

## Digital terrestrial television in Nigeria: A technical review of path loss modeling and optimization techniques

Abolaji Okikiade Ilori<sup>1</sup>, Kamoli Akinwale Amusa<sup>2</sup>, Tolulope Christianah Erinosh<sup>2</sup>

<sup>1</sup>Department of Electrical and Biomedical Engineering, Faculty of Engineering and Technology, First Technical University, Ibadan, Nigeria

<sup>2</sup>Department of Electrical and Electronic Engineering, Federal University of Agriculture, Abeokuta, Nigeria

### Article Info

#### Article history:

Received Jun 8, 2022

Revised Aug 11, 2022

Accepted Aug 28, 2022

#### Keywords:

Communication

Digital terrestrial broadcasting

Modeling

Optimization

Path loss

### ABSTRACT

The switch from analog to digital terrestrial broadcasting (DTTV) has resulted in a substantial shift in the contemporary television broadcasting environment, introducing a new means of transmitting content, as well as a new and upgraded process that will improve consumer satisfaction by ensuring greater reception. Despite the deadline, only a small percentage of terrestrial television stations in Nigeria have been digitalized. This work takes a critical review of various aspects of DTTV implementation, ranging from evolution to path loss estimation, prospects and challenges associated with the switch-over on the very high frequency (VHF) communication links as well as various optimization techniques that are adopted for DTTV in Nigeria and sub-Saharan Africa. Findings show that the prospects are bright and numerous benefits are accruable if the government of Nigeria can solve the problems facing its full migration. Furthermore, investigations into the path-loss of DTTV in the ultra-high frequency (UHF) communication links have enjoyed scanty attention, therefore, careful examination and suitable path-loss model development in this frequency regime for television (TV) services across various ecological and vegetation zones should be considered as it will aid the full deployment of DTTV in Nigeria.

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### Corresponding Author:

Abolaji Okikiade Ilori

Department of Electrical and Biomedical Engineering, Faculty of Engineering and Technology,

First Technical University

Ibadan, Oyo State, Nigeria

Email: [abolaji.ilori@tech-u.edu.ng](mailto:abolaji.ilori@tech-u.edu.ng)

## 1. INTRODUCTION

Digital terrestrial television (DTTV) encompasses all technical services employed in all-digital terrestrial sound and television broadcasting applications [1]. These are technological advancements that have resulted in terrestrial television. The broadcaster does not need to have a satellite link to the end-user for DTTV to work [2]. Some of the most prominent aspects of DTTV include the usage of coaxial cable-based circuits to route the network and the television receiver as well as fiber optic and/or microwave linkages between the studio and the broadcast site, or between this site and the receiving local community networks are some of the most common aspects of DTTV. When compared to analog television, this new platform gives a better picture and sound quality with less interference. As a result of the increased number of channels available, viewers have more options for programming, which may be accessed via personal computers and split-screen formats, allowing viewers to surf the web while watching television (TV) [2]. For a long time, terrestrial television broadcasting relied on analog transmission and reception technology until the International Telecommunications Union (ITU) suggested digital terrestrial television (DTT) technology.

This is made possible via the release of the upper ultra high frequency (UHF) for other services while yet ensuring access to high-quality TV services, in an attempt to make the UHF band more useful [3].

According to Allan and Robert [4], efforts must be made to ensure the development of DTTV for increased societal benefits. A recent European Union (EU) initiative has reaffirmed the significance of DTTV with its new interactive digital services, as well as the need for the introduction of policies that remove barriers to DTTV. When the policies are in place, they will encourage openness, interoperability, and freedom to make different choices by both operators and subscribers [5]. Due to a higher penetration rate enjoyed by analog TV over either personal computers or mobile communication devices, the switchover cannot be sporadic but rather a gradual process. This is apparent from the fact that television service represents a reliable, viable platform and a key 'customer friendly' point of access to a wide range of information services [4].

