ADAPTATION OF EMPIRICAL ELECTRIC FIELD STRENGTH MODELS FOR TERRESTRIAL TELEVISION BROADCAST IN EKITI STATE, NIGERIA

BY

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ABSTRACT

This study investigates the coverage areas of VHF and UHF signals of two television stations in Ekiti State, Nigeria by quantitative measurement of the electric field strength. The signal levels of the Nigeria Television Authority (NTA), Ado Ekiti, Channel 5, (175.25 MHz) and Broadcasting Service of Ekiti State (BSES), Channel 41, (631.25 MHz) transmitters were measured radially along several routes with the transmitting stations at focus. Their corresponding distances from the transmitting stations and locations were also measured and recorded. These measurements were taken using Digital Signal Level Metre, GE-5499, having a signal level range of 30 dBμV – 120 dBμV, and Global Positioning System (GPS) 72 – Personal Navigator. From the data obtained, Surfer 13 software application was used to draw the contour maps of the signal levels around the transmitting stations. The results obtained show that the present configurations of the transmitters of the two television stations do not give an optimal coverage of the state. Only 64.89 % of the entire land mass of the state has television signal coverage. Consequently, some areas in the state are completely out of television signal coverage. So, there is need to have repeater stations at certain intervals to provide reception of television signals throughout the state. Furthermore, this research alsoadapted some field strength models that are best suitable for Ekiti State, Nigeria. The models are free space, Hata, ITU-R P.529-3 and ERC Report 68 models. The results obtained show that the generalised free space model gives more accurate prediction for the field strength of the two television stations in Ekiti State, with the correction factor of -37.84 and Root mean square error of 6.28 dBμV/m for VHF signal(NTA Ado Ekiti) and the correction factor of -25.48 and Root mean square error of 6.21dBμV/m for UHF signal(BSES, Ekiti).

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ABBREVIATIONS, GLOSSARIES AND SYMBOLS

AM = Amplitude Modulation

BSES = Broadcasting Service of Ekiti State

CDMA = Code Division Multiple Access

COST =Cooperate in Science and Technology

EM = Electromagnetic

ELF = Extra Low Frequency

ERC = European Radio Communication Committee

ERC = Effective Radiated Power

FM = Frequency Modulation

FUTA = Federal University of Technology Akure

GPS = Global Positioning System

GSM = Global System for Mobile Communication

HF = High Frequency

ITU = International Telecommunication Union

LTE = Long Term Evolution

LOS = Line of Sight

MF = Medium Frequency

MSE = Mean Square Error

NBC = Nigeria Broadcasting Commission

NFMC = National Frequency Management Council

OFDM = Orthogonal Frequency Division Multiplexing

SPM = Standard Propagation Model

SUI = Stanford University Interim

TV = Television

UHF = Ultra High Frequency

VHF = Very High Frequency

MHz = Megahertz

GHz = Gigahertz

kHz = Kilohertz

cm = Centimetre

km = Kilometre

Hz = Frequency

m = Metre

kW = Kilowatt

W = Watt

dB = Decibel

dBμV = Decibel micro voltt

V/m = Volt per metre

μV/m = Microvolt per metre

dBμV/m = Decibel microvolt per metre

° = Degree

% = Percentage

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Radio communications, like all other communications, rely on the atmosphere as the medium through which the signals travel from the transmitter to the receiver. As a result, the quality of the communications is dependent on the physical factors that influence the propagation of electromagnetic (EM) signals in this medium (Ajewole *et al.,* 2013). The quality and high capacity networks together with accurate estimation of coverage is extremely important. Therefore, accurate design coverage of modern cellular networks and signal strength measurements must be taken into consideration in order to provide an efficient and reliable coverage area (Mardeni and Kwan, 2010).

At broadcast frequencies in Very high frequency (VHF) and Ultra high frequency (UHF) bands (30 MHz- 3 GHz), propagation is usually by ground waves which consist of direct wave, ground reflected and surface wave. Therefore, in these frequency bands, electrical parameters of the ground, curvature of the earth surface, height of the antenna and weather conditions influence wave propagation. The degree to which these factors affect propagation depends primarily on the frequency of the wave and the polarisation (Hall, 1991).

The electrical field strength at a given distance from the transmitter is attenuated by these parameters, with the result that radio services in VHF and UHF bands are limited to distances close to the transmitter. Electric field strength curves or propagation curves are essential parameters neccessary for the planning of VHF and UHF transmission especially for the determination of the coverage areas and the field strength signal levels desired.

The field strength of an antenna's radiation at a given point in space, is equal to the amount of voltage induced in a wire antenna 1m long located at that given point (Kennedy and Bernard, 1992). This field strength is affected by a number of conditions such as time of day, atmospheric conditions, transmitter-receiver distance, transmitter power and others like, terrain effect, transmitting and receiving antenna heights, and the gain of the transmitting antenna (Bothias, 1987). The present trend in broadcasting is to use widespread broadcast transmitter of VHF or UHF range of frequencies to serve areas not far away from the transmitter (Barclay, 1991).

The coverage areas of broadcast stations is the distance away from the transmitter in which the electric field transmitted signal; voice (audio) and picture (video) for television and voice alone for radio can be received by the veiwer or listener with the aid of a receiving antenna. All stations have their own expected coverage areas and their signals should not interfere with others (BON, 2010).

The coverage areas of broadcast stations are usually classified into primary, secondary and fringe areas (Ajewole *et al.*, 2013). Apart from weather conditions; the size of each of these areas also depends on the transmitter power, the directivity of the aerial, the ground conductivity and the frequency of propagation. The coverage area decreases with increase in frequency and reduction in the ground conductivity (Moses *et al.*, 2013).

The primary coverage area is defined as a region about a transmitting station in which the signal strength is adequate to override ordinary interference in the locality at all times, and corresponds to the area in which the signal strength is at least 60 dBμV. The quality of service enjoyed in this area can be regarded as grade A1. The appropriate value of the signal strength for this quality of service is also dependent on the atmospheric conditions and man-made noise in the locality. The signal strength also depends on whether the locality is rural, industrial or urban.

The secondary coverage area is a region where the signal strength is often sufficient to be useful but is insufficient to overcome interference completely at all times. The service provided in this area may be adequate in rural areas where the noise level is low. The secondary coverage area corresponds to the area in which the signal strength is at least 30 dBμV but less than 60 dBμV. The quality of service enjoyed in this area can be regarded as Grade B1 (Moses *et al.*, 2013).

The fringe service area can be regarded as that in which the electric field strength can be useful for some periods, but its service can neither be guaranteed nor be protected against interference. This is an area in which the electric field strength is greater than 0 dBμV but less than 30 dBμV. Such an area may be said to enjoy Grade B2 service (Ajewole *et al.*, 2013).

1.2 Radio Propagation

Radio propagation is the behaviour of radio waves when they are transmitted, or propagated from one point on the earth or into various part of the atmosphere (Westman, 1968). As a form of electromagnetic radiation like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering (Demetrius and Kenneth, 1969). Radio signal propagation is affected by the daily changes of water vapor in the troposphere and ionisation in the upper atmosphere, due to sun. Understanding the effects of varying conditions on radio propagation has many practical applications, from choosing frequencies for international

shortwave broadcasters, to designing reliable mobile telephone systems, to radio navigation, to operation of radar systems.

Radio propagation is also affected by several other factors determined by its path from point to point. This path can be a direct line-of-sight path or an over-the-horizon path aided by refraction in the ionosphere, which is a region between approximately 60 and 600 km. Radio waves at different frequencies propagate in different ways. At extra low frequencies (ELF) and very low frequencies (VLF) the wavelength is very much larger than the separation between the earth's surface and the D layer of the ionosphere, so electromagnetic waves may propagate in this region as a waveguide. Indeed, for frequencies below 20 kHz, the wave propagates as a single waveguide mode with a horizontal magnetic field and vertical electric field (Hall and Barclay, 1989).

1.2.1 Modes of radio wave propagation

The way that radio signal propagate, or travel from the radio transmitter to the receiver is of great importance when planning a radio communication network. Signal at VHF and UHF signal bands can be propagated by a variety of modes, depending on the particular mode that is dominant at the time of reception, the distances covered by the VHF and UHF signals can extend to hundreds or thousands of miles. Below are some of the modes for VHF and UHF propagation; such as ground mode (for ground or surface waves), direct mode(for direct or line-of-sight waves), ionospheric mode (for sky waves). Others are tropospheric and sporadic-E-propagations (Freeman, 2007). Figure 1.1 shows the mode of radio wave propagation.

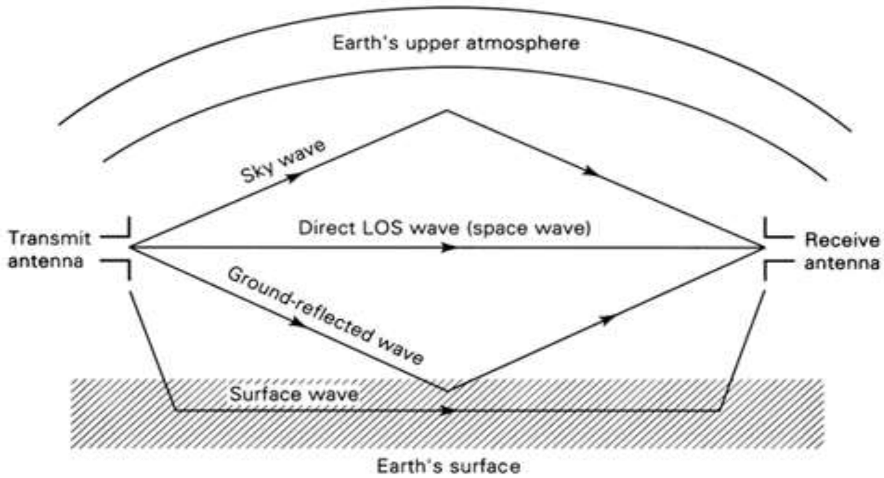


Figure 1.1: Mode of Radio Wave Propagation
Source: Freeman (2007)

1.2.2 Ground wave propagation

Ground wave propagation is a method of radio wave propagation that uses the area between the surface of the earth and the ionosphere for transmission. The ground wave can propagates a considerable distance over the earth’s surface particulaly in the low frequency and medium frequency portion of the radio spectrum. Ground wave radio signal propagation is ideal for relatively short distance propagation on these frequencies during the daytime. Sky-wave ionospheric propagation is not possible during the day because of the attenuation of the signals on these frequencies caused by the D region in the ionosphere. Ground wave radio signal is made up of a number of constituent waves. If the antennas are in the line of sight then there will be direct wave as well as a reflected signal. Direct signal is one that travels directly between the two antennas and is not affected by the locality. There will also be a reflected signal as the transmission will be reflected by a number of objects including the earth’s surface and any hills,or large buildings that may be present.

In addition to this there is surface wave, this tends to followthe curvature of the earth andenables coverage beyond the horizon. It is the sum of all these components that is known as the ground wave. Beyond the horizon the direct and reflected waves are blocked by the curvature of the Earth, and the signal is purely made up from the diffracted surface wave. It is for this reason that surface wave is commonly called ground wave propagation (Electronicsforu, 2019). Figure 1.2 shows the ground wave propagation.

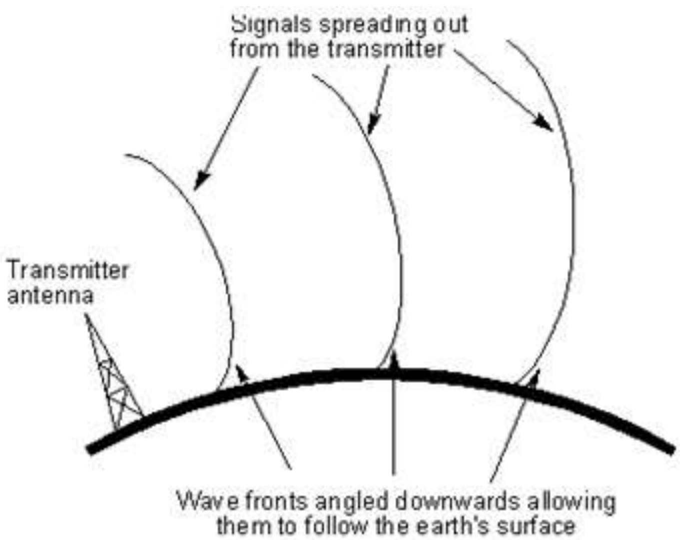


Figure 1.2: Ground wave propagation
Souce: Eletronicsforu (2019)

1.2.3 Surface wave

The radio signal spreads out from the transmitter along the surface of the Earth. Instead of just travelling in a straight line the radio signals tend to follow the curvature of the Earth. This is because currents are induced in the surface of the earth and this action slows down the wave-front in this region, causing the wave-front of the radio communications signals to tilt downwards towards the Earth. With the wave-front tilted in this direction it is able to curve around the Earth and be received well beyond the horizon (Freeman, 2007). Figure 1.3 shows the surface wave.

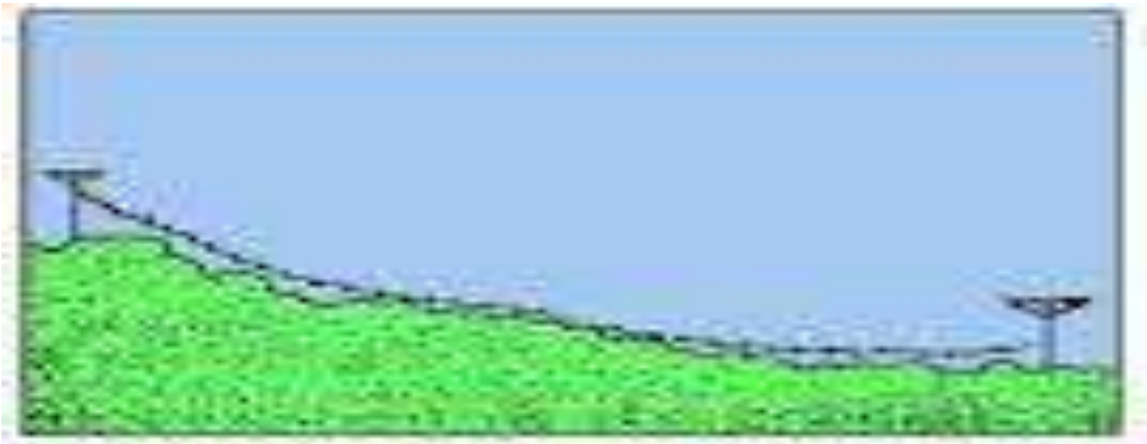


Figure 1.3: Surface wave
Source: Freeman (2007)

1.2.4 Line-of-sight propagation

Line-of-sight (LOS) propagation is the direct propagation of radio waves between antennas that are visible to each other. This is probably the most common of the radio propagation modes at VHF and higher frequencies. Radio signals at VHF are mainly used in LOS communication.

At VHF, the bands are divided into channels and one channel is usually as good as the next. This is in contrast to medium frequency (MF) and high frequency (HF) where the choice of a frequency channel may be crucial for good communications. For a wide coverage of Television (TV) signals, the transmitter should be as high as possible and free from obstructions. Moreso, the signals can travel through many non-mettalic objects and can be picked up through walls. To receive quality signals by a viewer, the receiving antenna should be positioned in such a way that it can see the transmitter very well and vice versa. That is the line of sight of the two antennas with respect to each other should be parallel (or the same).

Ground plane reflection effects are important factor in VHF line of sight propagation. Affecting this mode of propagation also, is the earth's curvature. Shore stations are usually on the tops of hills to provide maximum range, but even the highest hills do not provide coverage beyond about

80 km, because of the Earth’s curvature. VHF signals also suffer from atmospheric noise during severe electrical storms in the atmosphere, in the absence of such storms, interference mainly results from many users wishing to the limited number of channels, and this can be significant problem in densely populated areas.

1.2.5 Ionospheric wave propagation

Ionospheric wave propagation, also referred to as sky wave propagation, is the mode of radio wave propagation that relies on the ionosphere, which is made up of one or more ionized layers in the upper atmosphere. F2-layer is the most important ionospheric layer for long-distance, multiple-hop HF propagation, though F1, E, and D-layers also play significant roles.

The D-layer, when present during sunlight periods, causes significant amount of signal loss, as does the E-layer whose maximum usable frequency can rise to 4 MHz and above and thus block higher frequency signals from reaching the F2-layer. The layers, or more appropriately "regions", are directly affected by the sun on a daily diurnal cycle, a seasonal cycle and the 11-year sunspot cycle and determine the utility of these modes. During solar maxima, or sunspot highs and peaks, the whole HF range up to 30 MHz can be used usually around the clock and F2 propagation up to 50 MHz is observed frequently depending upon daily solar flux 10.7 cm radiation values. During solar minima, or minimum sunspot counts down to zero, propagation of frequencies above 15 MHz is generally unavailable (Hull, 1967).

1.2.6 Tropospheric ducting.

Tropospheric ducting is a type of radio propagation that tends to happen during periods of stable, anticyclonic weather. In this propagation method, when the signal encounters a rise in temperature in the atmosphere instead of the normal decrease(known as a temperature inversion), the higher refractive index of the atmosphere there will cause the signal to be bent. Tropospheric ducting affects all frequencies, and signals enhanced this way tend to travel up to (1,300 km) (though some people have received "tropo" beyond 1,600 km), while with tropospheric-bending, stable signals with good signal strength from (800 km) away are not common when the index of the atmosphere is fairly high.

Tropospheric ducting of UHF television signals is relatively common during the summer and autumn months, and is the result of change in the refractive index of the atmosphere at the boundary between air masses of different temperatures and humidity's. Using an analogy, it can be said that the denser air at ground level slows the wave front a little more than does the rare upper air, imparting a downward curve to the wave travel.

Ducting can occur on a very large scale when a large mass of cold air is overrun by warm air. This is termed a temperature inversion, and the boundary between the two air masses may extend for (1,600 km) or more along a stationary weather front.

Temperature inversions occur most frequently along coastal areas bordering large bodies of water. This is the result of natural onshore movement of cool, humid air shortly after sunset when the ground air cools more quickly than the upper air layers. The same action may take place in the morning when the rising sun warms the upper layers. Even though tropospheric ducting has been occasionally observed down to 40 MHz, the signal levels are usually very weak. Higher frequencies above 90 MHz are generally more favorably propagated.

