a power producing set and other auxiliary facilities are among the tools utilized to collect data for this campaign.

Using a straight forward field measurement approach methodology, the test facilities were set up in the measurement campaign setting. This was created to produce the necessary research data for use in additional analysis and study. The measurement campaign was conducted in the Nigerian Plateau State metropolis of Jos and its surroundings. Two major routes, A and B and a total of 96 measuring locations were established, spanning both the wet and dry seasons. On each route, 24 measuring points were permitted each season (i.e., route A subdivided into A1, A2 and route B into B1, B2; A1, B1 represent wet reason in different routes while A2, B2 represent dry season). The Deviser E8000A spectrum analyzer measured the strength of the received signal (dBm – decibel milliwatts). For the adoption of the specified ITU norms, the ITU's recommendations for field measurement, necessary equipment and settings were followed (Igbonoba and Omoifo, 2021). This was done to make sure that field measurements made in broadcasting using a spectrum analyzer would be highly stable and relative precise. The measurement tool for the field test system was the test equipment, which was transported in a van to the test locations within the selected zones.

The Integrated Television Services (ITS) signal was used for the measurement campaign. The network (ITS), which utilizes a frequency of 522 MHz assigned by the National Broadcasting Commission (NBC) of Nigeria, was the only DVB-T2 network provider in Plateau State at the time of this research. The equipment utilized for data gathering is listed in Table 2 along with their intended uses. Table 3 displays the ITS transmitter's operational network characteristics.

Table 2 Instrument and their uses during this research

S/N	Instrument	Uses
1	spectrum analyzer (E8000A series)	To measure RSS
2	Setup box / Decoder	To receive the DTTB signal
3	Receiving antenna	To receiving DVB-T2signals from the transmitting antenna
4	TV monitor	To establish TV signal on location
5	GPS enable smart phone	To measure the locations Longitude and latitude, and the elevation above sea level. And to monitor the line of sight from

		the base station.
7	Computer laptop	For storing measured data
8	Coaxial cable	To connect the antenna to the spectrum analyzer
9	Generating set	Generate power used in powering the equipment in the locations

Table 3 Transmission Characteristics of experimental station

S/N	Parameters	Characteristics
1	Base station geographic coordinate	Latitude: 9.89^0, Longitude 8.87^o
2	Base station elevation	530m
3	Base station carrier frequency	522MHz
4	Transmitter	2.5Kw
6	Effective Isotropic Radiated Power (EIRP)	62.14dBm
7	Height of transmitting mast(M)	107M
8	Transmitting Antenna gain(dB)	15dBi
9	Height of receiving antenna	10M
10	Antenna Pattern	Horizontal - Omnidirectional

Study area

The trial campaign was conducted in Jos, Plateau State, Nigeria. Geographically, the city is located at 09° 55' 00''N and 08° 53' 25''E and is 1,220 metres above sea level. The city of Jos is located in the rocky, hilly Guinea Savanna agro-ecological Zones of Nigeria's central belt. The Google map of Jos and its surroundings is displayed in Figure 1.