The benefits of digitization to producers and network owners are enormous when DTTV is adopted. Of significance among those gains accruable from the adoption of DTTV are improved spectrum use and efficiency through a significant increase in the number of channels available for signal transmission, which translates to enhanced capacity of the network. In addition, the superior quality of audio and image resolutions, consistent reception with an increase in distance, reduced transmission cost as well as energy consumption [4]. Many of these advantages are already been experienced to a reasonable extent with the scaled implementation of DTTV phases, which will subsequently be amplified once the full computerization of the process of TV production and storage is implemented. End-user acceptance of DTTV, on the other hand, has not been commensurate with that of other digital devices and services, despite the above-mentioned benefits of DTTV and other significant extended gains in an all-digital environment (quality, choice, competition, and progress). Some factors are working against DTV adoption, which include the already established legacy analog transmission services, uncertainties beclouding the deployment of digital TV services in terms of potential market distortions, and market failures among others. In contrast to the present widely deployed analog TV technology, DTTV uses digital encoding along with other digital signal processing techniques in the transmission of television signals. Globally, a significant leap in television technology occurred following the introduction of color television in 1950 [6]. The impetus is further aided by the General Instrument Corporation (GIC) which proposed DTTV in 1990 [7]. ITU agreement on digitization of 2006 resulted in a worldwide agreement on the migration to digital terrestrial television from its analog form.

In wireless communications generally, precise path loss estimation is crucial [7]. The troposphere's terrain and atmospheric conditions are critical to terrestrial path losses [8]–[10]. Radio scientists and engineers utilize path loss estimates to plan radio wave propagation and develop equipment required for satisfactory performance. With the continued rise of wireless communication applications, it becomes more important to determine the best locations for base stations as well as estimate the coverage regions [11]. The task is easily accomplished via a well-calculated and modeled path loss [12]. The signal sent in the UHF band is carried by a space wave that travels in a straight line through the troposphere from the transmitter to the receiver. Therefore, the signal received at a distance away from the transmitter could be the directly transmitted wave, reflected wave, diffracted wave, or some combinations of the three [8], [13] which is largely due to the impacts of the propagation path's topography profile as well as atmospheric components [7], [14]. In radio communication system management and planning, the propagation pattern of radio signals from the radio transmitter to the radio receivers, which is regulated by the regions of the troposphere through which they pass, is extremely significant. Changes in environmental characteristics such as air temperature, pressure, and humidity, among others, have an impact on radio signal propagation in the troposphere, likewise, precipitation which significantly results in the attenuation of signals in the UHF band [15]. Refractivity changes are frequently caused by changes in meteorological factors [16]. Changes in the refractive index of the troposphere determine the propagation path profile of radio waves [17]. Rapid changes in the propagation direction of a radio wave traversing the troposphere might cause signal attenuation due to these shifts. Hence, optimal planning of radio links, power budgets, and coverage areas in that frequency regime require radio refractivity studies as communication links in any radio communication system are constantly exposed to weather variability, which could increase the severe degradation in the system performance [18], [19]. Furthermore, it is also vital to investigate those elements impacting radio connection quality in these radio communication systems so that appropriate steps and adaptation choices can be taken to mitigate and regulate the attendant consequences.

In light of the foregoing, it is important to examine the DTTV communication network (transmission and reception) over a communication link (UHF and VHF) to ensure that Nigerians receive a satisfactory quality of service (QoS) when eventually deployed. The results of this work will be helpful for the precise prediction of path losses and the design of power budgets of links over digital terrestrial television and similar wireless channels on the UHF band. They will also aid radio network engineers in achieving

efficient radio coverage estimation, choosing the best location for base stations, allocating the appropriate frequencies, choosing the best antenna, and performing interference feasibility studies.