High mountainous areas and undulating terrain between the transmitter and receiver can form an effective barrier to tropospheric signals. Ideally, a relatively flat land path between the transmitter and receiver is ideal for Tropospheric ducting (Rijn, 2005).

1.2.7 Sporadic E

Sporadic E or E_s is an unusual form of radio propagation using characteristics of the Earth's ionosphere. Whereas most forms of sky wave propagation use the normal and cyclic ionization properties of the ionosphere's F region to refract (or "bend") radio signals back toward the Earth's surface, sporadic E propagation bounces signals off smaller "clouds" of unusually ionized atmospheric gas in the lower E region (located at altitudes of approximatelly 90 to 160 km).

This occasionally allows for long-distance communication at VHF frequencies not usually well-suited to such communication. Communication distances of 800–2200 km can occur using a single E_s cloud. This variability in distance depends on a number of factors, including cloud height and density (http:// www.amfmdx.net/ fmdx/ sporadic- e. Html, 2008).

1.3 Mechanism of Radio Wave Propagation

Ground waves exist only for vertical polarization, produced by vertical antennas when the transmitting and receiving antennas are closed to the surface of the earth. The transmitted radiation induces currents in the earth's surface being attenuated according to the energy absorbed by the conducting earth (John and Smith, 1997). The ineffectiveness of horizontal electric field is due to the energy loss through the earth as the signal propagates.

Ground wave propagation is common for frequencies of a few MHz. Sky wave propagation is mainly dependent on reflection from the ionosphere, a region above earth's surface of ratified air that is ionospheric by sunlight (primary ultraviolet radiation). The ionosphere is responsible for long distance communication in the high frequency band between 3 and 30 MHz, but it is very dependent on time of day, season, and longitude on the earth. It makes possible, long-range communication using very low power transmitters.

The most important propagation mechanism for short-range communication on the VHF and UHF bands is that which occurs in open fields, where the received signal is a vector sum of a direct line-of-sight signal and as signal from same source that is reflected off the earth (Rappaport, 1996). This shows that there exist a relationship between signal strength and range in line-of-sight signals and open field topographic. The range of line-of-sight when there is no reflection from the earth or ionosphere is a function of the dispersion of the waves from the transmitting antenna.

For this free-space case, the signal strength decreases in inverse proportion to the distance away from the transmitter antenna (Seybold, 2005).

1.4 Free Space Propagation

In free space, all electromagnetic waves obey the inverse-square law. The inverse-square law states that the power density of an electromagnetic wave is proportional to the inverse of the square of the distance from the source. That is, if the distance from a transmitter is doubled, the power density of the radiated wave at the new location is reduced to one-quarter of its previous value. The power density per surface unit is proportional to the product of the electric and magnetic field strengths. Thus, doubling the propagation path distance from the transmitter reduces each of their received field strengths over a free-space path by one-half (Westman, 1968). Also, the electromagnetic waves coming from a transmitter may experience three other phenomena: reflection, diffraction, and scattering. All of these factors affect the tranmitted signal as it is “carried” through the air medium to the distant receiving antenna.

The range of VHF transmission depends on the transmitting antenna height, transmitter power, receiver sensitivity, and distance to the horizon, since VHF signals propagate under normal conditions as a near line-of-sight phenomenon.Radio wave are weakly bent back toward the Earth by the atmosphere,so the distance to the radio horizon is slightly extended over the geometric line-of-sight to the horizon (Beasley and Miller, 2010).

1.5 Radio Frequency Spectrum

The radio frequencies spectrum (as shown in Table 1.1) is the part of the electromagnetic spectrum with frequencies from 30 Hz to 300 GHz. Electromangetic waves in this frequency range called radio waves and widely used in modern technology particulary in telecommunication. The generation and transmission of radio waves to prevent interference between different users is strictly regulated by national laws and coordinated by an international body; the International Telecommunication Union (ITU). The radio spectrums of different parts are allocated by the ITU for different radio transmission technologies and applications. Parts of the radio spectrum are sold or licenced in some cases to operators of private radio transmission services (for example, broadcast television stations or cellular telephone operators). Allocated frequency ranges are often referred to by their provisioned use (for example, cellular spectrum or television spectrum) (Robinson, 2003).

Classification	Frequency Band	Wavelength	Some applications
Extremely low frequency	3 - 30 Hz	100,000 – 10,000 km	Communication with submarines
Super low frequency	30 - 300 Hz	10,000-1000 km	Communication with submarines
Ultra low frequency	300 - 3000 Hz	1000-100 km	Communication with mines
Very low frequency	3 - 30 MHz	100-10 km	Time signals and for military communication
Low frequency	30 - 300 MHz	10-1 m	AM radio broadcasting
Medium frequency	300 - 3000 MHz	1000-100 m	AM broadcast and aeronautical mobile
High frequency	3 - 30 GHz	100 – 10 m	Radio link satellite communication
Very high frequency	30 - 300 GHz	10 – 1m	FM and TV broadcasting

Table 1.1: Radio Frequency Spectrum (Seybold and John, 2005)

1.6 Statement of the Research Problem

The major challenge facing the coverage area of television signal is the unwanted reduction in the signal strength due to environmental factors (such as terrain and building pattern) and atmospheric factors (such as temperature, pressure, humidity and water vapours) which may reduce the strength of the signal. Therefore, it is important to understand how these factors impact on the propagating radio signal. There are numerous propagation prediction models but none of these models can be generalised for all environments and localities. Propagation models are usually suitable for particular areas such as (urban, suburban and rural), terrain and climate. To overcome these drawbacks, a propagation models parameter (such as height of the mast, frequency, power of transmitter, distance, and mobile antenna height) can be adjusted according to the targeted environment to achieve minimal error between predicted and measured signal strength.

1.7 Justification of the Study

For a proper coverage area prediction, propagation models are necessary. Use of inaccurate propagation models result in high co-channel interference and poor network coverage. hence, this research work will provide a model for ascertaining the electric field strength of the study area, which will enhance optimal performance of Television (TV) broadcasting system within the coverage area.

1.8 Aim and Objectives of the Study

The aim of this research is to determine the coverage areas of VHF/UHF television signal in Ekiti State, and adapt the existing empirical electric field models to suit the state.

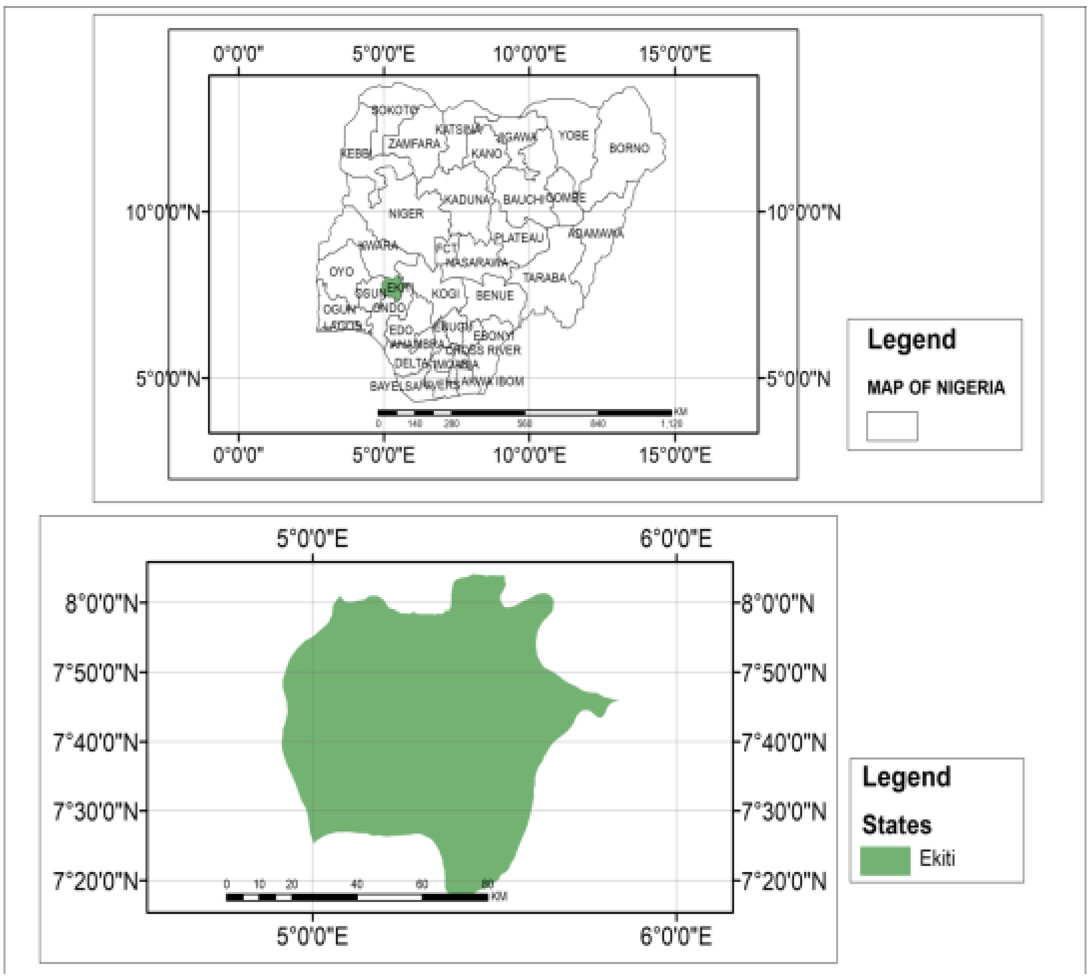
The objectives of this research are to:

(i) modify some field strength models and determine the one that is most suitable for the state; and

(ii) determine the coverage areas of the VHF and UHF television stations in Ekiti State.

1.9 Study Area

The study was carried out in Ekiti State, Nigeria. The State is located in the South Western part of Nigeria between latitude 7°40'N and latitude 7.667°N and longitude 5°15'E and 5.250°E with the capital at Ado-Ekiti. The State is bounded in the North by Kwara State and Kogi State while Osun State occupies the West and Ondo State lies in the South and extends to the eastern part. Ekiti State has sixteen local government areas with an overall population of about 2,384,212 people that spread over an approximately 88.7 km^2. The region lies at about 250 m above the sea level and rhythmically undulating surface. The landscape consists of ancient plains broken by steep-sided out cropping dome rocks. These rocks may occur singularity or in groups or in ridges and the most notable of these are to be found in Efon-Alaye, Ikere Ekiti and Okemesi Ekiti. The State is dotted with rugged hills, notable ones being Ikere-Ekiti hills in the south, Efon-Alaye hills on the western boundary and Ado-Ekiti hills in the center. The state enjoys a tropical



climate with two distinct seasons. These are the rainy season (April-October) and the dry season (November-March) and the temperature ranges between 21°C and 28°C with high humidity (Salau, 2016). Figure 1.4 shows the map of Ekiti State in Nigeria.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Coverage Area of Radio Station

The coverage of a radio station is the geographic area where the station can communicate. Broadcasters and telecommunications companies frequently produce coverage maps to indicate to users the station's intended service area. Coverage depends on several factors, such as topography (mountains) and buildings, technology and radio frequency. Some frequencies provide better regional coverage, while other frequencies penetrate better through obstacles, such as buildings in cities. The ability of a mobile phone to connect to a base station depends on the strength of the signal. That may be boosted by higher power transmissions, better antenna and taller antenna masts. Signals will also need to be boosted to pass through buildings, which is a particular problem designing network for large metropolitan areas with modern skyscrapers. Signals also do not travel deep underground, so specialised transmission solutions are used to deliver mobile phone coverage into areas such as underground parking garages and subway terrain (Moses, 2011).

The International Telecommunications Union (ITU) is responsible for the international allocation of the radio frequency in Nigeria while the National Frequency Management Council (NFMC) has the mission to regulate the telecommunications, radio, television frequencies adequately (NIGCOMSAT, 2011).

The Nigeria Broadcasting Commission (NBC) ensures that transmissions are in compliance with certain regulations including non-interference with other networks. It also ensures that television and radio signals reach their target locations.

A transmitting antenna supplied with power, P, will radiate electromagnetic waves in the entire space. Due to free-space loss caused by spreading, the strength of the field created by these waves weakens as the inverse of the square of the distance from the transmitting antenna. As VHF/UHF signals operate on line-of sight basis, the curvature of the earth limits the maximum distance (radio horizon) to which the waves can travel away from the transmitter. Varying atmospheric conditions can also degrade or enhance signal levels during abnormal propagation conditions. The field strength, when expressed in terms of 1 kW Effective Radiating Power (ERP) and plotted against distance, gives the field strength curve. VHF and UHF propagation curves are developed for TV and Frequency Modulation (FM) broadcasting (Prasad, 2006).

However, a number of propagation models have been developed to predict the strength of radio signals at various distances from their points of transmission. Yoshihisa Okumura (1968) carried out a number of propagation studies in the city of Tokyo, Japan and produced a set of curves of field strength against distance. The Okumura model for urban areas is a radio propagation model that was built using the data collected in the city of Tokyo, Japan. The model is ideal for using in cities with many urban structures but not many tall blocking structures. The model served as a base for Hata models. Okumura model was built into three models which are urban, suburban and open area (Shabbir *et al.*, 2011). Almost all the propagation models are enhanced from Okumura model. It can be used for frequency up to 3000 MHz and the distance between transmitter and receiver can be around 100 km while the receiver height can be 3 m to 10 m.

2.2 Propagation Models

Propagation models are main tools which are daily in use for designing, planning and analysing wireless communication networks. It is important to point out that there is no general method or algorithms that is universally accepted as the best propagation models. Therefore, each model can be useful for some specific environment and accuracy of any particular technique depends on the fit between the parameters available for the area concerned and the parameters required by the model.

Although there are lots of different kinds of models, none of them can be applied as a universal solution for all kinds of propagations situations. Choosing the appropriate propagation model depends on systems parameter (such as frequency and antenna height) and terrain parameters (such as urban area, suburban area and rural area). Propagation models can be divided into three main groups deterministic, statistical and empirical models (Abhayawardhana *et al.*, 2005).

2.2.1 Deterministic model

Deterministic models make use of the physical laws which determine radio wave propagation mechanisms for a particular location. These models require a three dimensional (3-D) data of the propagation environment. Accuracy of the deterministic models is usually very high but on the expense of high computing complexity (Athanasiadou *et al.*, 2000).

2.2.2 Stochastic model

Stochastic models, on the other hand, require the least information about the environment but provide the least accuracy (Karasawa, 2007). They model the environment as a series of random variables.

2.2.3 Empirical model

Empirical models are based on the extensive measurements and mainly give prediction of field strength. They are more often used in practice than statistical and deterministic propagation models, because of low cost and model simplicity with acceptable accuracy (Milanovic *et al.*, 2010).

2.3 Field Strength Models

Field strength models are radio signal propagation models which present the electric field strength as a function of the signal distance from the point of transmission. There are various empirical field strength models for broadcasting services but attention will be given to free space model, Hata model, International Telecommunication Union Radio (ITU-R P.529-3) and European Radio Communications Committee (ERC Report 68) model because they are widely accepted (Moses *et al.*, 2015; Obiyemi *et al.*, 2012; Oluwafemi and Femi-Jemilohun, 2017; Kiran and Rajkot, 2015; Faruk *et al.*, 2013).

2.3.1 Free space model

Free-space propagation model is used to predict received signal strength when the path between the transmitter and receiver is a clear and unobstructed line-of-sight. (Obiyemi *et al.*, 2012). The ideal propagation radiates in all directions from transmitting source and propagating to an infinite distance with no degradation.

Attenuation occurs due to spreading of power over greater areas. The resulting power flux density, S, at a distance d is calculated using equation 2.1 (Nadir *et al.*, 2008).

$$S = \frac{P_T}{4\pi d^2} \quad (2.1)$$

$S = P_T - 20\text{logd} - 41$ (2.2)

where:

S = Power flux density in decibels relative to 1 W.m^{-2}

P_T = Power in decibels (dB) relative to 1 kW

d = Distance (km)

The equivalent field strength, E is given as:

$$E = \sqrt{S.120\pi} \tag{2.3}$$

$$= \frac{\sqrt{30P_T}}{d} \tag{2.4}$$

$$\text{or } E\ (mV/m) = \frac{173\sqrt{P_T(KW)}}{d\ (km)} \tag{2.5}$$

$$E = P_T - 20\ \text{logd} + 104.8 \quad \text{in dB}\mu V/m \tag{2.6}$$

This relationship applies when the power radiates isotropically.

2.3.2 Hata model

The Hata model is a population propagation model for radio propagation planning. The model is based on an empirical relation derived from Okumura's report on signal strength variability measurements (Okumura, 1968). The simple modeling of path loss is still dominated by the Hata empirical model (Hata, 1980) where the propagation results are fitted to a simple analytical expression, which depends on antenna height, environment, frequency and other parameters. Hata's method is basically an extension of Okumura's method and employs propagation curves instead of parametric equations (Aromoogum *et al.*, 2010). It is applicable to frequencies between 150 MHz and 1500MHz, transmitter-receiver separation distance from 1km to 20 km, transmitter antenna height between 30 m and the height of receiver antenna from 1 m to10 m. The original Hata equation is given in terms of a path loss in dB. This equation can be corrected to give the field strength with respect to a 1 kW Effective Radiated Power (ERP) transmitter (SPR, 2001).

E = 69.82 – 6.16 log f+13.82 log h_b+ a (h_m) – (44.9 – 6.66 log(h_b)) $\times$ log d ($dB\mu V/m$) (2.7)

where:

E = Field strength at a distance from a 1 kW ERP transmitter in $dB\mu V/m$.

f = Frequency of the transmission (MHz)

h_b = Height of the base station or transmitter (m)

h_m = Height of the mobile or receiver (m)

d = Distance between the receiver and transmitter (km)

2.3.3 ITU-RP.529-3 model

The ITU-R determines the analytical expressions that are suitable for same frequency ranges and correspond approximately to some of its propagation curves. The equation is given by (ITU-R, 1999).