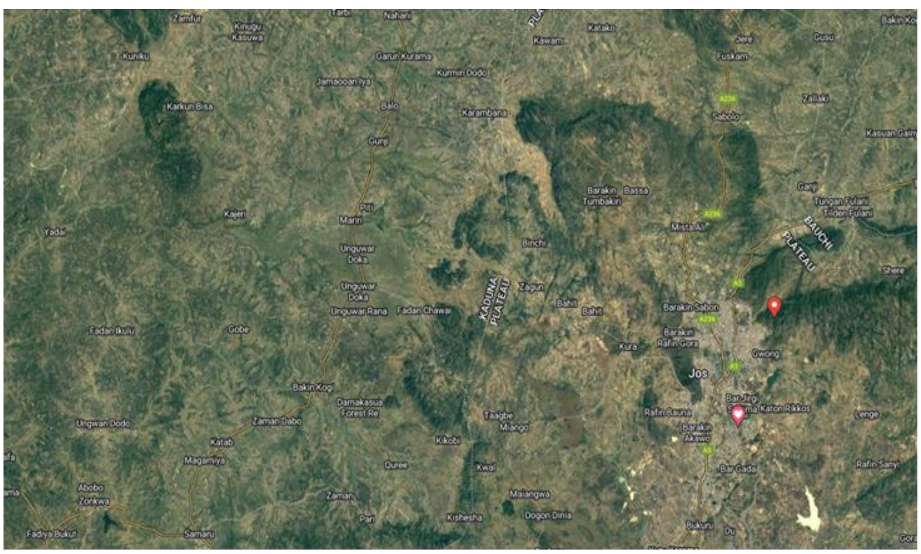

Figure 1 Google Map of Jos City

Experimental set-up

The E8000 series spectrum analyzer and DVB-T2 receiver with cable system were attached to the signal receiving antenna as indicated in figures 2 and 3. The received signal strength (RSS) was thereafter measured and recorded at the appropriate measuring sites in the months of July/August and November/December of 2021 using a spectrum analyzer from the E8000 series.

Figure 2 Field Connection of Receiving Antenna

Figure 3 Connection of E8000 A series Spectrum Analyzer to the Receiving Antenna.

Data presentation

The data from the field measurement at various transmitter distances is shown in Tables 4 and 5, together with the location coordinates and the observed variable value of the received signal strength over 96 locations in both the wet and dry seasons.

Table 4 RSS Data of DVB-T2 Signal along Route A_1, A_2.

S/N	Location	Coordinate (Latitude/ Longitude)	Log Distance from Tx	RSS, A1 (dBm)	RSS, A2 (dBm)
1	Tudun Wada Urban	Lat:9.90, Log:8.88	3.46	-41.6	-36.4
2	Tudun Wada Rural	Lat:9.87, Log:8.88	3.52	-41.7	-36.9
3	Airforce Military Sch.	Lat:9.87, Log:8.89	4	-42.3	-37.4
4	State Low cost, Rantya	Lat:9.86, Log:8.86	6.17	-43	-38

5	NTA TVC, Rayfield	Lat:9.50, Log:8.53	6.73	-48.4	-42.7
6	NTA TVC, Rayfield	Lat:9.52, Log:8.54	6.76	-48.2	-43.6
7	Maiadiko	Lat:9.83, Log:8.89	8	-50	-44
8	Building Material	Lat:9.84, Log:8.86	7.67	-50.6	-44.8
9	Lamingo	Lat:9.90, Log:8.93	8	-50.8	-45.1
10	Kwang	Lat:9.85, Log:8.82	3		
11	State Low cost, Bukuru	Lat:9.83, Log:8.86	8.54	-51.4	-45.2
12	DU	Lat:9.52, Log:8.55	8.95	-53	-45.9
13	DU	Lat:9.50, Log:8.54	10.91	-53.2	-47.6
14	Mararaba Jumai	Lat:9.72, Log:8.86	10.93	-87.1	-85.2
15	Riyom Hq	Lat:9.66, Log:8.87	12.67	-54.4	-62
16	Riyom Market	Lat:9.62, Log:8.74	13.73	-54.5	-66
17	Heipeng Airport	Lat:9.66, Log:8.89	14.01	-65.1	-67.4
18	Barkin Ladi Urban	Lat:9.68, Log:8.88	14.4	-68.4	-65.9
19	Forest	Lat: 9.68, Log:8.79	15.87	-72.2	-67.7
20	Mangu Town	Lat: 9.69, Log:8.80	16.16	-72.7	-65.9
21	Mangu Gindri	Lat:9.67, Log:8.82	16.74	-72.6	-68.4
22	Butura Bokkos	Lat:9.42, Log:8.95	16.91	-72.7	-68.8
23	Bokkos Town	Lat:9.43, Log:8.89	17.9	-72.5	-67.8
24	Bokkos Mangar	Lat:9.38, Log:8.86	18.46	-73.2	-69.5

Table 5 RSS Data of DVB-T2 Signal along Route B_1, B_2.