## 2. DIGITAL SWITCH-OVER IN SUB-SAHARA AFRICA

The Western Nigeria television service (WNTS), received Africa's maiden terrestrial television broadcast signals on Saturday, October 31, 1959, after the establishment of the broadcasting corporation, Western Nigeria television network (WNTN) by the then premier of the western region; late Awolowo [10]. Nigeria, being among the first set of African countries to launch television services transmission through the Nigerian Television Authority (NTA), has over 96 stations spread across the country. The NTA claims to be Africa's largest terrestrial television network [20].

Nigeria's transition from analog to digital broadcasting is part of a global program led by the ITU in response to the 2006 radiocommunication conference (RRC-06). The Geneva 2006 agreement specified June 17, 2015, and June 17, 2020, as the deadlines for countries to transit to digital services using existing analog television transmission frequencies, without having to protect adjacent countries' analog services from interference. These deadlines are usually viewed as internationally imposed analog switch-off dates, at least along national boundaries. In line with the Geneva 2006 agreement, the government of the Federal Republic of Nigeria, approved June 17, 2012, as the switchover deadline date and established a Presidential Advisory Committee (PAC) on the transition from analog to digital broadcasting in Nigeria on October 13, 2008, to anchor and fast-track the transition processes. The PAC's mandate included, among other things, the provision of guidance/advice on the digital transition's implementation strategy, which was the theme of a retreat held at Enugu to that effect [21]. However, due to the country's political difficulties, the Nigerian government was unable to execute the PAC report's recommendations until 2012.

Findings from literature reveal that different approaches that have been adopted for digital switchover depend on local requirements and available resources, resulting in diverse experiences between nations [22]. In Africa and parts of Asia, for example, pay-DTT platforms have emerged as a key player in the analog to the digital transition process, whereas public service broadcasters, most notably in Europe, have driven DTT platform roll-out based on an extensive free-to-air television service offering. Many countries are making the switchover from analog to digital terrestrial television via different platforms. After decades of service, the digital television platform is replacing the analog one that is being phased out at a faster rate. As more nations adopt digital television technology, analog television is becoming obsolete as its maintenance becomes increasingly difficult and expensive. The enormous benefits of digital switchover in terms of increased spectrum use efficiency and the introduction of more new services for the viewers' enjoyment, contribute to DTTV's long-term viability as a viable commercial platform.

There is no gain in saying that the switch to digital TV is not an easy feat. First and foremost, digital frequency plans must be implemented and coordinated with neighboring nations. Second, viewers will need to upgrade their television receiving equipment, and many transmission sites will need to be modified in a short time. Depending on the size of the country and the number of viewers affected by the analog switch-off, the process can be both capital and labor-intensive. The success of the switchover process is heavily dependent on the level of synergy between all active stakeholders in the broadcasting industry (government regulators, and broadcasting station operators) [23]. However, the advantages accruable from the efficient spectrum utilization when DTV is deployed invest a worthwhile. Depending on the technology used and the required QoS, a dedicated frequency channel meant to broadcast one analog TV service can now accommodate anywhere from four to twenty-two digital television services. As a result, viewers will have access to many additional and new television services that were previously unavailable via analog television. Due to the unavoidable scarcity of frequency spectrum, efficient use of those that are available means that some capacity has been made available for new sorts of services via DTV services. In Africa and Asia, the launch of mobile telecom services using frequencies in the 700 MHz and 800 MHz (694 to 862 MHz) bands are considered part of the digital dividend [22].