E = 69.82 – 6.16 log(f) + 13.82 log h_b + a (h_m) – (44.9 – 6.55log(h_b)(log d)^b (2.8)

where:

E = Field strength for 1 kW ERP

f = Frequency (MHz)

h_b = Base station antenna height in the range of 30-200 m.

h_m = Mobile station antenna height in the range 1-10 m.

d = Distance (km)

a(h_m) = (1.1log f – 0.7) h_m – (1.56 log f – 0.8) (2.9) b = 1 for d ≤ 20 km (2.10)

b = 1 + (0.14 + 1.87 × $10^{-14}f$ + 1.07 × 10^{-3} h_b) $\left(\log\frac{d}{20}\right)^{0.8}$

for 20 km $< d <$ 100 km (2.11)

where:

$$h_b = \frac{h_b}{\sqrt{1+7\times10^{-8}h_b^2}} \qquad (2.12)$$

This model is suitable for use over the ranges:

Frequency range, 150-1500 MHz

Base station height, 30-200 m

Mobile height, 1-10 m

Distance range, 1-100 km

2.3.4 ERC report 68 model

In this model, there are a number of equations for different frequency ranges. The equation covers the same frequency range as the original Hata equation. This equation has only the distance term raised to the power b and the equation equates approximately to the original Hata equation for distances less than 20km. The first constant is equal to 69.75 instead of 69.82. The equation is given by (SPR, 2001):

E = 69.75 – 6.16 log(f) + 13.82 log(h_b) + α × (44.9 – 6.55log(h_b)) × (log(d)) + a(h_m)

+ b(h_b) (2.13)

where:

α = 1 if d < = 20 km (2.14)

α = 1+ (0.14+1.87× 10^{-4} × f +1.07× 10^{-3} × h_m) × (log($d/20$))$^{0.8}$

if d > 20 km (2.15)

a(h_m) = (1.1log(f) –0.7)×minimum(10,h_m)– (1.56 log(f) – 0.8)

+ maximum (0,20log($h_m/20$)) (2.16)

b(h_b) = minimum (0, 20 log($h_b/30$)

(2.17)

This model is suitable for the ranges:

Frequency range 150 – 1500 MHz

Base station height 1-200 m

Mobile height 1-200 m

Distance range 1-100 km

2.4 Converting Propagation Loss to Field Strength at the Receiver

The original Hata equation is given in terms of a loss in dB. The Okumura curve and some modified Hata models are given in field strength (dB (µV/m)). We need to convert the Hata equation into field strength so the different equations can be easily compared (SPR, 2001).

Original Hata equation is given by:

$$L_p = 69.55 + 26.16\log f - 13.82\log \mathrm{h_b} - \mathrm{a}(h_m) + (44.9 - 6.66\log \mathrm{h_b})\log \mathrm{d} \quad (\mathrm{dB}) \quad (2.18)$$

The relationship between power received by an isotropic antenna and field strength at the receiving site is given as:

$$P_{r=}(\frac{\lambda}{4\pi})^2\frac{E^2}{30} \quad \text{in W (EIRP)} \quad (2.\ 19)$$

$$P_r = \left(\frac{c}{4\pi f h_z}\right)\frac{E^2}{30} \quad \text{in W (EIRP)} \quad (2.20)$$

Converting from a linear equation to logarithmic and with f in MHz:

P_r= 169.537 – 120 – 21.984 - 20log$f + E - 14.771$ in dBW (EIRP) (2.21)

Adding all the constants together we get:

$$P_r = E - 20\log f + 12.782 \quad (2.22)$$

The power received is also equal to the power transmitted P_t minus the propagation loss L_p as shown in equation 2.23:

$$P_r = P_t - L_p \quad (2.23)$$

Using equation 2.22 and 2.23 we can calculate an equation that shows the relationship between loss and field strength depending on the power transmitted.

$$E = P_t + 20\log f - 12.782 - Lp \qquad dB\ (V/m) \quad (2.24)$$

All field strengths were measured with respect to 1 kW EIRP transmitter. Setting P_t equal to 32.15 dB, then equation 2.24 becomes:

$$E = 19.37 + 20\log f - L_p \qquad dB\ (V/m) \quad (2.25)$$

To convert dB (V/m) to dB (μV/m) 120 dB is added and so that equation (2.25) gives:

$$E = 139.37 + 20\log f - L_p \qquad dB\ (uV/m) \quad (2.26)$$

Replacing Lp by the Hata equation for propagation loss equation (2.26) becomes:

$$E = 69.82 - 6.16\log f + 13.82\log h_b + a(h_m) - (44.9 - 6.66\log h_b)\log d \quad dB(\mu V/m) (2.27)$$

where:

p_r = Received power

Λ = wavelength (m)

Lp: Propagation loss in an urban area in a small to medium city (dB)

E = Field strength at a distance from a 1 kW ERP transmitter (dBμV/m)

f = Frequency of the transmission (MHz)

h_b = Height of the base station or transmitter (m)

h_m = Height of the mobile or receiver (m)

d = Distance between the receiver and transmitter (km)

2.5 Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) also known as Root Average Squared prediction Error (RASPE) (as shown in equation 2.28) is the most apparent metric for analysing error of predictive models. It is an efficiency method of estimating the accuracy of path loss model in the RMSE, which is the difference in decibel (dB) between the measured path loss and estimated path loss (Castro *et al.*, 2011; Nadir *et al.*, 2008; Diawuo and Cemberbatch, 2015)

$$RMSE = \sqrt{\frac{\sum(X_M - X_E)^2}{n}} \tag{2.28}$$

where:

X_M = Measured data

X_E = Estimated data

n = Number of measured data points

2.6 Mean Prediction Error (MSE)

The mean prediction error between the measured and the predicted values can be expressed in equation 2.29 (Ogbulezie *et.al.*, 2013)**.**

$$MSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_m - P_r)^2} \tag{2.29}$$

where:

P_m = Measured path loss

P_r = Predicted path loss

N = Number of measured data points

2.7 Clear-air Effects on Radio Waves

The primary propagation factors that influencing radio wave apart from rain are: diffraction, absorption, atmospheric losses, reflection, refraction, multipath fading, gaseous attenuation, cloud attenuation and tropospheric scintillation (Salonen, 1993).

2.7.1 Diffraction

Diffraction (as shown in Figure 2.1) is the propagation mode where radio waves are bent around sharp edges. For example, this mode is used to send radio signals over a mountain range when a line-of-sight path is not available. However, the angle cannot be too sharp or the signal will not diffract. The diffraction mode requires increased signal strength, so higher power or better antennas will be needed than for an equivalent line-of-sight path. Diffraction was described by Huygens-Fresnel theory (Born and wolf, 1999) and the principle of superposition of waves, when the wave encounters an obstacle in its first Fresnel zones (Clarke and Brown, 1980) (Maximum signal power exists in the first Fresnel zone).

Diffraction depends on the relationship between the wavelength and the size of the obstacle. Lower frequencies diffract around large smooth obstacles such as hills. For example, in many cases where VHF (or higher frequency) communication is not possible due to shadowing by a hill, it is still possible to communicate using the upper part of the HF band where the surface wave is of little use. Diffraction phenomena by small obstacles are also important at high frequencies. Signals for urban cellular telephony tend to be dominated by ground-plane effects as they travel over the rooftops of the urban environment.

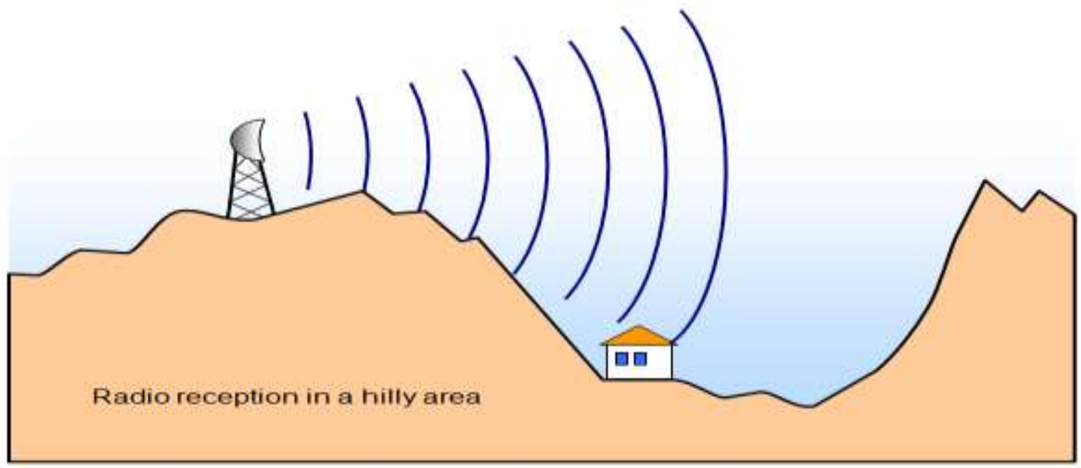


Figure 2.1: Diffraction of radio wave

Source: Keith (2013)

2.7.2 Atmospheric losses

Atmospheric absorption losses consist of an atmospheric basic absorption as well as a strongly weather-dependent back up absorption by rain and fog. The electromagnetic waves are weakened when penetrating air and water vapour layers. In this process mainly water vapour and diatomic oxygen are involved. A part of electromagnetic energy is converted into heat, and some scattered due to the molecular dipole action. Atmospheric absorption also increases with higher transmitter frequency; losses are always present and cannot be avoided.

2.7.3 Reflection

Radio waves can experience reflection from different surfaces they collide with during transmission between places (as shown in Figure 2.2). The wavelength of the radio signal determines the size of an area required from a smooth surface is always equal to the angle at which the ray strikes the reflecting surface (Gibson, 2002).

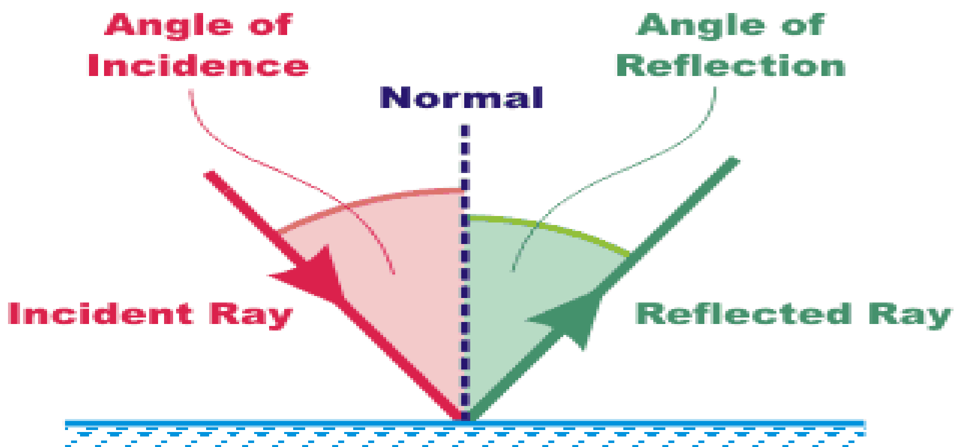


Figure 2.2: Reflection of radio wave

Source: Gibson (2002)

2.7.4 Refraction

It is possible for radio waves to be refracted. Refraction is the change in the direction of propagation of a wave when it's transmitting medium changes. At the boundary between the media, the wave's phase velocity is altered, usually causing a change in direction. Its wavelength increases or decreases, but its frequency remains constant. The sudden increase in the speed of incident wave causes the wave to curve backward to Earth.

2.7.5 Multipath fading

Multipath fading effect in most form of radio communications links in one form or another. Multipath fading can be detected on many signals across the frequency spectrum from the HF bands right up to microwaves and beyond. It is experienced not only by shot wave radio communications where signals fade in and out over a period of time, but it is also experienced by many other forms of radio communication systems including cellular telecommunications and many other uses of the VHF and UHF spectrum. Multipath fading occurs in any environment where there is multipath propagation and there is some movement of elements within the radio communications system. This may include the radio transmitter or receiver position, or in the elements that give rise to reflections. The signals fade completely away, whereas at other times the fading may not cause the signal to fall below a useable strength.

Multipath fading may also cause distortion to the radio signal. As the various path that can be taken by the signals vary in length, the signal transmitted at a particular instance will arrive at the receiver over a spread of times. This can cause problems with phase distortion and intersymbol interference when data transmissions are made. As a result, multipath fading may be necessary to incorporate features within the radio communications system that enables the effects of these problems to be minimized. Multipath fading is a feature that needs to be taken into account when designing and developing a radio communications system. In any terrestrial radio communication systems, the signal will reach the receiver not only via the direct path, but also as a result of reflections from objects such as buildings, hills, ground water, that are adjacent to the main path. At times there will be changes in the relative path length and this could result from either the radio transmitter or receiver moving, or any of the objects that provides a reflective surface moving. This will result in the phases of the signals arriving at the receiver changing, and in turn resulting in the signal power varying as a result of the different ways in which the signals will add together. It is this that causes the fading that is present on many signals.

2.8 Atmospheric Effect on Radio Wave Propagation

2.8.1 Fading

Fading is the deviation of the attenuation affecting a signal over certain propagation media. The fading may vary with time, geographical position or radio frequency, and is often modeled as a random process.

A fading channel is a communication channel comprising fading. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading.

The presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can traverse. As a result, the receiver sees the superposition of multiple copies of the transmitted signal, each traversing a different path. Each signal copy will experience differences in attenuation, delay and phase shift while travelling from the source to the receiver. This can result in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver. Strong destructive interferences is frequently referred to as a deep fade and may result in temporary failure of communication due to a serve drop in the channel signal-to- noise ratio.

A common example of multipath fading is the experience of stopping at a traffic light and hearing and frequency modulation (FM) broad degenerate into static, while the signal is re acquired if the vehicle moves only a fraction of a meter. The loss of the broadcast is caused by the vehicle stopping at a point where the signal experience severe destructive interference. Cellular phones can also exhibit similar momentary fades.

Fading channel models are often used to model effect of electromagnetic transmission of information over the air in cellular networks and broadcast communication. Fading channel models are also used in underwater acoustic communication to model the distortion caused by the water mathematically, fading is usually modeled as a time-varying random change in the amplitude and phase of the transmitted signal (Lars and Jens, 2006)

2.8.2 Slow fading

Slow fading arises when the coherence time of the channel is large relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. The received power change caused by shadowing is often modeled using a log- normal distribution with a standard deviation according to the log-distance path loss model (David and Viswanath, 2006).

2.8.3 Fast fading

Fast fading occurs when the coherence time of the channel is small relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel varies considerably over the period of use.

In a fast channel, the transmitter may take advantage of variation in the channel conditions using time diversity to help increase robustness of the communication to a temporary deep fade. Although a deep fade may temporarily erase some of the information transmitted, use of an error correcting code coupled with successfully transmitted bits during other time instances (interleaving) can allow for the erased bits to be recovered. In a slow fading channel, it is not possible to use time diversity because the transmitter sees only a single realization of the channel within its delay constraint. A deep fade therefore last the entire duration of transmission and cannot be mitigated using coding.

The coherence time of the channel is related to a quantity known as the Doppler spread of the channel. When a user (or reflectors in its environment) is moving, the user's velocity causes a shift in the frequency of the signal transmitted along each signal path. This phenomenon is known as the Doppler shift. Signal travelling along different paths can have different Doppler shifts corresponding to different rates of change in phase (Lars and Jens, 2012).

2.8.4 Selective fading

Selective fading or frequency selective fading is a radio propagation anomaly caused by partial cancellation of a radio signal by itself – the signal arrives at the receiver by two different paths, and at least one of the path is changing (lengthening or shortening). This typically happens in the early evening or early morning as the various layers in the ionosphere move, separate, and combine. The two paths can both be sky wave or one of the two being ground wave.

Selective fading manifest as a slow, cyclic disturbance; the cancellation effects, or ''null'', is deepest at one particular frequency, which changes constantly, sweeping through the received audio. As the carrier frequency of a signal is varied, the magnitude of the change in amplitude will vary. The coherence bandwidth measures the separation in frequency after which two signals will experience uncorrelated fading. Since different frequency components of the signal are affected independently, it is highly unlike that all part of the signal will be simultaneously affected by a deep. Certain modulation schemes such as orthogonal frequency division multiplexing (OFDM) and Code division multiple access (CDMA) are well – suited to employing frequency diversity to provide robustness to fading. OFDM divides the wide band signals into many slowly modulated narrow band subcarriers, each exposed to flat fading rather than frequency selective fading.

Frequency –selective fading channels are also dispersive, in that the signal energy associated with each symbols is spread out in time. This cause transmitted symbols that are adjacent in time to interfere with each other.

2.9 Theory of an Antenna

An antenna (or aerial) is an electrical device which converts electric power into radio waves, and vice versa. It is usually used with radio transmitter or radio receiver (Graft, 1999). In transmission, radio transmitter supplies an oscillating radio frequency electric current to the antenna's terminal, and the antenna radiates the energy from the current as electromagnetic waves (radio waves).

In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage to its terminals, which is applied to receiver to be amplified.

Antennas are essential components of all equipment that use radio communication. They are used in systems such as radio broadcasting, broadcast television, two way radio, communications receivers, radar, cell phones, and satellite communications as well as other devices such as garage door openers and wireless microphones.

Typically an antenna consists of an arrangement of metallic conductor ("elements"), electrically connected (often through a transmission line) to the receiver of transmitter. An oscillating current of electrons forced through the antenna by a transmitter will create an oscillating magnetic field around the antenna elements, while the electronic charge also creates an oscillating electric field along the elements. These time-varying fields, when created in the proper proportions, radiate away from the antenna into space as a moving transverse electromagnetic field wave. Conversely, during reception, the oscillating electric and magnetic fields of an incoming radio wave exert fore on the electrons in the antenna elements, causing them to move back and forth, creating oscillating currents in the antenna.

Antennas may also include reflective or surfaces not connected to the transmitter or receiver, such as parasitic elements, parabolic reflectors or horns, which serve to direct the radio waves into a beam or other desired radiation pattern. Antennas can be designed to transmit or receive radio waves in all directions equally (omnidirectional antennas), or transmit them in a particular direction, and receive from that one direction only (directional or high gain antennas).