S/N	Location	Coordinate (Latitude/ Longitude)	Log Distance from TX	RSS, B1 (dBm)	RSS, B2 (dBm)
1	Hill Station	Lat:9.54, Log:8.52	3.87	-42.2	-36.5
2	Police HQ, Gomwalk RD.	Lat:9.91, Log:8.88	4.7	-42.4	-36.7
3	T $ T Junction	Lat:9.90, Log:8.90	4.9	-42.5	-37
4	Tafawa Belewa RD.	Lat:9.92, Log:8.89	6.07	-42.8	-37.2
5	Tafawa Belewa RD.	Lat:9.92, Log8.88	6.24	-43	37.4
6	Polio Field	Lat:9.93, Log:8.87	6.53	-43.1	-37.6
7	Rukuba Road	Lat:9.95, Log:8.86	6.53	-48.7	-41.3
8	Agwan Rukuba	Lat:9.93, Log:8.91	7.19	-49.8	-42
9	UJ Senior Staff QTR.	Lat:9.95, Log:8.90	8.6	-52.7	46.5
10	Faringada	Lat:9.58, Log:8.89	8.89	-52.8	-46.7
11	Bauchi RD. Junction	Lat:9.95, Log:8.90	9.03	-53.2	-46.5
12	UJ Naraguta Hostel	Lat:9.96, Log:8.89	9.26	-53.6	-47
13	Naraguta Village, Bauchi RD.	Lat:9.99, Log:8.90	10.03	-54.4	-48
14	Army Engineers, Zaira RD.	Lat:9.97, Log:8.85	10.56	-54.5	-49.1
15	Zarazon Health Care	Lat:9.98, Log:8.87	11.08	-56.8	-51.8
16	Central Market	Lat:9.99, Log:8.85	11.41	-59.4	-55.2
17	LEA School	Lat:9.96, Log:8.88	11.61	-60.3	-54.1
18	Rukuba Barrack	Lat:9.96, Log:8.85	12.62	-65.1	-60.8
19	Bassa Hq	Lat:9.95, Log:8.87	13.05	-68.8	-62.8
20	NNPC Depot	Lat:9.92, Log:8.88	13.44	-71.5	-66.1
21	Angware	Lat:9.93, Log:8.85	14.22	-71.7	-69.1
22	Riyom Manchok Axis	Lat:9.94, Log:8.86	15.58	-72	-69.2
23	Jengre	Lat:9.95, Log:8.87	16.64	-72.3	-69.4
24	Pamayaji	Lat:9.94, Log:8.86	16.77	-72.4	-69.7

3. RESULT AND DISCUSSIONS

The figure 4 and 5 present the graphical illustration of the propagation curve signal strength plotted from data presented in Table 4 and 5. The signal propagation curves for routes A and B during the dry and wet seasons are shown in Figures 4 and 5. The RSS data collected in the field suggests that there is an undulation in the time between the wet and dry seasons. Yet, it does not change in the opposite direction as the inverse square rule would predict. This was caused by the unusual topography and weather along the courses. The path-loss increases as the distance grows from the broadcasting stations to the receiving stations.

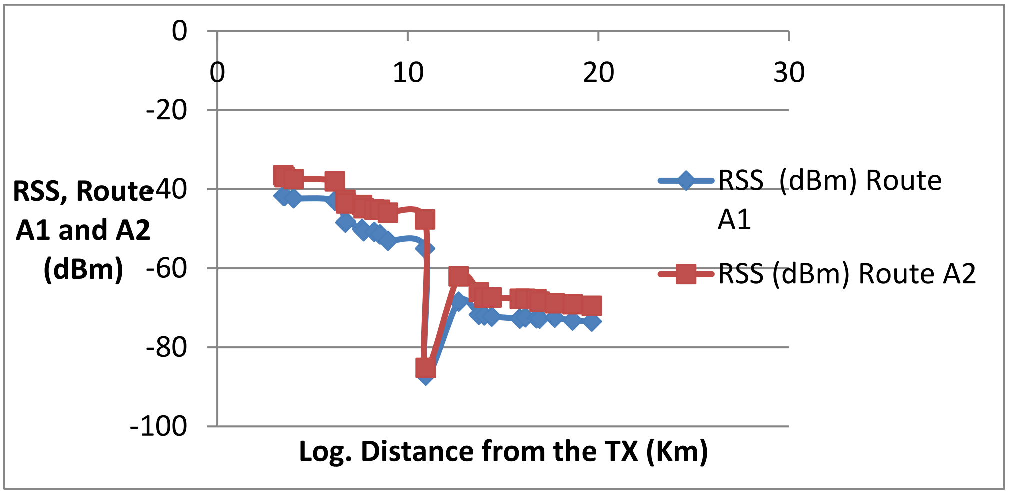

Figure 4 Propagation Curve of Signal Strength with Log. of Distance of Route A.