Without a doubt, digital television will be the only method to ensure the future of terrestrial television. Historically, free television services have relied heavily on the terrestrial platform. Broadcasters, both national and local, rely on the terrestrial platform to reach their target audiences. Despite the existence of numerous other television delivery systems such as cable, satellite, and internet protocol television (IPTV), the terrestrial platform remains the cornerstone in the transmission of television services. It is one of the few television services that allow viewers to see local programming. Depending on the service package selected, services are often supplied for free or for a little membership cost. According to Maduka [23], digital broadcasting has numerous advantages over analog broadcasting and that program presentation will have been substantially improved by the time analog broadcasting is completely phased out. This assertion can be justified in terms of broadcast signal clarity and quality (both received and sent), and spectrum efficiency. Furthermore, the switch from analog to digital will open up a world of possibilities for the broadcasting

industry because a large quantity of spectrum will be available in each country for radio and television transmissions, thus more frequencies will be available to TV stations around the country [23]. It will also enable the industry to experiment with interactive broadcasting, as television sets will be capable of far more than just receiving signals. In actuality, audio and video output from digital television transmissions will be clearer and more powerful [23].

Under digital technology, television sets would be able to execute the functions of computers and telephone mobile terminals. This means that television sets will be able to connect to the internet and also be able to save data from audio and video signals received. In essence, the broadcast media's fleeting nature would have been lessened, if not eliminated as the value of broadcast media would begin to rise. Furthermore, digital television can broadcast several programs over a single transmission channel, unlike traditional analog television with the additional capability of transmitting visuals with resolutions ranging from 720 to 1080 horizontal lines, as opposed to the 480 lines of analog television.

Figure 1 shows a typical analog and digital broadcasting view and in the past two decades, several types of digital terrestrial broadcasting systems have been developed. Although they are aimed at different services, they have several technical characteristics. Typically, multi-carrier technology is used, and psycho-acoustic or psycho-visual effects are used to reduce the amount of data that must be communicated significantly to keep the audio and video signal's qualities within thresholds. Furthermore, advanced error protection measures are used to secure the transmission from disruption [24]. The signal is acquired using either a computerized set-top box (STB) or a coordinated tuner provided with TV sets that interpret the signal received using a standard TV reception device. In the case of digital terrestrial broadcasting, basic requirements are [25]: i) Spectrum requirements, including spectrum utilization mode (multi-frequency network or single-frequency network), target frequency bands (III-IV bands), and the amount of spectrum required to establish DTT broadcast networks that meet the first two requirements and ii) Minimum technical specifications for the receiver of the transmitted DTT broadcast programs such as sensitivity, selectivity, and operating frequency range, connectivity characteristics, possible power supply to the active antenna via the feeder, middleware for adopted hybrid broadcast broadband system, and conditional access capabilities.