Antennas are required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field. Radio waves are electromagnetic waves which carry signals through the air (or through space) at the speed of light with almost no transmission loss. Radio transmitter and receiver are used to convey signals (information) in system including broadcast (audio) radio, television, mobile telephones, Wi-Fi (WLAN) data networks, trunk lines and point-to-point communications links (telephone, data network), satellite links, many remote controlled devices such as garage door openers, and wireless remote sensors, among many others. Radio waves are also used directly for measurements in technologies radar, global positioning system (GPS) and radio astronomy in each and every case, the transmitters and receivers and receiver involved require antennas, although these are sometime hidden (such as the antenna inside an amplitude modulation (AM) radio inside a laptop computer equipped with Wi- Fi) (Balanis and Wiley, 2000).

2.9.1 Characteristics of an antenna

2.9.1.1 Polarisation

The Polarisation of an antenna is the orientation of the electric (E-plane) of the radio wave with respect to the Earth's surface and is determined by the physical structure of the antenna and by its orientation. It has nothing in common with antenna directionality terms: "horizontal", "vertical", and "circular". Thus, a simple straight antenna will have one polarisation when mounted vertically, and a different polarisation when mounted horizontally. "Electromagnetic wave polarisation filters are structures which can be employed to act directly on the electromagnetic wave to filter out wave energy of an undesired polarisation and to pass wave energy of a desired polarisation.

Reflection generally affect polarisation. For radio waves the most important reflector is the ionosphere-signals which reflect from it will have their polarisation changed unpredictably. For signals which are reflected by the ionosphere, polarisation cannot be relied upon. For line -of - sight communications which depends strongly on polarisation, it can make a large difference in signal quality to have the transmitter and receiver using the same polarisation; many tens of dB difference are commonly seen and this is more than enough to make the difference between reasonable communication and a broken link. For radio antennas, polarisation corresponds to the orientation of the radiating element in an antenna. A vertical omnidirectional antenna will have vertical polarisation (the most common type).

An exception is a class of elongated waveguide antennas in which vertically placed antennas are horizontally polarised. Many commercial antennas make are marked as to the polarisation of their emitted signals (Kraus *et al.*, 2006).

2.9.1.2 Reciprocity

It is a fundamental property of antennas that the electrical characteristics of an antenna described by gain, radiation pattern, impedance bandwidth, resonant frequency and polarization, are the same whether the antenna is transmitting or receiving. For example, the "receiving pattern" (sensitivity as a function of direction) of an antenna when used for reception is identical to the radiation pattern of the antenna when it is driven and function as a radiator. This is a consequence of the reciprocity theorem of electromagnetics (Stutzman and Thiele 2012; Lonngren *et al.*, 2007).

2.9.1.3 Radiation pattern

The radiation pattern of an antenna is a plot of the relative field by strength of the radio waves emitted by the antenna at different angles. It is typically represented by a three dimensional graph, or polar plots of the horizontal and vertical cross section. The pattern of an isotropic antenna, which radiates equally in all directions, would look like a sphere. Many non-Directional antennas, such as monopoles and dipoles, emit power in all horizontal directions, with the power dropping off at higher and lower angles; this is called an Omni-directional pattern and when plotted looks like a torus or donut. The radiation of many antennas shows a pattern of maxima or "lobes" at various angles, separated by "nulls", angles where the radiation falls to zero. This is because the radio wave emitted by different parts of the antenna typically interfere, causing maxima at angles where the radio waves arrive at distant points in phase, and zero radiation at other angles where the radio wave arrive out of phase. In a directional antenna designed to project radio wave in a particular direction the lobe in that direction designed larger than the others and is called the "main lobe". The other lobes usually represent unwanted radiation and are called ‘’side lobes’’. The axis through the main lobe is known as the principal axis or bore sight axis.

2.9.1.4 Directivity

The directivity of an antenna refers to the radiation beam pattern. A directional antenna concentrates its radiation in a relatively narrow beam. If the beam narrow in either the horizontal or vertical plane, the antenna will have high degree of directivity in that plane. An antenna can be highly directive in one plane only or in both planes, depending upon its use. In general, we use three terms to describe of directional qualities associated with an antenna: Omni-directional, bidirectional, and unidirectional. Omni-directional antennas radiate and receive equally well in all directions, except off the ends. Bidirectional antennas radiate or receive efficiently in only two directions. Unidirectional antennas radiate or receive efficiently in only one direction.

2.10 Review of Related Works

Researchers globally have shown great effort towards providing efficacy of the existing path-loss models and also turning such models to achieve minimal error for a given environment. Once the error can be defined, it would be easier for practicing engineers to choose a better model for optimum coverage and interference analysis.

Chen and Hsieh (2006) provided a fast and precise dual least square approach to tune the generally used propagation models, like Cooperate in Science and Technology (COST) 231 Hata’s model. The experiment was conducted within the Banquo city, Taiwan. The tuned model, called Banquo model, has been verified in the static Monte Carlo simulation and has proved to be more optimal for local environmental area. Similar works on model turning are presented by

Mardeni and Priya (2011); Nissirat *et al.* (2012); Fujitani *et al.* (2010); Ajose and Imoize (2013); Mardeni and Kwan (2010); Mardeni and Lee (2010); Castro *et al.* (2011); Medeisis and Kajackas (2007). In all these, measurements were conducted in a given areas and optimisation techniques were employed to tuned the model parameters to decrease the prediction errors.

Armomoogun *et al.* (2010) studied the importance of path loss prediction and coverage area in radio and television station broadcast system, since the wave interacts with the environment leading to attenuation of signal. The results showed that propagation curve an essential tool for radio wave propagation planning, design and loss estimation.

Sharma and Singh (2010) concluded that propagation path loss models may give different results if they are used in different environment other than in which they were design. Different path loss models were compared with measured field data. The field measurement data were obtained in the urban, suburban and rural environments in India at 900 MHz and 1800 MHz frequency bands with the help of spectrum analyser. The results showed that EEC-33 and Stanford University Interim (SUI) models gave the best results in urban areas. In suburban areas, ECC-33, SUI and COST 231- Hata models were of good performance. Okumura-Hata and Long-distance models have better performance in rural areas.

Chebil *et al.* (2011) investigated path loss model for mobile communications in Malaysia. The results revealed that SUI and COST 231 models over predicted the path loss while long-normal shadowing and Lee models were in choose agreement with the measures path loss.

Shoewu (2011) validated that some empirical path loss models with field measurements carried out at different locations within Epe town and its environs. The data were collected from the live radio base stations transmitting at 900 MHz and 1800 MHz. The respective path loss values were estimated and compared with the results of the existing models. The results indicated an appreciable consistency with these models except for rural areas. The work showed that the Okumura-Hata model is very effective for radio wave propagation path loss prediction in Suburban and urban areas in the Western part of Nigeria.

Obiyemi *et al.* (2012) provided propagation measurements at VHF/UHF bands conducted in Ilorin Middle-Belt, Nigeria. The work concluded that Okumura's model is the most suitable for prediction of field strengths for television broadcast services and for other communication system designs in the VHF and UHF bands. However, the root mean square errors (RMSE) of 34 dB and 33 dB are obtained in the VHF and UHF bands, respectively, which are far beyond the acceptable range 6-7 dB for urban areas (Abhayawardhana *et al.,* 2005) and 10-15 dB for suburban and rural areas (Blasunstein *et al.,* 2003). Therefore, the said model cannot provide optimum path-loss prediction in the study area.

Dalela *et al.* (2012) provided turning of COST 231- Hata model based on measurements conducted in 2.3 GHz in Western India. Linear iteration method were used in turning the model and it was found that the tuned model achieves better RMSEs compared with the conventional COST 231-Hata model.

Isabona and Azi (2012) optimised Walfisch-Bertoni model using least squares method on data obtained in Benin, Nigeria, at operating frequency of 1900 MHz. The optimised model is found to predict path-loss with improved accuracy of about 25- 30 % compared to the original model.

Plamen (2012) compared the following path loss model free space path loss model, Hata-Okumura Model, COST 231 model and Stanford university interim model. He found that, no single model is suited for all environment at 3.5 GHz frequency band. Free space path loss model show minimum path loss for all type of environment. Hata-Okumura model and COST 231 W-I model are most suitable in densely populated areas, but in rural area they are no so suitable.

Prasad and Ratnamala (2012) presented the analysis of measurements taken at 1.8 GHz in the dense urban environments of Delhi for base stations. Coverage predictions utilising various models and their comparison with observed data were carried out. Measured path loss was compared with the theoretical path loss values evaluated by COST- 231 and Hata models. Path loss exponents, mean errors, and standard deviations of all the prediction methods were derived and suitable models for path loss prediction methods were distinguished.

Ogbuleize *et al.* (2012) carried out a survey on site specific measurements and propagation models for GSM in three cities in Northern Nigeria using Okumura Hata model and COST- 231 model. From the measurements carried out, it was demonstrated that the established models for path loss calculation overestimate the path loss in every one of the urban communities. The standard deviations ranged from 6.9 dB to 45.87 dB for the Okumura Hata model at 900 MHz while for the COST 231 ranged from 9.24 dB to 24.37 dB. Likewise, for Okumura Hata at 900

MHz, the mean square error (MSE) ranged from 2.1 dB to 14.52 dB. For COST 231- Hata at this frequency, it was from 2.06 dB to 14.18 dB. This concur with the international range.

Ogbulezie *et al.* (2013) conducted an adaptable and suitable propagation path loss models for the cities of Port Harcourt and Enugu, two empirical propagation models were considered and two sites were selected for each of the city under study and drive test measurements were conducted along the major routes. These measurements were compared with the prediction results obtained by Okumura-Hata and COST 231- Hata models. The results showed that average path loss values for the routes ranged from 135.01 dB to 138.48 dB at 900 MHz and 142.26 dB to 147.30 dB at 1800 MHz. The standard deviations varied from 2.71 dB to 15. 94 dB for the Okumura-Hata model at 900 MHz whereas for COST 231 -Hata model it was from 1.91 dB to 15.04 dB. Similarly, the mean square errors ranged from 0.8 dB to 5.04 dB for Okumura-Hata model at 900 MHz. For COST 231-Hata model at 900 MHz, it was from 0.6 dB to 4.76 dB. The mean square error at 1800 MHz varied from 0.11 dB to 5.40 dB.

Faruk *et el.*(2013) provided the error bounds and efficacy for predicting path-loss for ten empirical widely used path-loss models based on field strength measurements conducted in the VHF and UHF frequencies in the same region. It was concluded that no single model could consistently provide a good fit.

Famoriji *et al.* (2013) revealed an inverse relationship between atmospheric radio refractivity and UHF received signal level with correlation coefficient value of 0.97. The study also revealed a direct relationship between atmospheric radio refractivity and relative humidity and an inverse relationship between atmospheric radio refractivity and temperature.

Sheowu and Akinyemi (2013) investigated the effect of climate change on GSM signal propagation by sampling the three ITU regions in Nigeria at different climatic seasons of rain (May-June) and harmattan (November-March). The result obtained revealed that climate affect signal propagation.

Abraham (2013) proposed that Cost 231- Hata model is suitable for network coverage prediction across the mountain terrains of the Jos-Plateau, Nigeria with acceptable gain of 6dB.

Oyetunji (2013) worked on the determination of Propagation Path Loss and Contour Map for Federal University of Technology Akure (FUTA) FM Radio using Okumura model and COST 231- Hata model. The paper reviewed different models for predicting transmission loss and utilized the COST - 231 model for the study because of its versatility. The result offers valuable information for building up the propagation loss contour map which was created for the station. An assumption was made that with the unpredictable landscape, model predictions can be utilized for exact spectrum management in Nigeria.

Chebil (2013) reported the measurement results of the propagation path loss in four locations in the suburban area of Kuala Lumpur. The measured path loss at each location was extracted from the data and compared with corresponding results obtained from the six models under study: Log- normal shadowing, Lee, SUI, COST 231- Hata, Egli and ECC-33 models. The analysis of the result showed that SUI and Log-normal models gave better prediction and can be used to estimate path loss for prediction of mobile coverage in a macro cellular in Malaysia.

Ogbede and Edeko (2013) conducted a research work on modification of Hata empirical propagation model for application in VHF band in Edo State, Nigeria. In the work, a quantitative measurement of the signal strength of a VHF Television broadcasting station (NTA) Edo was monitored on 189.25 MHz frequency. The results obtained using the root mean square error (RMSE) performance metrics showed that the Hata propagation model do not accurately predict the path loss for television signal propagation in Edo State as the value of (RMSE) obtained is found to be in excess of the 7 dB allowed for radio prediction. Better result is obtained when the Hata model is modified. Modification based on the result from Hata model gave a lower and acceptable root mean square error.

Segun and Olasunkanmi (2014) conducted an empirical path loss model for GSM network deployment in Markurdi, Nigeria. In the work, the performance of Okumura – Hata model, COST 231- Hata model, Standard Propagation Model (SPM) and SUI model were evaluated. A drive test was conducted to obtain the field measured data with which models were appraised. The analysis of the results showed that Okumura- Hata model, COST 231-Hata model, SPM and SUI model gave RMSE values of 11.39 dB, 11.59 dB, 8.11 dB and 18.48 dB respectively for GSM 900; and 10.75 dB, 9.78 dB, 12.39 dB and 16.99 dB respectively for GSM 1800. It was concluded that SPM and COST 231-Hata model would be more suitable for GSM 900 and GSM 1800 network planning in Markurdi, Nigeria.

Adewumi *et al.* (2015) studied the influence of atmospheric parameters on UHF radio propagation in South Western Nigeria. Received signal level was observed to increase with temperature while relative humidity increased with signal path loss. The result showed that air temperature and relative humidity have significant influence on UHF signal propagation with the tropospheric region of South Western Nigeria.

Moses *et al.* (2015) developed a field strength model for terrestrial television broadcast in UHF band in Markurdi City, Nigeria using free space, Hata, ITU R-P and ERC 68 models. From the measurement carried out, free space model gave more accurate prediction in Markurdi City with average Root Mean Square Error (RMSE) of 4.1 dBμV/m as compared to other models.

Zilinskas *et al.* (2015) investigated the influence of atmospheric radio refractivity on World Interoperability for Microwave Access (WiMAX) signal level. The studied reveal that atmospheric radio refractivity, as a combination of temperature and relative humidity, has impact on the variation of received signal level.

Hanchinal and Muralidhara (2016) carried out a survey on the effects of the atmospheric on radio path loss in cellular mobile communication system using free space path loss, Hata model and COST 231 model. It was stated that radio propagation is site specific and vary significantly with different terrains, environment impacts, the distance between the transmitter and the receiver and the frequency of operation. It was also pointed out that accurate characterisation of the radio channel through key parameters which is more of numerical model is essential for: predicting signal coverage, achievable information rates and quality of service. The conclusion was that there is a requirement to consider the climatic factor in modelling prediction propagation to accomplish an accurate plan for the next generation of wireless system.

Nkerdeh (2016) proposed that there are two common radio propagation models, Okumura-Hata and the COST 231- Hata models which are suitable in determining the radio coverage for long-term evolution (LTE) and considered base station antenna at different frequencies.

Oluwafemi and Jemilohun (2017) conducted an experimental work on the propagation profile and signal strength variation of VHF signal. In the studied, a path loss models through a real time application of outdoor VHF signal propagation measurement of the Nigeria Television Authority (NTA) channel 5 and carrier frequency of 175.25 MHz in Ado-Ekiti were taken in three routes covering the entire State. The result from the data analysis showed that the signal is generally poor along the routes considered as the deviation of the measured path losses from the free space path loss exceed 6 dB.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Case Study

This research was carried out for two different television stations, namely:

i Nigeria Television Authority (NTA), VHF Channel 5 (175.25 MHz), Ekiti State

ii Broadcasting Service of Ekiti State (BSES), UHF Channel 41(631.25 MHz) Ekiti State

3.1.1 The Nigeria Television Authority, Ado Ekiti (NTA Ado Ekiti, Channel 5)

NTA Ado Ekiti, Channel 5 has 5 kW transmitter, Rohde and Schwarz (Germany product).

The station transmitting frequency for video was 175.25 MHz. The output power of the transmitter fluctuated between 3.2 – 3.5 kW all through the period of this work. The mast on which the transmitting antenna was mounted was 133 m high.

3.1.2 Broadcasting Service of Ekiti State, Ado Ekiti (BSES, Ado Ekiti Channel 41)

BSES Ado Ekiti, Channel 41 has 20 kW transmitter, Harris solid state type (Germany product).

The station video carrier frequency was 631.25 MHz. The output power of the transmitter was constant at 3.2 kW all through the period of this work. The mast on which transmitting antenna was mounted was 200 m high.

Plate I: Nigeria Television Authority (NTA) channel 5, transmitting station mast, Ado Ekiti (133 m above sea level)

Plate II: Broadcasting Service of Ekiti-State, channel 41(BSES) transmitting station mast (200 m above the sea level)

3.2 Materials

3.2.1 Digital signal lever meter

The signal lever meter is also known as Field Strength Meter (FSM) (Plate III). A signal level meter is used for measuring a signal level of a transmitter, to install new equipment in a network, for routine maintenance and detect faults. Signal level meter is used to ensure minimum acceptable signal levels within service area.

Plate III: Digital Signal Level Meter GE-5499

The specification of Digital Signal Lever Meter GE-5499 is shown in Table 3.1

Table 3.1: Specification of the digital signal level meter GE-5499

Item	Unit	Parameter
Frequency range	MHz	45 – 860
Level	dBµV	30 – 120
Resolution	dBµV	0.1
Level accuracy	dB	± 1
Band width	kHz	>300
Attenuator	-	Automatic
RF impedance	Ohms	75
AC voltage	V	99

3.2.2 Global positioning system (GPS)

The GPS has official name NAVSTAR GPS. It was developed by the Defence Department of the United State and managed by the Air Force 50th Space Wing of the United State (Plate IV). It is a global navigation satellite system (GNSS) and it is freely used by civilian for navigation purposes, to determine current location, time, and velocity (Geoffrey, 2011).