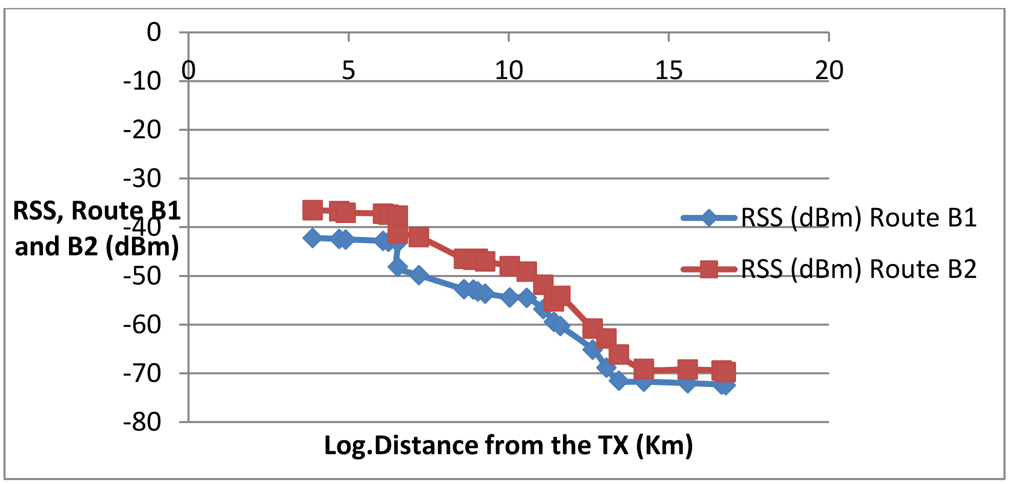

Figure 5 Propagation Curve of Signal Strength with Log. of Distance of Route B.

The typical finding regarding the effect of LOS distance on RSS in routes A1 and A2 (during the wet and dry seasons) is that RSS decreases to approximately -87.1 dBm and -85.2 dbm of its average initial base station value of (-41.6 db and -36.4 db) at approximately 12.38 Km from the base station, as shown in Figure 4. Figure 5 showed a similar change, with the RSS dripping from -42.2 dBm and -36.5 dBm to -54.4 dBm and -48 dBm, respectively, at a distance of around 10.07 kilometers from the base station. According to the analysis in Figure 4, the signal strength drops to just under half of what it was initially, however in Figure 5, the decrease was not quite as great. Moreover, the distance is known as the Average Half Decay (AHD) in cases where the reduction is up to half of its starting value.

4. CONCLUSION

Using the output of the RSS field measurement parameter, this work has produced a clearly defined signal propagation curve for digital television broadcasting in Nigeria. As shown in Figure 4, the typical observation on the effect of LOS distance on RSS in routes A1 and A2 (during the wet and dry seasons) suggests that RSS drops to about -87.1 dBm and -85.2 dBm of its average initial base station value of (-41.6 dBm and -36.4 dBm) at about 12.38 Km from the base station. Figure 5 showed a similar change, with the RSS dripping from -42.2 dBm and -36.5 dBm to -54.4 dBm and -48 dBm, respectively, at a distance of around 10.07 kilometers from the base station. According to the analysis in Figure 4, route A produced an average half decay (AHD) with a signal strength decrease that was only slightly greater than half of its initial value in contrast to Figure 5, where the decrease was not quite as great as its initial value. The results of this study will help radio scientists and engineers better understand radio wave propagation, channel estimation and equipment design on the UHF band. It will further help them understand how to predict the power received or lost at a specific distance from the transmitter, which is helpful in path loss calculation and modeling. This study has supplied broadcast engineers with the proven signal strength propagation curve they require for effective digital television (DTV) planning and deployment in Nigeria.

Authors' contribution

Dr EEC Igbonoba: The report of the research work was done by the first author in addition to the supervision of the field measurement campaign.

Dr AT Bankole: The second author contributed immensely in carrying out the field measurement campaign.

Acknowledgment

No acknowledgment

Ethical issues

Not applicable.

Informed consent

Not applicable.

Funding

This study has not received any external funding.

Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Ajayi GO, Owolabi IE. Coverage areas of the 10 kw, 702 kHz medium wave transmitter at Minna and feasibility studies for full Radio coverage of Niger State. Technical report of the electrical communication consultancy unit (ECCU), department of electrical and electronics engineering, University of Ife, Nigeria 1997; 1-3.
2. Ajewole MO, Akinbolati A, Adediji AT, Ojo JS. Precipitation effect on the coverage areas of terrestrial UHF television stations in Ondo State, Nigeria. Int J Eng Technol 2014; 4(9): 524- 35.
3. Ajewole MO, Oyedum OD, Adediji AT, Moses AS, Eichie JO. Spatial variability of VHF/UHF electric field strength in Niger State, Nigeria. Int J Digit Inf Wirel Commun 2013; 3 (3):26-30.
4. Akinbolati A, Ajewole MO, Adediji AT, Ojo JS. Determination and classification of coverage areas of terrestrial UHF television transmitters in Ondo State, Nigeria. Int Org Sci Res J Appl Phy 2015; 7(4):16-26.
5. Akinbolati A, Akinsanmi O, Ekundayo KR. Signal strength variation and propagation profiles of UHF radio wave channel in Ondo State, Nigeria. Int J Wirel Microw Technol 2016; 6(4):12-27.
6. Akinbolati A, Joseph E, Okpala C. Propagation curves and pathloss evaluation for UHF wave (channel 22, 479.25 MHz) within Katsina metropolis. Fudma J Sci 2017; 1:189-96.
7. Akinbolati A, Olanegan OO, Adetunji AA. Mathematical modeling of a UHF signal's propagation curve. Am J Eng Res 2018; 7:227-35.
8. Ayekomilogbon OT, Famoriji JO, Olasoji YO. Evaluation and modeling of UHF radio wave propagation in a forested environment. Int J Eng Innov Technol 2013; 2(12):101- 06.

9. Ayeni AA, Faruk N, Surajudeen-Bakinde NT, Okanlawon RA, Adediran YA. Spatial utilization efficiency metric for spectrum sharing system. Int J Digit Inf Wirel Commun 2015; 5(1):44-51.
10. Bothias L. Radio wave propagation. McGraw-Hill Inc. New York St. Louis and Francisca Montreal Toronto 1987.
11. CCIR report 239-6. Propagation statistics required for broadcasting service using the frequency range 30-1000MHz. Recommendation and report of the ITU-R, Geneva, In Hall M (Ed); Ibid 1986; 256.
12. Collin RE. Antennas and radio wave propagation. McGraw Hill Inc. New Delhi 1985; 401-09.
13. Goldsmith A. Wireless communications. Cambridge university press 2005.
14. Houssaini DE, Khriji S, Besbes K, Kanoun O. Performance analysis of received signal strength and link quality in wireless sensor networks. 15th International multi-conference on systems, signals and devices (SSD) 2018; 173-8. doi: 10.1109/SSD.2018.8570634
15. Igbonoba EEC, Omoifo O. Determination of DVB-T2 signal quality in Nigeria: A case study of Jos, Plateau State, Nigeria. Niger J Technol 2021; 40:81–8.
16. ITU-R. Recommendation on VHF/UHF propagation curves for the frequency range 30-1000MHz 1995; 370-7. www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.370-7- 199510
17. Kennedy G, Bernard D. Electronic communication system. McGraw-Hill/Macmillan, Singapore 1992; 80-5.
18. Luo C, Casaseca-de-la-Higuera P, McClean S, Parr G, Ren P. Characterization of received signal strength perturbations using Allan Variance. IEEE transactions on aerospace and electronic systems 2018; 54:873-89.
19. Nisirat MA, Ismail M, Nissirat L, Al-Khawaldeh SA. Terrain roughness correction factor for Hata path loss model at 900MHz. Prog Electromagn Res C 2011; 22:11-22.
20. Nkordeh N, Idachaba F, Bob-Manuel I, Oni O. Received signal strength measurement: Suboptimal handing-over. Proc World Congr Eng, London, UK 2016; I.
21. Pahlavan K, Levesque A. Wireless information networks. Ser. Wiley series in telecommunications and signal processing, Wiley 2005.
22. Xi W, Han J, Li K, Jing Z, Ding H. Big data: Principles and paradigms-location inferring in internet of things and big data 2016. doi: 10.1016/B978-0-12-805394-2.00013-1
23. Zeinab T, Hamide K, Mesound B, Mehri M, Javad AS. Received signal strength estimation in Vehicle-to-Vehicle communications using neural networks. Int J Digit Inf Wirel Commun 2013; 3(3):26-30.
24. Zekavat R, Buehrer R. Handbook of position location: Theory, practice and advances. Ser. IEEE series on digital and mobile communication, John Wiley and Sons 2011.