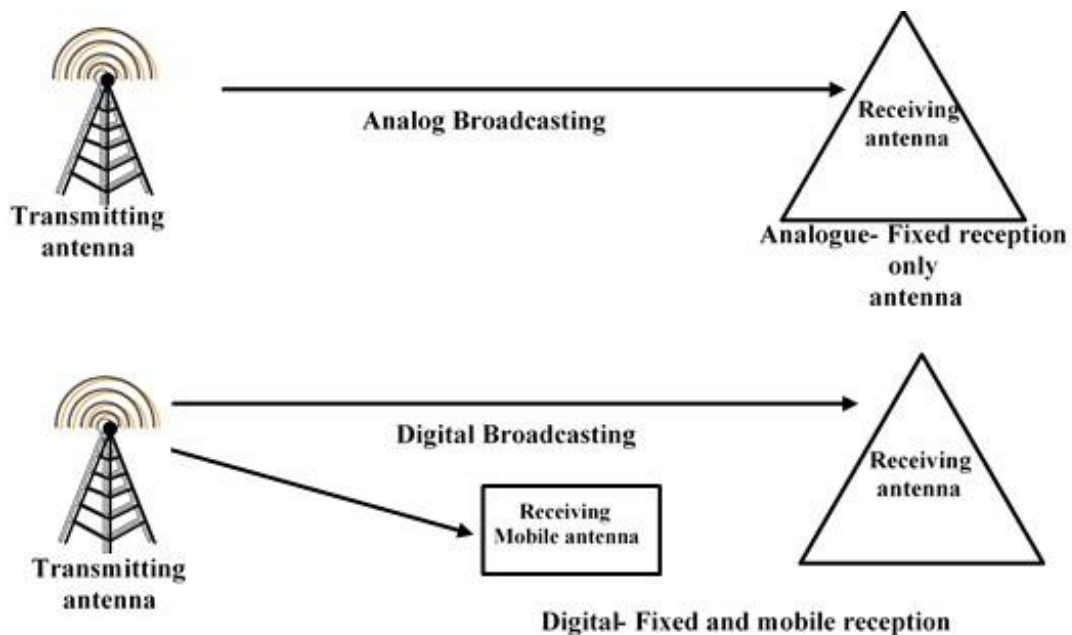


Figure 1. Overview of different broadcasting scenarios

### 3. DTTV PATH LOSS ESTIMATION

After being launched into space through transmit antennas, television signals, which are carried by electromagnetic waves are picked up by receiving antennas. There is a disparity between the intensities of the transmitted and received signals. The difference in the intensities of the transmitted and received signals is regarded as path loss [25]. For a long time, path loss has been a key concern in communication systems, especially in wireless communications, making estimation techniques for path loss an ever-increasing task,

and to replace outdated methodologies, new prediction models for increased frequencies have been developed. As a result, a model that is appropriate for a variety of applications and contexts must be identified [26]–[28]. In practice, path loss at a destination is determined using a variety of models [26], [29], [30], depending on several factors out which the conditions of terrain between transmit and receive stations are paramount. The quality of the terrestrial television signal received by viewers is of great interest to broadcasting industry stakeholders, which is influenced by noise of various forms [31] and external factors such as atmospheric parameters that cause signal loss as well as alteration of the radio signal's horizon [32]–[34]. Path loss prediction is an important aspect of communication system design, especially for wireless systems and because the environment is always changing, it is crucial in radio and television broadcast systems. Optimization of the coverage area, transmitter power, and the avoidance of other radio transmitters' signal interference concerns are all aided by an accurate and reliable prediction approach [7]. The accuracy of a given path loss precision model in a specific environment is determined by the fit between the parameters required by the model and those available for the area in question [35].

Meteorological variables such as air temperature, atmospheric pressure, and relative humidity, have a significant impact on the propagation of electromagnetic waves in the troposphere, although other factors like the composition of the troposphere also have a far-reaching effect on tropospheric radio wave propagation. However, it is pertinent to note that changes in those aforementioned meteorological variables conditioned the troposphere's components, which in turn influenced the propagation of electromagnetic waves in the troposphere [36]–[38]. In particular, the intensity of radio signals is inversely proportional to the air temperature, atmospheric pressure, as well as relative humidity [38], [39]. The intensity of a transmitted radio signal, for example, is inversely related to the relative humidity at a given air temperature and atmospheric pressure. The same holds for the air temperature at a specified pressure and relative humidity levels. Furthermore, the strength or quality of the received signal is affected by the geographical location as well as the topography of the DTTV signal receiving antenna, it has been found that the higher the altitude of the receiver antenna, the better the received signal strength [3], [8], [40].

The two cities chosen in Nigeria as pilots for fully digitalized TV broadcasting are Abuja and Jos while other areas are to follow later in the process of digital transition [31]. Since the received signal strength (RSS) is dependent on factors like atmospheric conditions, which vary across Nigeria, it is necessary to model atmospheric parameters with the RSS in these cities, in order to ensure satisfactory signal reception when DTTV services are eventually deployed. Outcomes of investigation on profiles of DTTV services deployment in Abuja and Jos revealed that atmospheric factors and noise temperature have a significant impact on the RSS [31]. In addition to the fact that digitalized TV signals are strengthened and more robust in terms of signal interference and attenuation than analog TV signals, greater RSS levels are feasible during the rainy period than dry season due to the presence of less dust (which attenuates transmitted signals) in the sky [31].