Plate IV: GPS Receiver

3.3 Methods

The signal levels of the transmitted video signal were taken along some radial routes from the transmitting stations at focus (Figure 3.1) using digital signal level meter (GE-5499) with a dipole antenna of 1.5 dB gain connected to it. The corresponding transmitter-receiver distances, elevation above the sea level and locations were also measured using global positioning system (GPS) 72-Personal Navigator. Measurements were taken all around the towns and villages in all the local government areas in Ekiti State until the signals faded away completely.

3.3.1 Electric field strength models estimation

Data processing and computation were carried out using Microsoft office excel application software. This application was used because it has capabilities of spreadsheet data and statistical analysis. From the measured signal levels, the field strength values in dBμV/m were calculated for a 1 kW Effective Radiated Power (ERP) transmitter to aid comparison with other models. The field strength for each route was obtained and the corresponding field strength as predicted by the free space, Hata, ITU-R.P529-3 and ERC Report 68 models were also estimated (as shown in equation 2.6 to 2.17).

For each model, the Root Mean Square Error (RMSE) (as shown in equation 2.28) was determined along all the routes. Also, the Mean Prediction Error (MPE) (as shown in equation 2.29) was determined and used as a correction factor to modify each model to get the least RMSE. As a result of different routes considered, there are a number of correction factors for each model for the city. So, to generalise each model for all routes in Ekiti State, the average values of the MPE of the four radial routes considered were estimated and used as the correction factors to generalised the field strength models.

3.3.2 Determination of the coverage area

The signal level contour maps around the transmitting stations were drawn for the two television station using Suffer 13 software application, to show the television stations coverage areas. The coverage areas were classified into three for electric field strength E as (Ajewole *et al.*, 2013):

(i) Primary coverage areas, $E > 60$ dBμV

(ii) Secondary coverage areas, 60 dBμV $> E > 30$ dBμV

(iii) Fringe coverage areas, 30 dBμV $> E > 0$ dBμV

Figure 3.1: Routes along which measurement were taken
Source: (www.googleearth /map gallery)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results of Electric Field Strength Models and Signal Coverage Areas for NTA Signal in Ekiti State

4.1.1 Electric field strength

The comparison of the field strength models with the measured field strength for four routes considered are shown in the Figures 4.1 to 4.4. From the Figures shown, it can be observed that the field strength models follow the same trend for all the routes and also, the field strength predicted by Hata and ITU-R P.529-3 models overlap at each other. The free space model has the highest field strength prediction while the ERC Report 68 model has the lowest field strength prediction. Table 4.1 show the Root mean square error (RMSE) of the field strength models for each route considered. From the results, Hata model has the least average RMSE of 8.09 dBμV/m for all the routes.

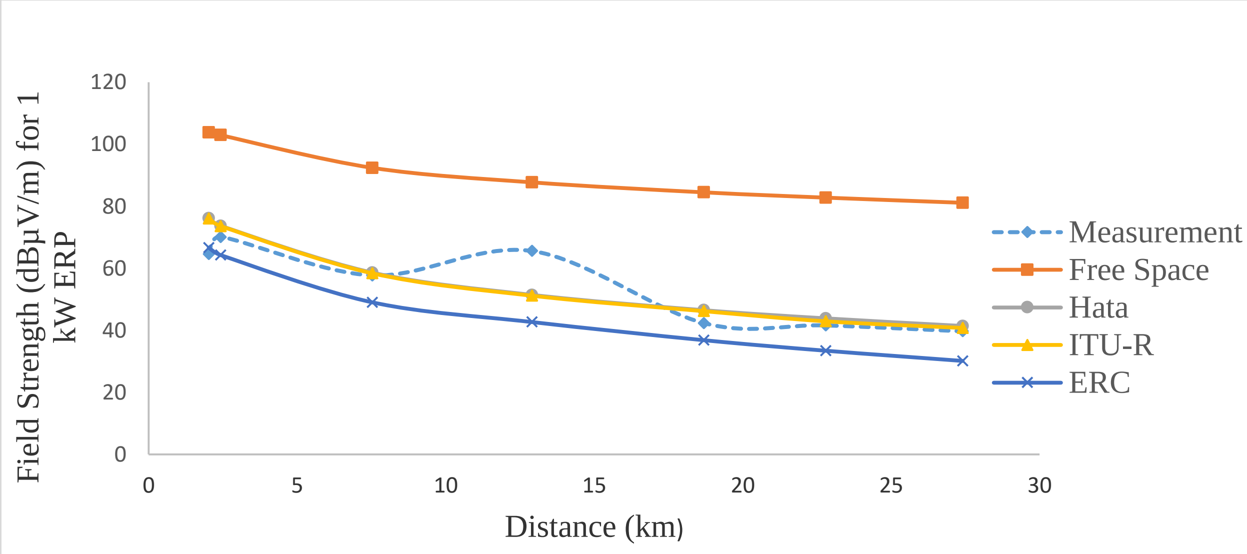


Figure 4.1: Field strength models for route A

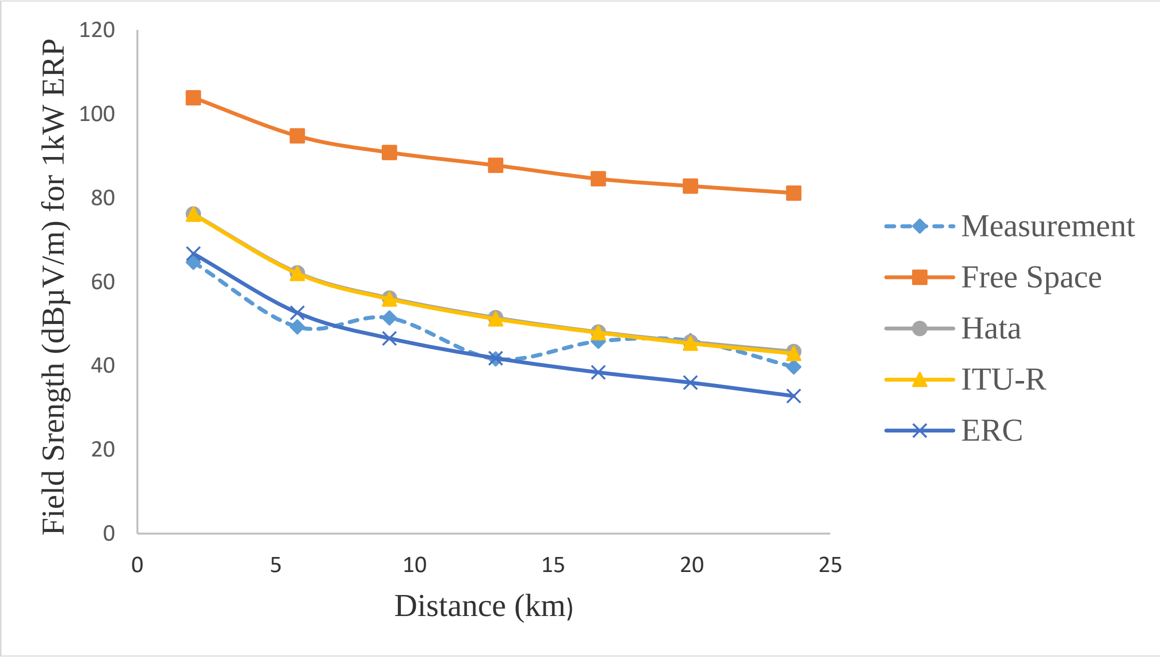


Figure 4.2: Field strength models for route B

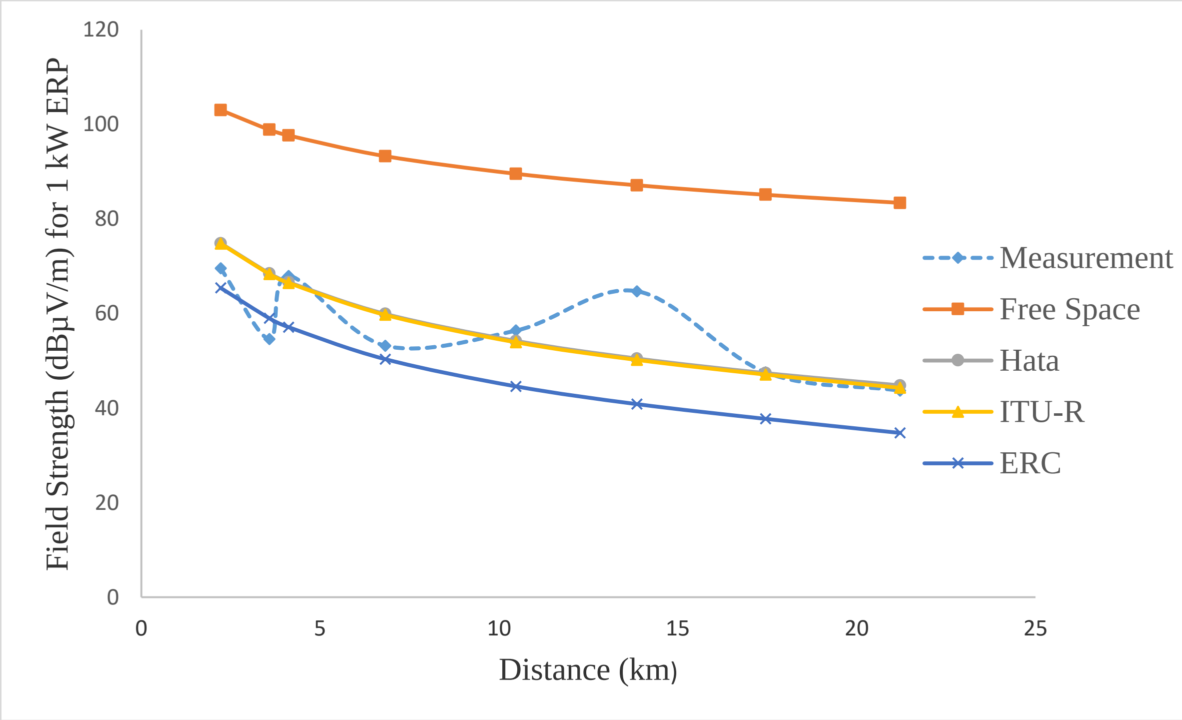


Figure 4.3: Field stre ngth models for route C

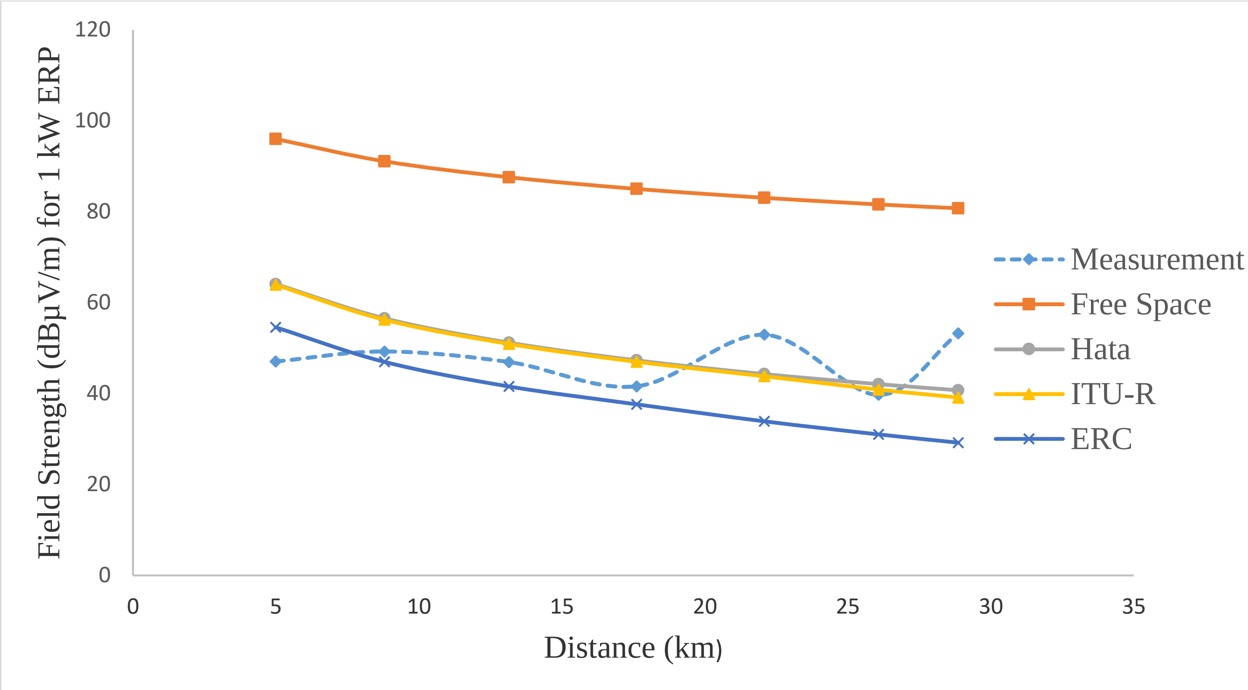


Figure 4.4: Field strength models for route D

Table 4.1: Root mean square error of the field strength models

Route	Free Space (dBμV/m)	Hata (dBμV/m)	ITU-R (dBμV/m)	ERC (dBμV/m)
A	36.84	7.28	7.26	10.87
B	41.16	7.89	7.73	5.87
C	35.62	7.72	7.74	11.44
D	38.82	9.49	9.71	12.65
Average	38.11	8.09	8.11	10.20

4.1.1.1 Modified field strength models

The modified field strength models are shown in Figures 4.5 to 4.8. Table 4.2 shows the correction factors used for the modified field strength models while Table 4.3 gives the RMSE of the modified field strength models for each route. Both Hata and ITU-R P. 529-3 models has the highest field strength prediction and overlap each other while the free space model has the lowest field strength prediction. Therefore, the models follow the same trend for the routes and the free space model give the least average RMSE of 5.84 dBμV/m for all the routes.

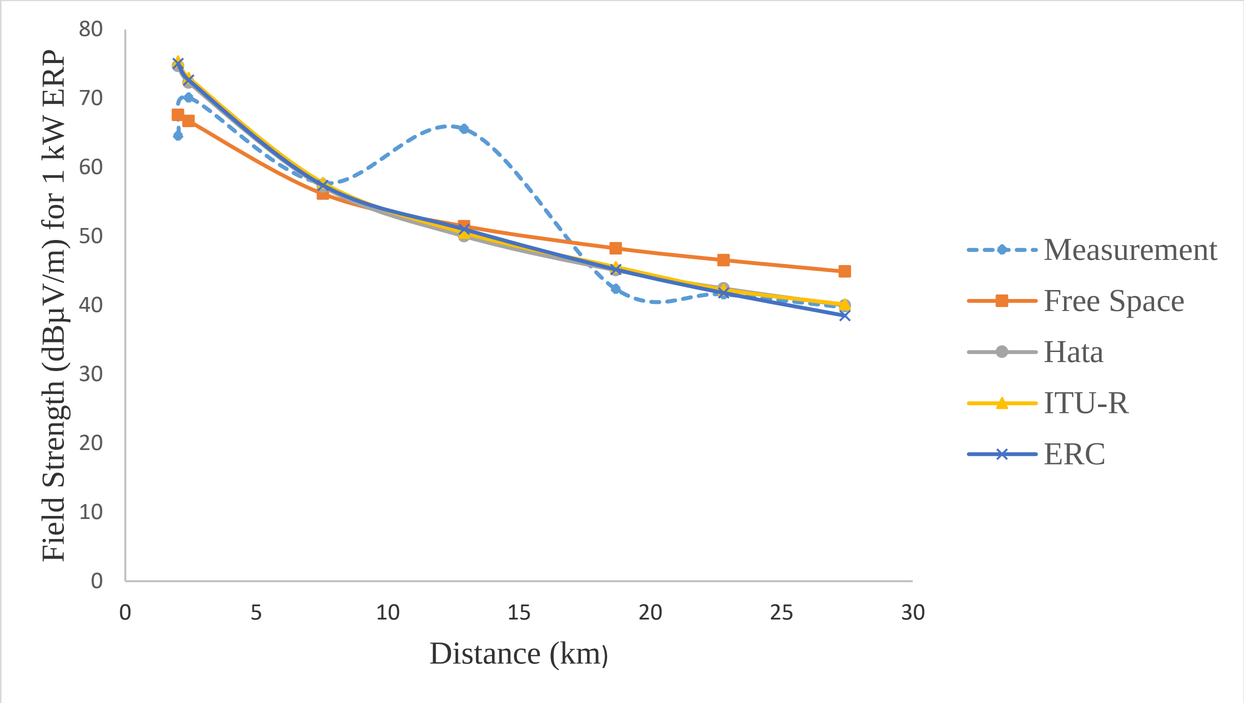


Figure 4.5: Modified field strength models for route A

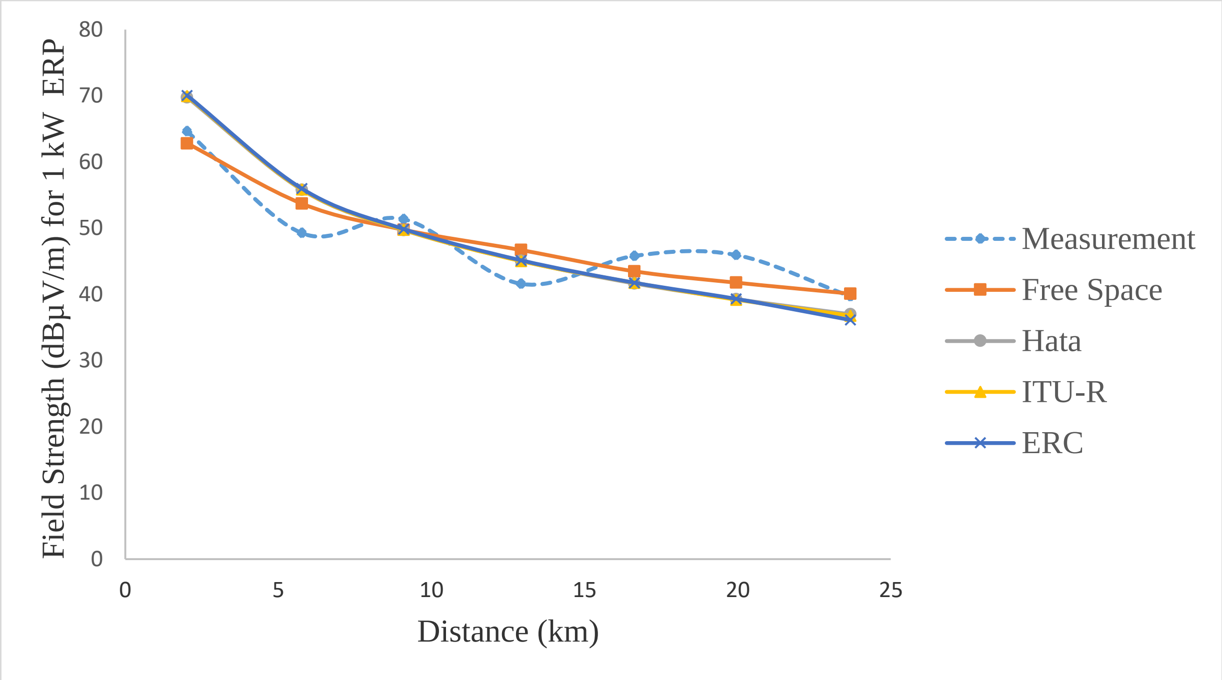


Figure 4.6: Modified field strength models for route B

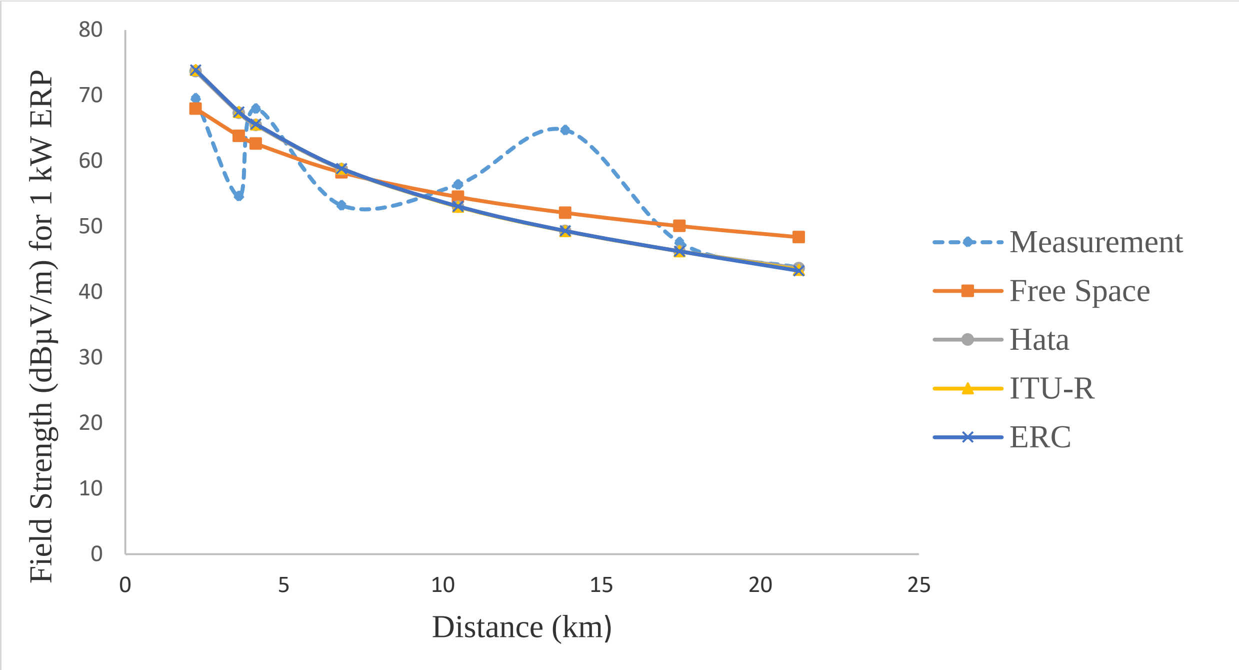


Figure 4.7: Modified field strength models for route C

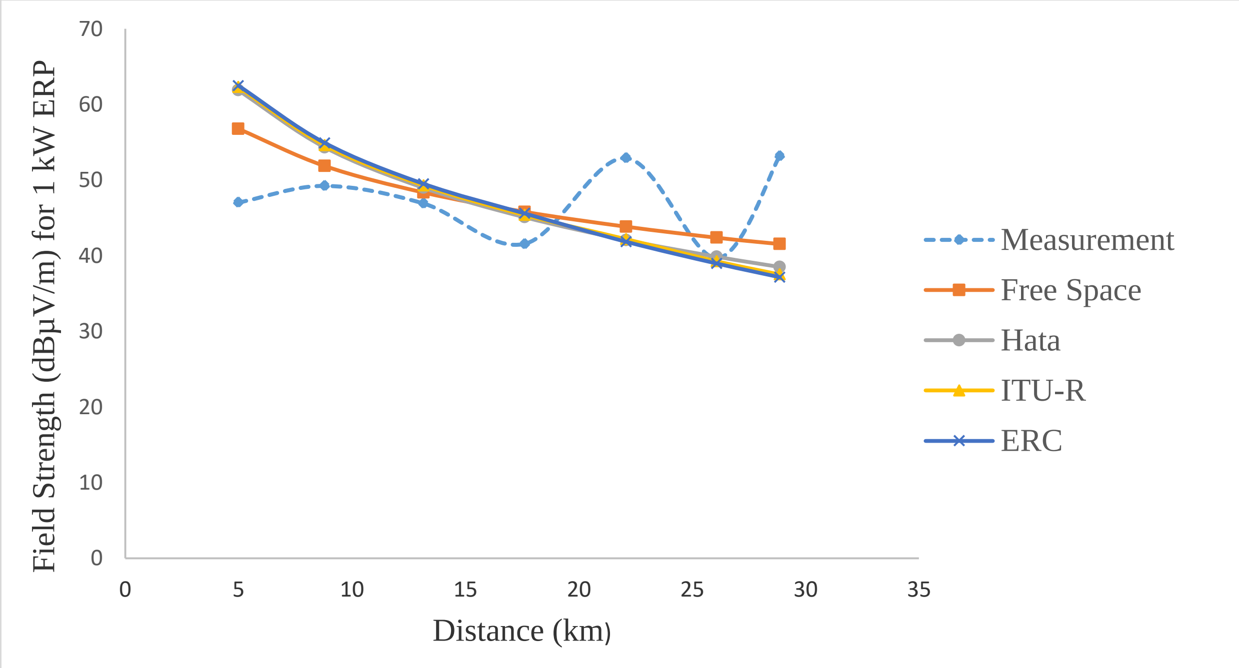


Figure 4.8: Modified field strength models for route D

Table 4.2: Correction factors used for the modified and the generalised field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	-36.24	-1.41	-0.63	8.37
B	-41.03	-6.36	-6.11	3.36
C	-35.04	-1.18	-0.89	8.48
D	-39.19	-2.19	-1.59	7.98
Average	-37.87	-2.78	-2.30	7.04

Table 4.3: Root mean square error values of the modified field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	6.63	7.14	7.19	6.93
B	3.26	4.67	4.73	4.81
C	6.44	7.63	7.68	7.68
D	7.04	9.22	9.58	9.81
Average	5.84	7.16	7.29	7.30

4.1.1.2 Generalised field strength models

The generalised field strength models are shown in Figures 4.9 to 4.12. The free space has the lowest field strength prediction. The correction factors used to generalise the field strength models are the average values of the mean prediction error of all the four routes. Table 4.4 shows the RMSE values of the generalised field strength models for all the routes. From the results, the free space model has the least error for all the routes considered with 6.38 dBµV/m, 4.54 dBµV/m, 7.04 dBµV/m, and 7.16 dBµV/m which corresponding to routes A, B, C and D respectively. It is observed from the Table that, the free space model has the average least value of the RMSE of the generalised field strength models for all the routes considered.

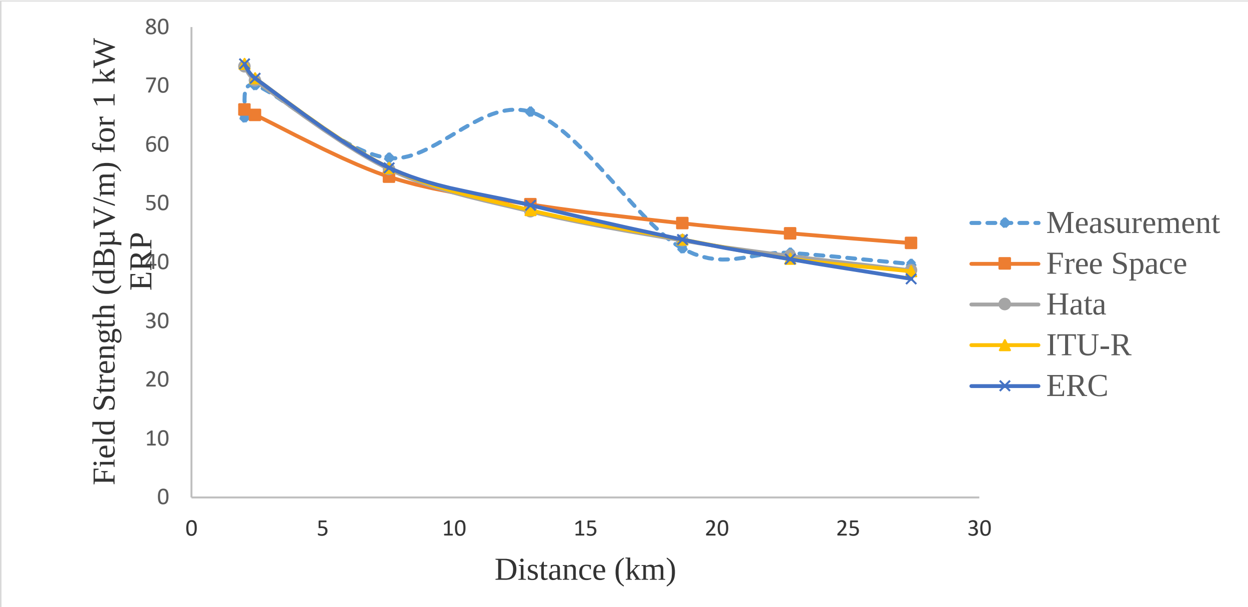


Figure 4.9: Generalised field strength models for route A

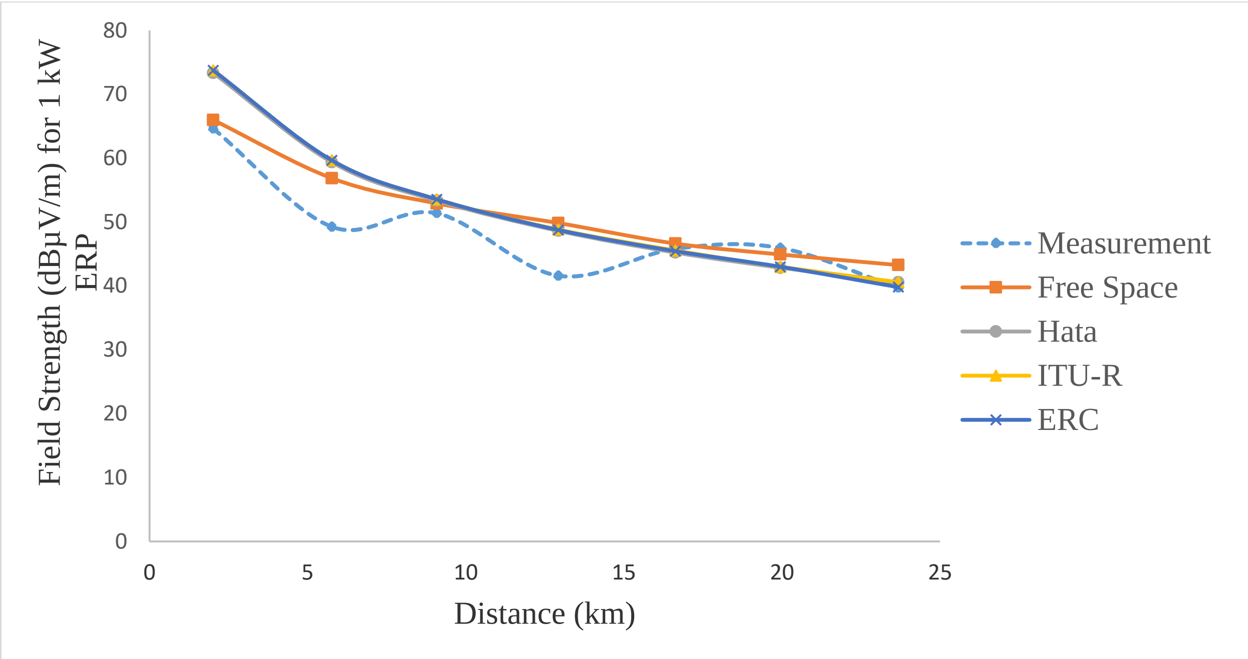


Figure 4.10: Generalised field strength models for route B

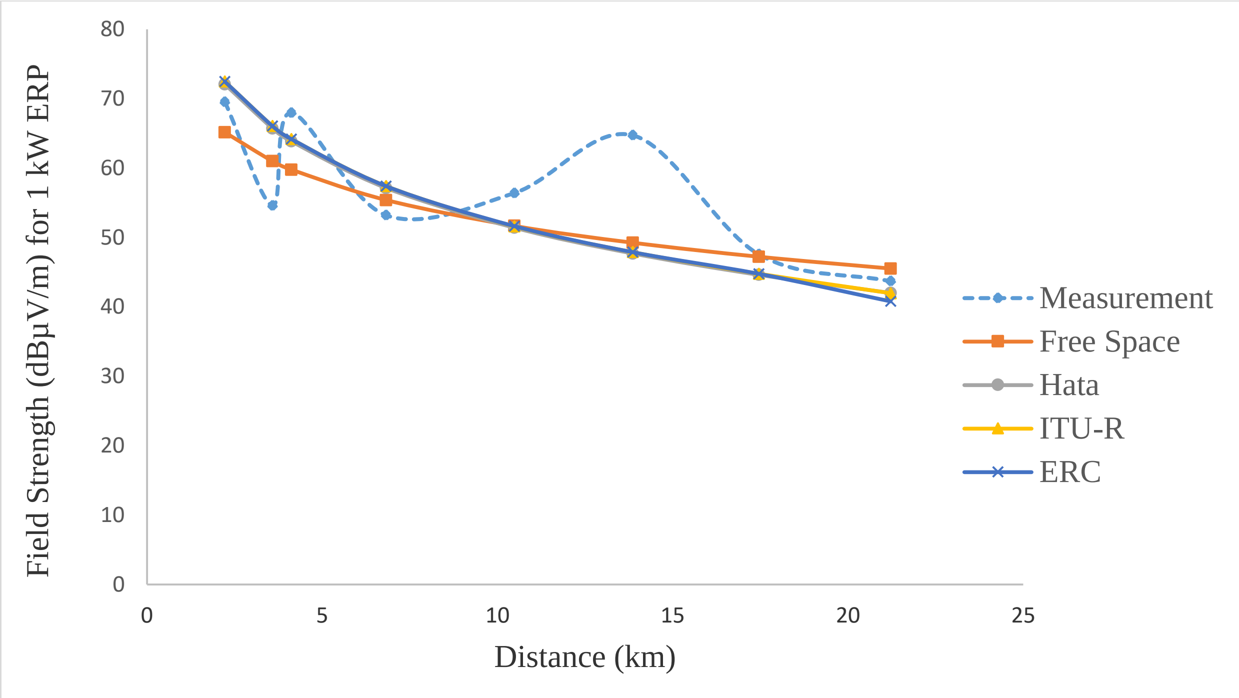


Figure 4.11: Generalised field strength models for route C

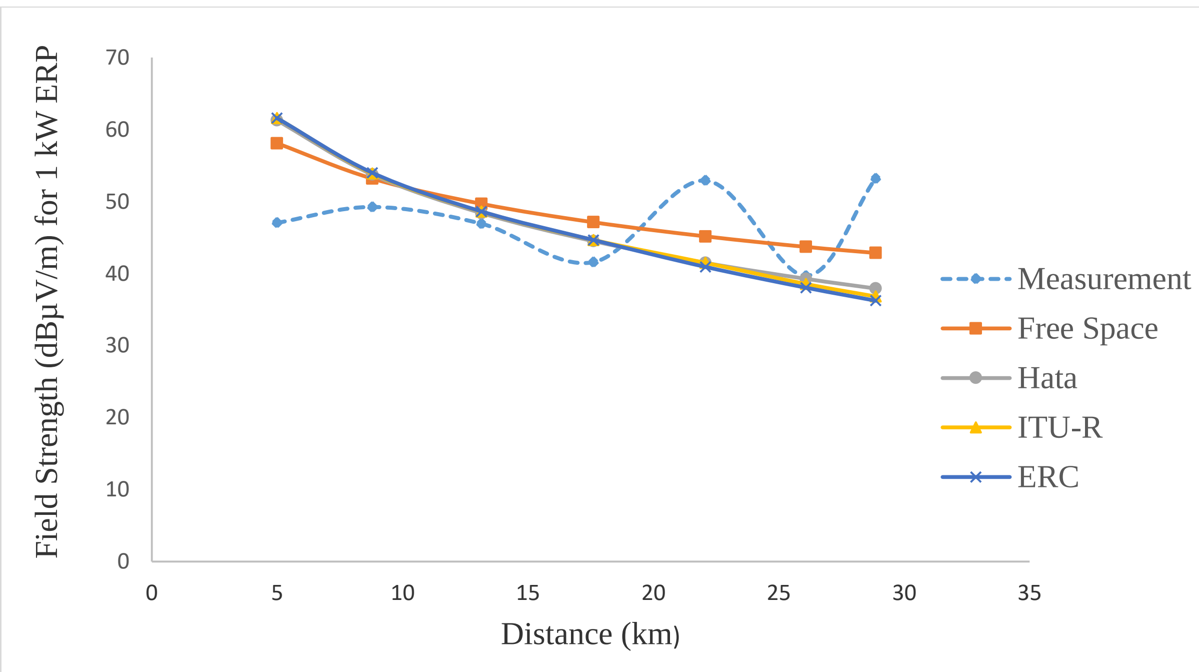


Figure 4.12: Generalised field strength models for route D

Table 4.4: Root mean square error values of the generalised field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	6.38	7.26	7.29	7.06
B	4.54	5.88	6.07	6.04
C	7.04	7.81	7.81	7.85
D	7.16	9.24	9.61	9.86
Average	6.28	7.54	7.69	7.70

4.1.2 Signal Coverage Area

The contour map of the signal coverage for NTA Ado Ekiti transmitting station is shown in Figure 4.13 and the signal coverage is given in Tables 4.5 to Table 4.6 as percentages of the transmitting station relative to total landmass of Ekiti State as well as the local government area. It is obvious that the television station does not have an optimum coverage for the State. The television station covers only 40.16 % of the entire state.