The relationship between the distance between the transmitting station and RSS was investigated in [41] using Ibadan, the South-Western part of Nigeria as a case study. It was found that the RSS level decreases with an increase in the separation between the transmitting and receiving stations. In addition, the signal-to-noise ratio (SNR), modulation error rate (MER), and bit error rate (BER) of the signal within a 40 kilometer radius of Ibadan were all found to be within the ITU's stable signal standard. With these findings, it can be safely concluded that a complete conversion from analog to digital transmission in Nigeria will not pose significant challenges as envisaged, since the existing TV operators' operating parameters meet the ITU as well as European telecommunication system industry (ETSI) requirements that are adopted in Nigeria. In a related exercise, findings from statistical path loss models derived from experimental data collected in Port Harcourt, South-South region of Nigeria were presented in [42], where it was established that the distance between the transmitting station and RSS has an inverse relationship. In another word, the lower the RSS value, the longer the distance. Aside from that, it has been established that the height of the receiver antenna is directly proportional to the RSS level, because the received power level increases as the receiver antenna height rise [3], [43].

Results of an experimental investigation into causes of DTTV signal attenuation in Port Harcourt, Nigeria, were presented in [44]. It was found that there exists a direct relationship between the transmitter-receiver (T-R) distance and signal attenuation. When the receiver is located outside the transmitter's coverage region, the signal either fades out or becomes too weak to be detected by the receiver. Precipitation (rain, moist air) and atmospheric meteorological conditions were equally submitted as contributing factors to the attenuation of the DTTV broadcast signal in Port Harcourt, Nigeria. Path losses arising from three DTT base station (DTTBS) was evaluated via the use of the Okumura-Hata model in [9]. Those DTTBS are located in Lagos, Kaduna, and Katsina cities, respectively. It was found that irrespective of the route and season of the year, values of estimated path loss increase as the line-of-sight separation between DTTBS and receiving point increases. Furthermore, it was discovered that profiles of path loss on these routes exhibit a steady exponential pattern, suggesting the need for high-power repeater stations to guarantee wider coverage and

acceptable QoS. It was found that estimated path losses in urban areas were higher than those in sub-urban areas while estimated path losses during rainy seasons were larger in values than those during the dry season months. Specifically, Kaduna had the highest values of path loss, followed by Ikorodu-Lagos, while Katsina had the lowest. Going by these findings, it is suggested that DTTBS service providers on these channels should make conscious efforts to compensate for the unique losses in metropolitan areas, as well as during the rainy season, to maintain satisfactory QoS [9].

To overcome the effect of attenuation on the DTTV path, it was advocated in [45] that signal attenuation can be reduced through an increase in the received antenna height as well as an increase in transmit power. The use of higher antenna height leads to minimal signal attenuation that is traceable to multipath effects because of clearance above obstructions, resulting in lower path loss. The rainy season is usually characterized by a cloudy sky in addition to the occurrence of both gradual and spontaneous downpours, resulting in large path loss values than what obtain during the dry seasons. The consequence of these phenomena is that there is a likelihood of the DTTV signal being attenuated more during the wet season when compared to the dry season. Thus, the increased attenuation experienced by radio signals during the wet season can be attributed to the effects of climatic conditions and surface radio refractivity. To mitigate these effects, increased height of the receiving antenna along with high transmit power are usually adopted in practice. For, instance, subscribers in Akure, Western Nigeria, are advised to utilize a receiving antenna located at a height of 3 meters while DTTBS operators are encouraged to raise the output power of their transmitter during wet seasons to compensate for losses associated with the season.