The coverage area of the transmitting station shows that only 13.53 % of the state has primary coverage area and 11.57 % is within the secondary coverage area while 15.06 % of the state lies within fringe coverage areas of the television station. Tables 4.7 to 4.9 captures some of towns and villages within the coverage area.

The present configuration of the transmitter does not provide optimal coverage in the state. Therefore, there is need for installation of boaster stations in Ikole, and Emure Local Government Areas of Ekiti State to give adequate coverage across the state.

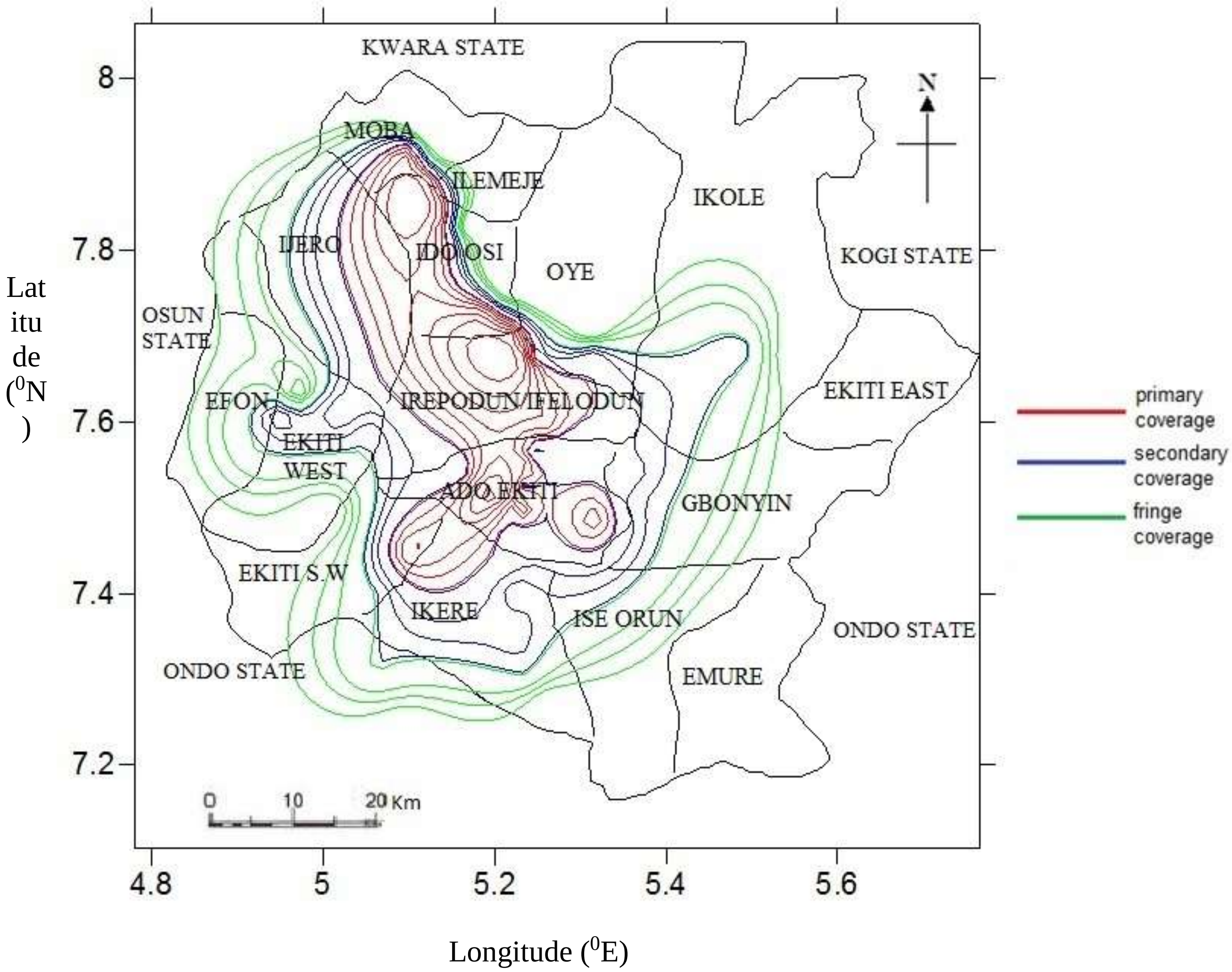


Figure 4.13: Coverage area of the NTA Ado Ekiti, Channel 5 in Ekiti State

Table 4.5: Percentage of the coverage area of NTA television transmitting station relative to total landmass of Ekiti State

Station	% of primary coverage area	% of secondary coverage area	% of fringe coverage area	Total % of coverage area
NTA Ado Ekiti, channel5	13.53	11.57	15.06	40.16

Table 4.6: The percentage of each local government areas covered by the NTA Ado Ekiti, channel 5 transmitting station in Ekiti State

LGA	Approximate distance (km)	% of Primary coverage area	% of Secondary coverage area	% of Fringe coverage area	Total % of coverage area
Ado Ekiti	2.22	68.9	24.5	0	93.40
Oye	24.59	0.8	8.90	11.30	21.00
Ikole	48.29	0	5.70	14.00	19.70
Gbonyin	19.76	0	12.24	18.87	31.11
Ise Orun	32.2	0	6.31	24.20	30.51
Ikere	14.65	15.8	22.35	18.82	56.97
Ekiti South West	15.48	13.04	14.49	29.70	57.23
Ekiti West	17.61	0	17.36	43.10	60.47
Efon	28.75	0	8.60	44.00	52.60
Moba	31.23	16.7	13.30	24.50	54.50
Ijero	23.4	26.3	35.08	10.52	71.90
Irepodun/Ifelodun	6.32	50.0	4.50	0	54.50
Ilemeje	31.6	3.63	14.50	20.00	38.17
Ido Osi	29.98	60.0	17.14	8.57	85.71

Table 4.7: Some towns and villages within the primary coverage area

LGA	Latitude (°N)	Longitude (°E)	Elevation (m)	Approximate distance (km)	Town/Villages
Ado- Ekiti	7.618	5.207	426	2.22	Ado, Fajuyi
Oye	7.799	5.489	555	18.42	Oye
Ikere	7.552	5.215	405	9.09	Ikere town
Ekiti South West	7.611	5.129	527	7.53	Ilawe, Igbarao
Irepodun/Ifelodun	7.678	5.192	449	5.27	Afao, Iyin
Moba	7.961	5.140	555	37.04	Otun
Ijero	7.836	5.686	503	23.40	Ijero town
Ido Osi	7.787	5.243	561	18.27	Ifaki, Ora
Ilemeje	7.978	5.261	538	30.60	Iye

Table 4.8: Some towns and villages within secondary coverage area

LGA	Latitude (°N)	Longitude (°E)	Elevation (m)	Approximate distance (km)	Town/Villages
Ado Ekiti	7.616	5.223	428	3.58	Ado Ekiti
Oye	7.792	5.281	565	20.3	Oye Ayegbaju
Ikere	7.518	5.224	388	12.93	Ikere, Odo-oja
Ekiti South West	7.564	5.099	405	12.93	Igbara- odo
Irepodun/Ifelodun	7.669	5.125	570	8.78	Iworoko, Afao
Moba	7.996	5.121	543	37.04	Otun
Ijero	7.820	5.082	452	25.2	Ijero
Ido Osi	7.787	5.243	561	18.27	Ifaki, Ora
Ilemeje	7.970	5.258	547	32.6	Ijeshamodu
Efon	7.724	4.95	437	28.86	Efon Alaye
Ekiti West	7.685	5.089	496	13.15	Aramoko
Gbonyin	7.626	5.386	387	21.22	Ijan,Oke-Orun
Ise Orun	7.470	5.465	392	32.15	Ise
Ikole	7.795	5.545	520	32.5	Ikole

Table 4.9: Some towns and villages within the fringe area

LGA	Latitude(°N)	Longitude(°E)	Elevation (m)	Approximate distance (km)	Town/Villages
Ikole	7.796	5.545	428	32.52	Ikole
Oye	7.799	5.489	555	24.59	Ilupeju
Ikere	7.388	5.26	383	27.84	Ikere area
Ekiti South West	7.422	5.06	355	27.41	Igbara
Ekiti West	7.725	5.018	514	22.08	Erio Ekiti
Moba	7.996	5.121	543	48.29	Otun,
Ijero	7.836	5.686	505	26.7	Ijero
Ido Osi	7.903	5.165	567	30.00	Ayetoro
Ilemeje	7.97	5.258	547	30.64	Iye
Efon	7.680	4.924	513	30.36	Efon valley
Gbonyin	7.678	5.574	396	33.02	Orun
Ise Orun	7.47	5.465	395	32.17	Ise

4.2 Results of Electric Field Strength Models and Signal Coverage Areas for BSES in Ekiti State

4.2.1 Electric field strength

The comparison of the field strength models with the measured field strength for four routes considered are shown in the Figures 4.14 to 4.17. The models have the same trend for all the routes considered. From the Figures shown, the free space model has the highest field strength prediction while the ERC Report 68 model has the lowest field strength prediction. The RMSE of the field strength models for each route is shown in the Table 4.10. For routes A, B, C and D, Hata model has the least RMSE of 11.71 dBμV/m