The acceptable threshold for radio prediction value for TV signal is 10 dB with lower values indicating better performance [25]. Estimates of path loss obtained via the use of existing path-loss models returning values that are greater than 10 dB are considered inaccurate [25], going by the results of path loss estimated over DTTV channels within Abuja city in Nigeria. This observation is in agreement with intuition since applications of these models are functions of environmental conditions and terrain profiles of the space between transmit and receive antennas. This explains why the use of any of the existing models in an environment different from the one for which it was designed, often produces high prediction errors. Thus, the application of existing path loss models for wireless radio communications to DTTV channels has limitations in that they are designed for specific types of land terrain such as open areas, suburban areas, and urban areas [7], [46]. It is therefore critical to develop a suitable path-loss model for DTTV channels based on their unique environmental characteristics to achieve acceptable QoS and radio link predictability.

#### 4. PATH LOSS MODELLING

Path loss prediction models are very essential tools for radio coverage estimation, metrics for finding the location of the base station, allocation of frequency, antenna selection as well as the feasibility of the effect of interference during the planning and organization of radio network channel characteristics and signal attenuation prediction. As the distance between the mobile user and the serving base station increases, a more accurate and reliable path loss model to estimate the strength of the radio signal received becomes more important [47], [48]. It is also important to note that a very key advantage of using path loss models for planning and optimization of the radio network is that it saves costs and is time efficient [49], [50].

Path loss models are divided into two categories: fully empirical and deterministic models. Some models exhibit traits of both types and are so referred to as semi-empirical models [51]. Empirical models are based on data that are measured in the real world. These empirical models are basic but not very precise because only a few parameters are employed. In addition, they are easy in terms of implementation with higher computational efficiency in time and cost. However, they are deficient in effectively managing specific geographical propagation environments unlike deterministic models [52]–[54]. Empirical models for the macrocellular environment, such as the Hata, Okumura, and COST-231 Hata models, are noteworthy. The European Cooperation in Science and Technology (COST) has recommended the extension of COST-231 Hata model to higher frequencies. These models estimate the mean path loss based on a set of factors that include, but are not limited to, the transmitter and receiver antenna heights as well as the distance between them. While some of the required factors are propagation environment-specific, others are based on systematic interpretation of collected data from the service area. The majority of these models have been extensively tested for usage in diverse wireless communication links and networks [55], [56].

In Faruq *et al.* [57], the performance comparison of empirical, heuristics, and geospatial models for path-loss prediction in the VHF and UHF bands in urban contexts is carried out. Depending on the performance indicators used as a benchmark, all three strategies performed admirably for the task of path loss estimation. Empirical models utilized in the study returned the smallest standard deviation errors when compared to the two other techniques. It should be noted, however, that the application of the geospatial method required sample measurements before predictions could be made inside the neighborhoods, making

the method not to be self-servicing. The heuristic approaches (path loss models based on artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS), and Kriging techniques) can be used to create predictions based on the trained network, whereas empirical methods do not require training measurements. All that is required by the empirical models are propagation parameters. Consequently, empirical models remain the most straightforward and generally applicable approach for path loss estimation out of the three methods. In terms of prediction accuracy, heuristic approaches are the best. Oftentimes, a compromise between simplicity, the convenience of use, and accuracy are required. Nowadays, a combination of the two methods, usually heuristic and empirical, is used to improve the accuracy of path loss estimates and reduction in computational overhead [57].

A machine learning-based modeling mechanism for Air-to-Air (AA) path loss was proposed in [58]. Data generated using ray-tracing software for an urban AA scenario was subsequently divided into two, training and test sets, respectively, for algorithms implementation. Random forest and k-nearest-neighbors (k-NN), were the two machine learning techniques, used in the creation of the path loss model. The test data was utilized in assessing the accuracy of the proposed machine-learning-based models as well as a comparison of obtained path loss estimates with those from two selected empirical models. For such a complicated environment, it was shown that machine learning models provide a flexible technique based on the training data, with random forest having the best prediction performance. Furthermore, it was discovered that, among the five input features examined in the modeling of AA scenario route loss, path visibility is the most important, followed by propagation distance and elevation angle.

In a similar vein, the investigation reported in [59] is concerned with an improved ITU-R model for path loss prediction over the DTTV channel. It was revealed that the use of the ITU-R P.1812-4 recommended model for DTTV propagation path loss estimation along with field measured data and particle swarm optimization (PSO) technique led to improved accuracy. This is evident in the values of root mean square error (RMSE), grey relation grade, and mean absolute percentage error (GRC-MAPE). Based on findings in [59], it was submitted that the PSO technique can be used in any telecommunication system or measuring environment. Results of path loss estimation in the VHF band using the neuro-fuzzy (NF) model were presented in [60] where NTA Ilorin was used as the transmitting station in the study. Among other models, the NF model was found suitable for the prediction of the path-loss over the VHF band in Ilorin, Nigeria going by the relatively lowest values of RMSE it returns when compared with what obtains in other empirical models.

## 5. CONCLUSION

The full migration or deployment of DTTV in Nigeria, as seen above, has a lot of promise for the Nigerian broadcasting business and can improve economic, socio-economic, and technological development. DTTV provides greater services than analog broadcasting because of its upgraded features. Although there are various obstacles on the way to DTTV deployment and operation, the multiple benefits that are accountable for DTTV deployment are significant enough to justify the investment move. Concerning Nigeria's context, the government needs to provide an enabling environment for the smooth transition to flourish while TV broadcast service operators must put in place an adequate transition plan to avoid being left behind. Path loss estimation models over DTTV channels in the UHF bands are scanty in the literature, thus, there is a need for the development of a path loss model for DTTV communication channels that is suitable for deployment in various ecological and vegetation zones in Nigeria. This is considered relevant to faster transition and full deployment of DTTV services in Nigeria.

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## BIOGRAPHIES OF AUTHORS






**Abolaji Okikiade Ilori**     is currently a PhD student of Communication and Digital Signal (Electrical and Electronic Engineering) at Federal University of Agriculture, Abeokuta, Ogun State, Nigeria, he holds a Master's degree in Electrical and Electronic Engineering (Communication) from University of Lagos, Nigeria in 2014 and a B. Tech in Electrical and Electronic Engineering (Communication) from Ladoko Akintola University of Technology, Ogbomoso, Oyo State, Nigeria in 2008). His research interests are in Wireless Communication, Radio waves propagation, System Engineering and Renewable energy. He can be contacted at email: [bjtemilor@gmail.com](mailto:bjtemilor@gmail.com).



**Kamoli Akinwale Amusa**     received the B.Eng. degree in Electrical Engineering from the University of Ilorin, Ilorin, Nigeria, the M.Sc. degree in Electrical and Electronics Engineering from the University of Lagos, Akoka, Nigeria and the Ph.D. degree in Electrical and Electronics Engineering from the Federal University of Agriculture, Abeokuta, Nigeria. His major field of study is communications engineering and digital signal processing. He has published few papers on antennas and signal processing. His current research interests include electromagnetic fields, signal processing, antennas and radio-wave propagation. He teaches at Federal University of Agriculture, Abeokuta, Nigeria. He works at Federal University of Agriculture, Abeokuta, Nigeria. He can be contacted at email: [amusaka@funaab.edu.ng](mailto:amusaka@funaab.edu.ng).



**Tolulope Christiana Erinosh**    obtained B.Eng. and Msc. degrees in Electrical and Electronics Engineering from the Federal University of Agriculture, Abeokuta and University of Lagos, Akoka, Lagos, Nigeria respectively. She is currently undergoing her PhD. in Electrical and Electronics Engineering with bias in Telecommunication and Digital Signal Processing at the Federal University of Agriculture, Abeokuta, Nigeria. Her research areas of interest are: electromagnetic fields, Signal Processing, Radio Frequency Energy harvesting and Clean Energy. Currently, she teaches at Federal University of Agriculture, Abeokuta, Nigeria. She can be contacted at email: erinoshotc@funaab.edu.ng.