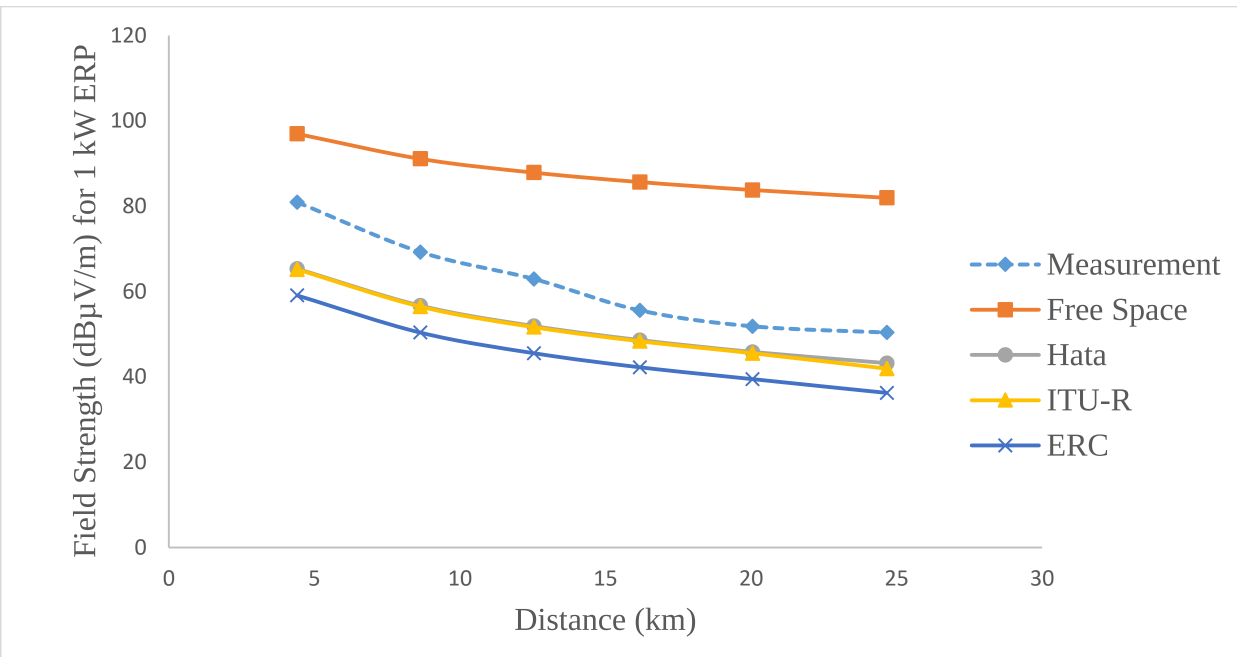


Figure 4.14: Field strength models for route A

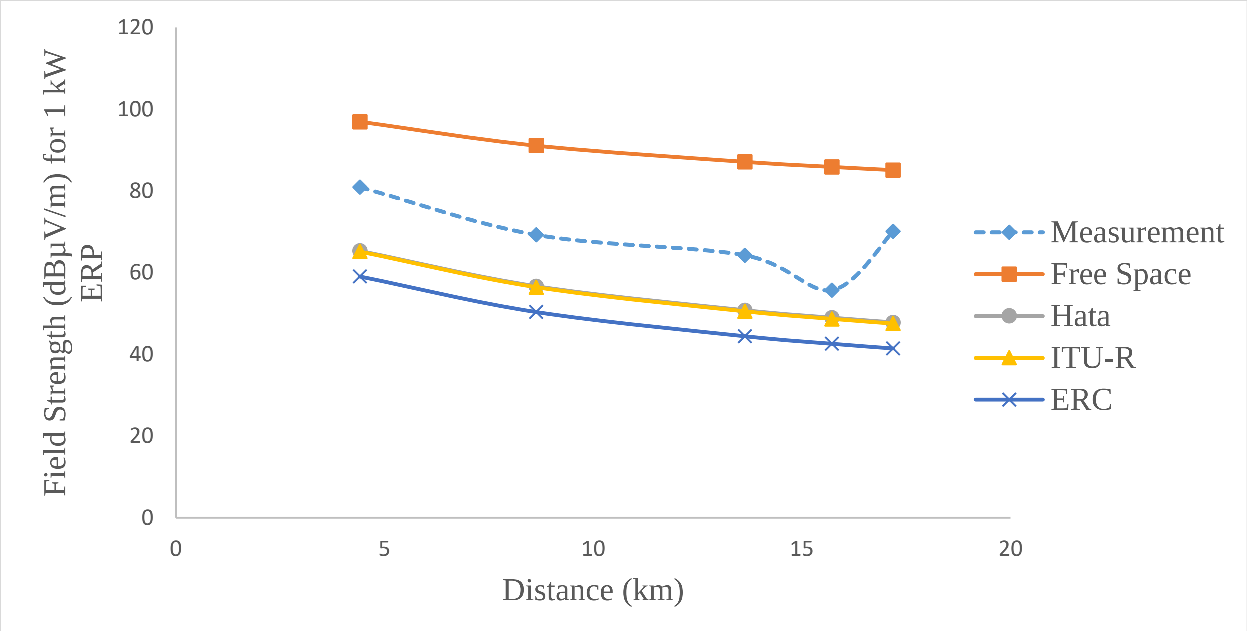


Figure 4.15: Field strength models for route B

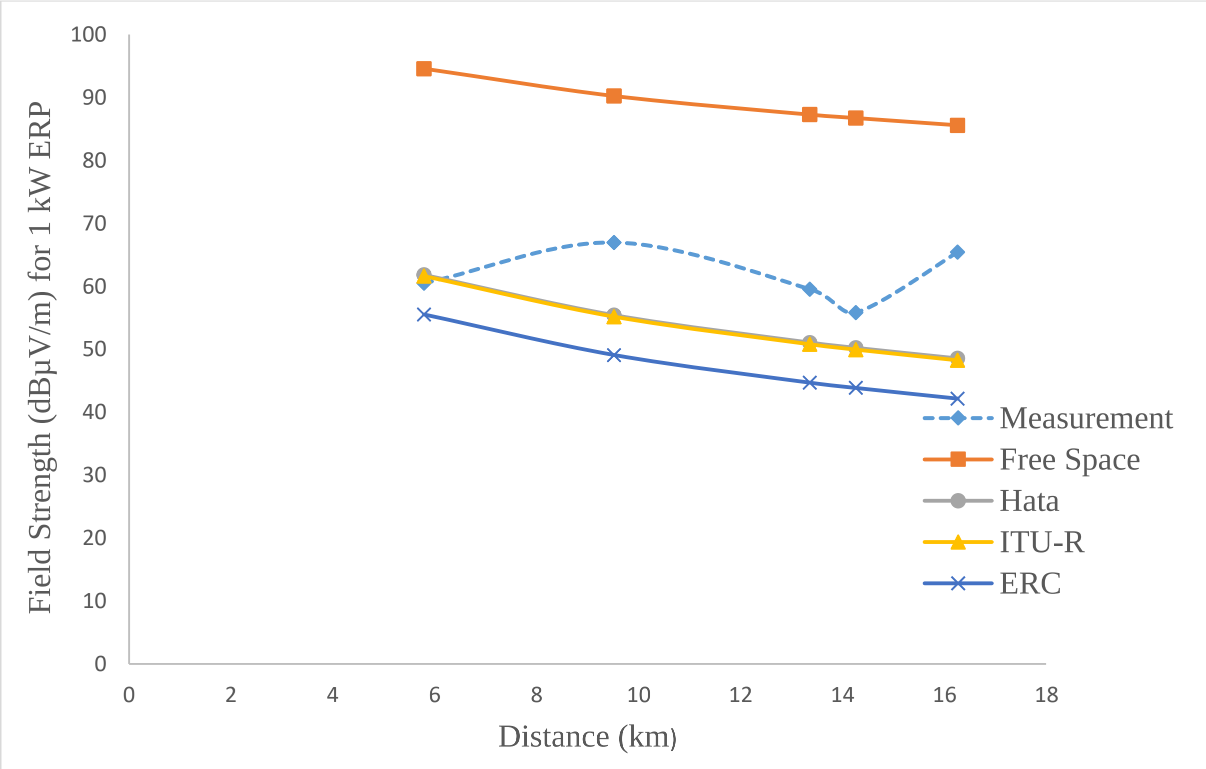


Figure 4.16: Field strength models for route C

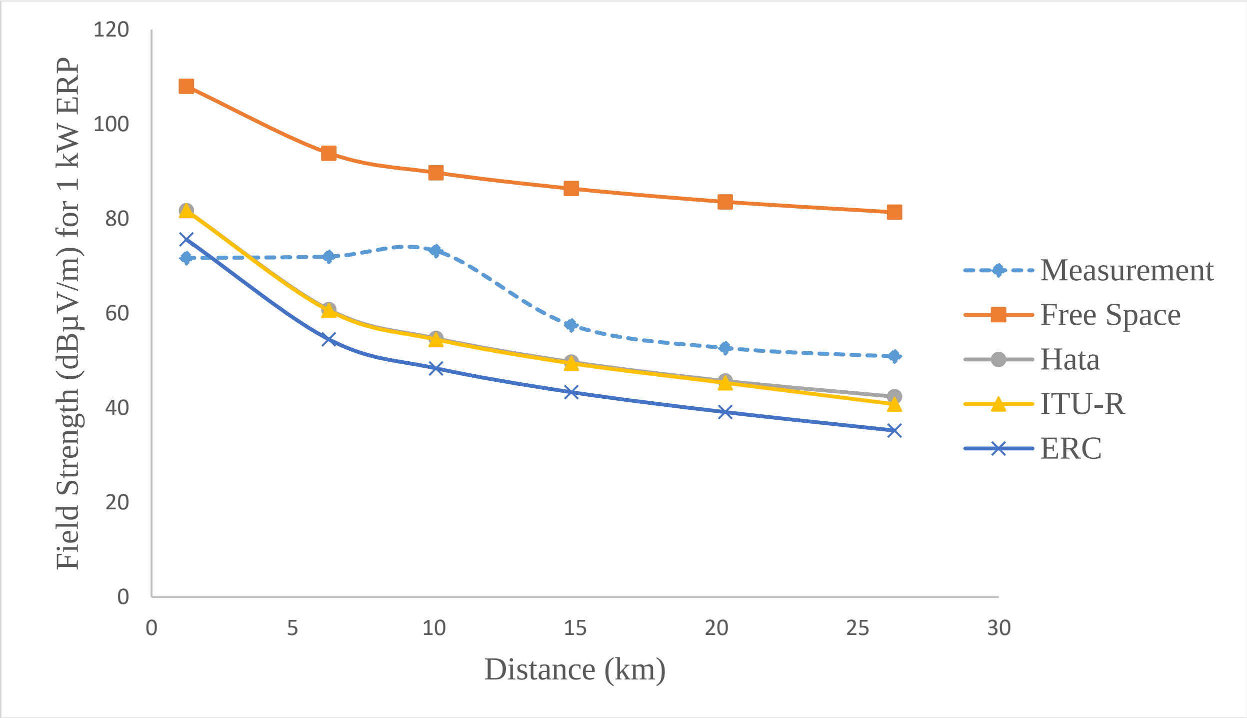


Figure 4.17: Field strength models for route D

Table 4.10: Root mean square error of the field strength models

Route	Free Space (dBμV/m)	Hata (dBμV/m)	ITU-R (dBμV/m)	ERC (dBμV/m)
A	26.70	10.47	11.24	16.67
B	21.87	14.98	15.02	20.83
C	27.60	10.22	10.45	15.80
D	28.24	11.18	11.57	16.17
Average	26.10	11.71	12.07	17.36

4.2.1.1 Modified field strength models

Figure 4.18 to 4.21 shows the modified field strength models for all the routes considered. Table 4.11 shows the correction factors used for modified field strength models while Table 4.12 gives the RMSE of the modified field strength models for each route. From the Figures shown, free space model has the lowest field strength prediction with all the models follow the same trend.

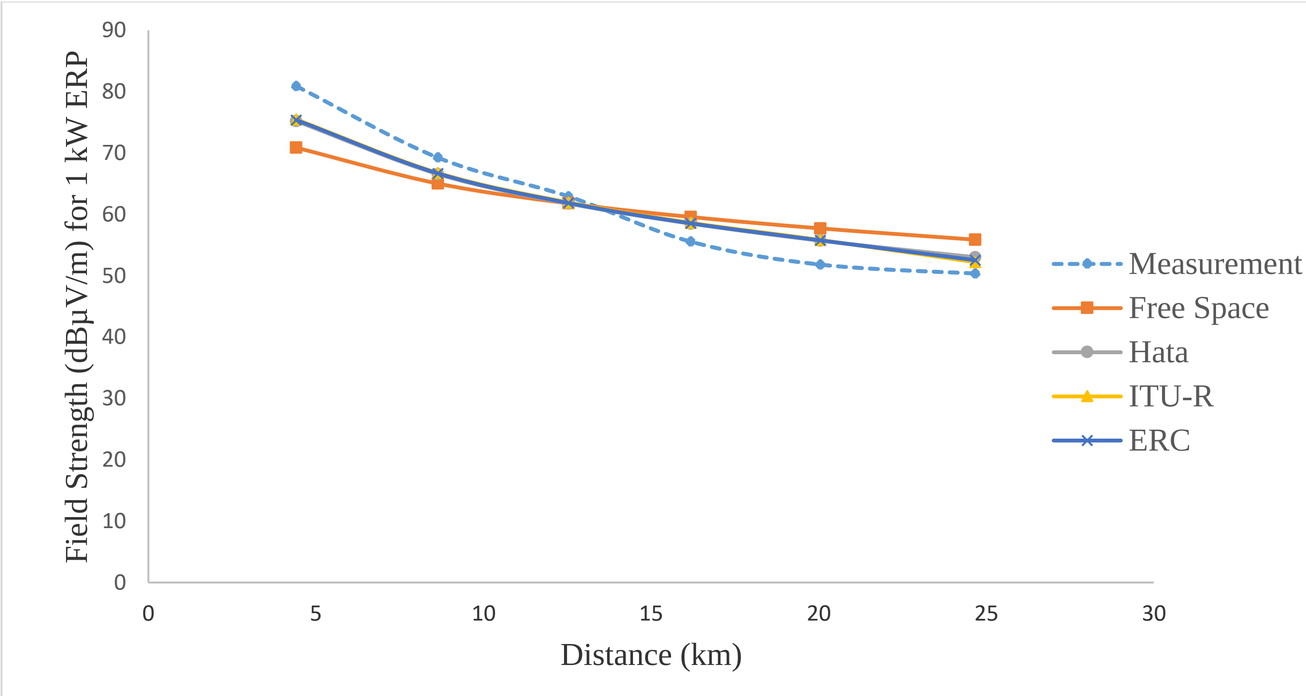


Figure 4.18: Modified field strength models for route A

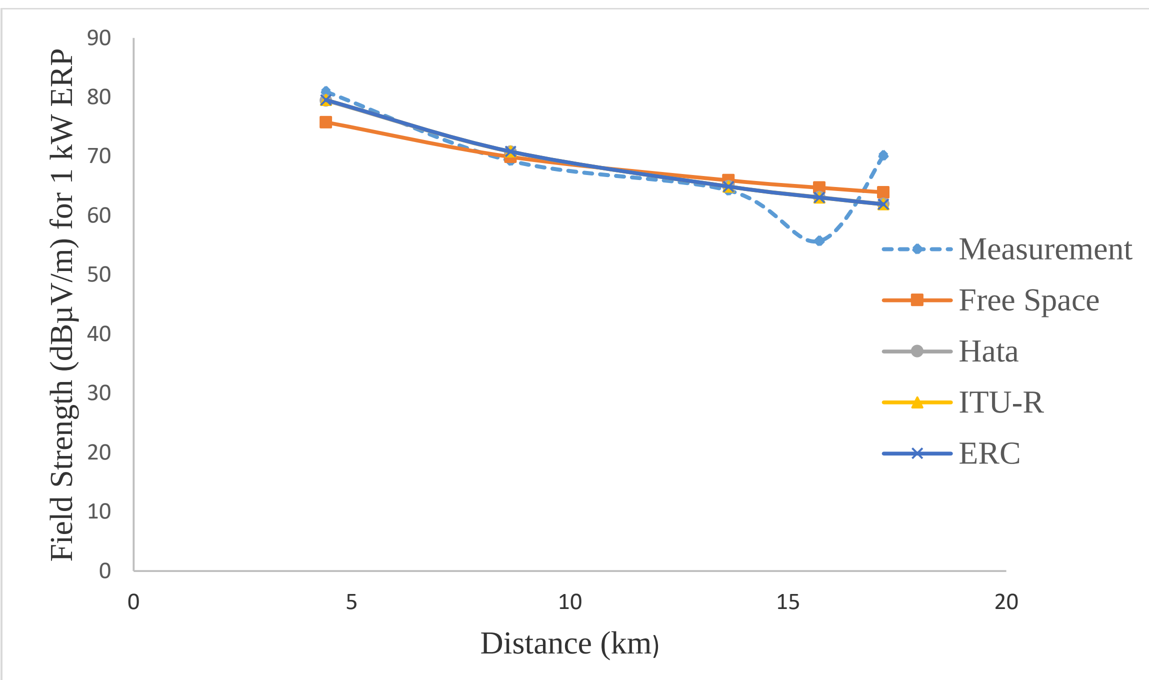


Figure 4.19: Modified field strength models for route B

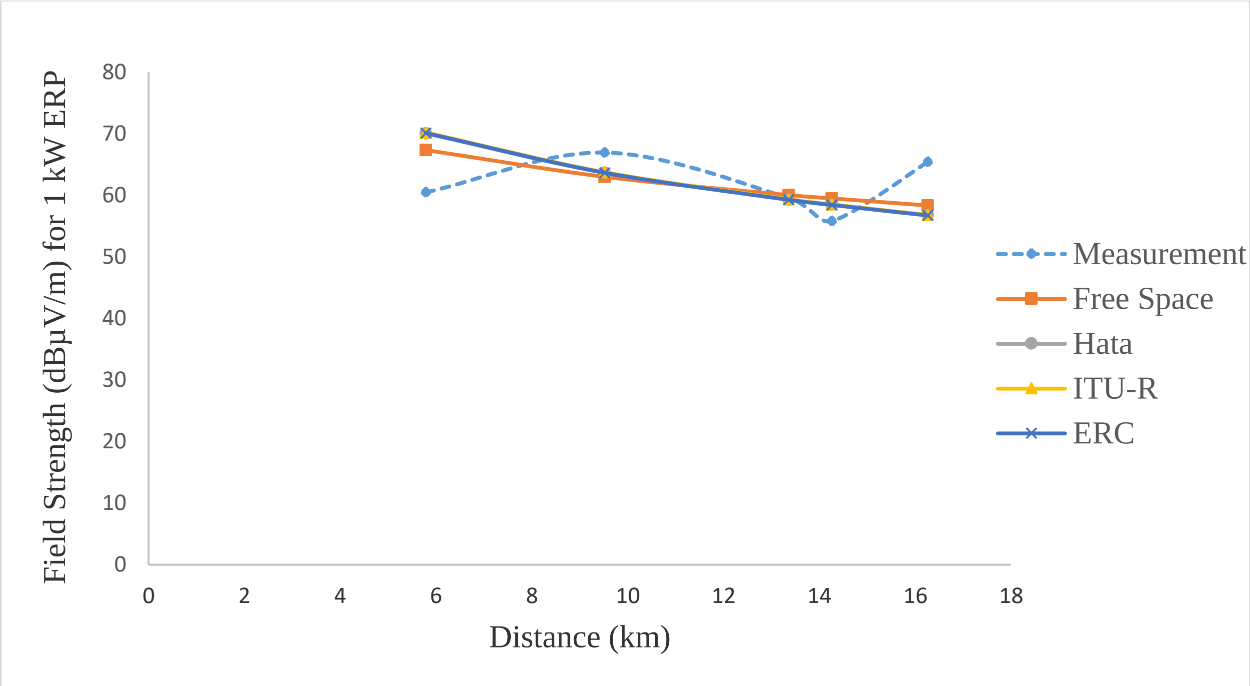


Figure 4.20: Modified field strength models for route C

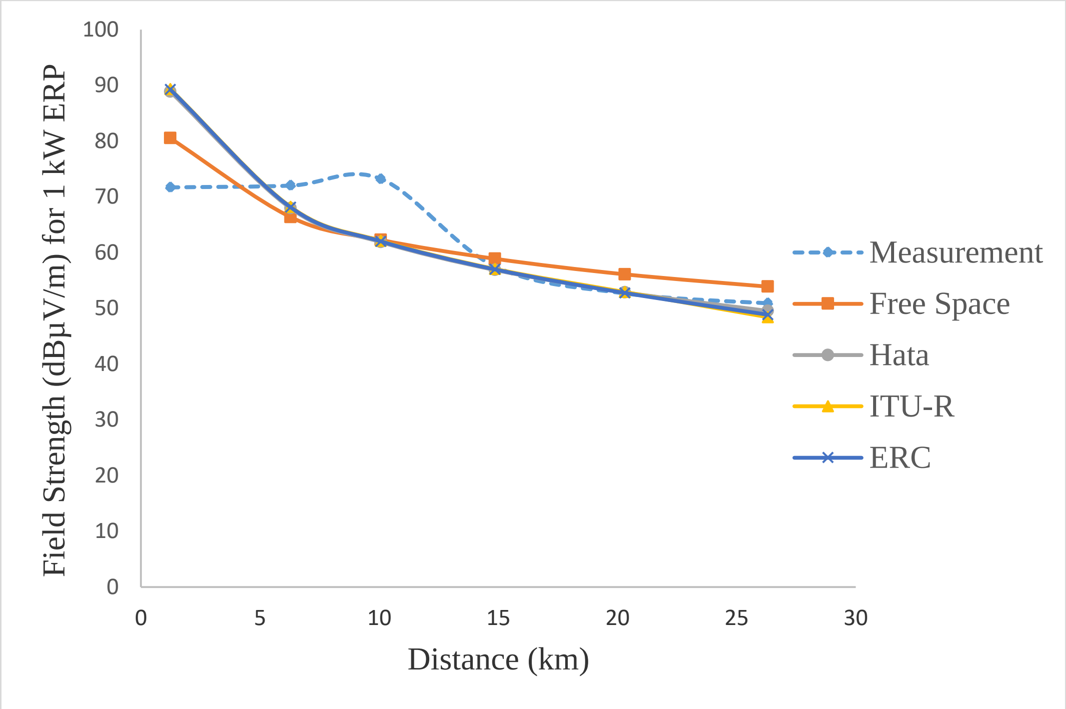


Figure 4.21: Modified field strength models for route D

Table 4.11: Correction factors used for the modified and the generalised field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	-26.06	9.89	10.32	16.33
B	-21.18	14.11	14.36	20.46
C	-27.22	8.24	8.57	14.58
D	-27.49	7.16	7.62	13.64
Average	-25.48	9.85	10.21	16.25

Table 4.12: Root mean square error of the modified field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	5.78	3.46	3.30	3.35
B	5.45	4.99	4.99	5.47
C	5.02	6.06	6.09	6.08
D	6.48	8.59	8.71	8.69
Average	5.68	5.77	5.77	5.89

4.2.1.2 Generalised field strength models

The generalised field strength models is shown in Figures 4.22 to 4.25. The free space has the lowest field strength prediction. The correction factors used to generalise the field strength models for Ekiti are the average values of the mean prediction error of all the four routes. Table 4.13 shows the RMSE values of the generalised field strength models for each routes and the RMSE values for Ekiti are the average values of the RMSE of the generalised field strength models for all the routes. It is observed from the results that, free space model has the average least RMSE of 6.21 dBµV/m for all the routes considered.

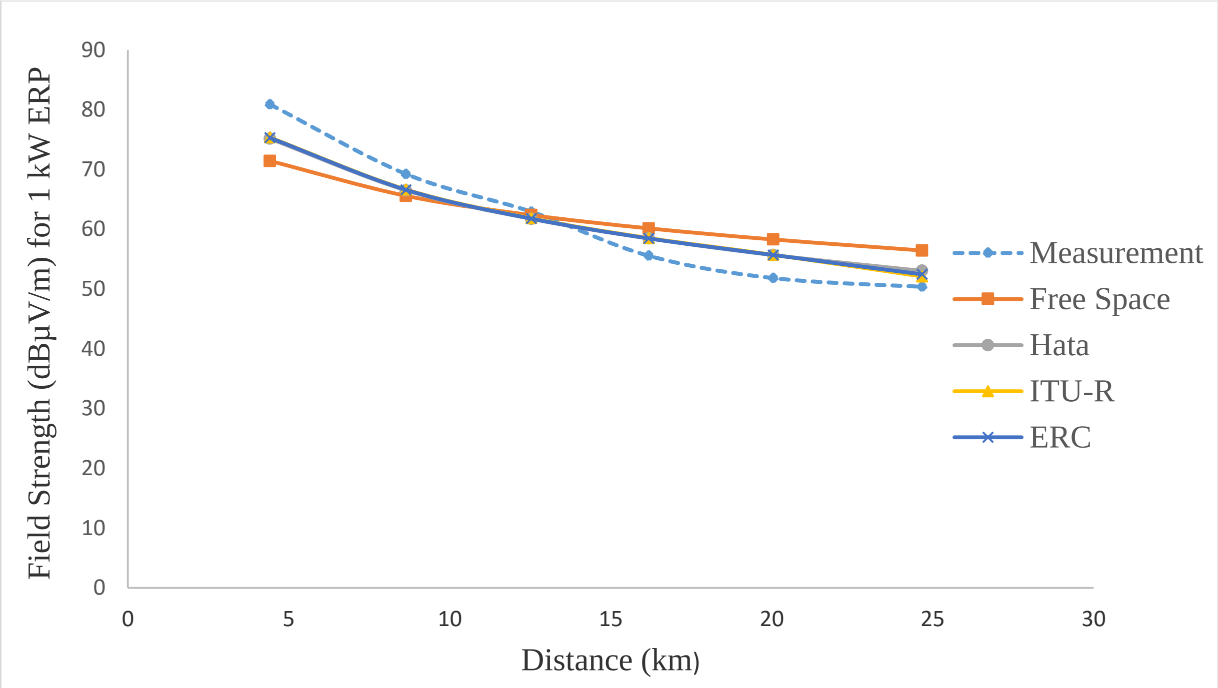


Figure 4.22: Generalised field strength models for route A

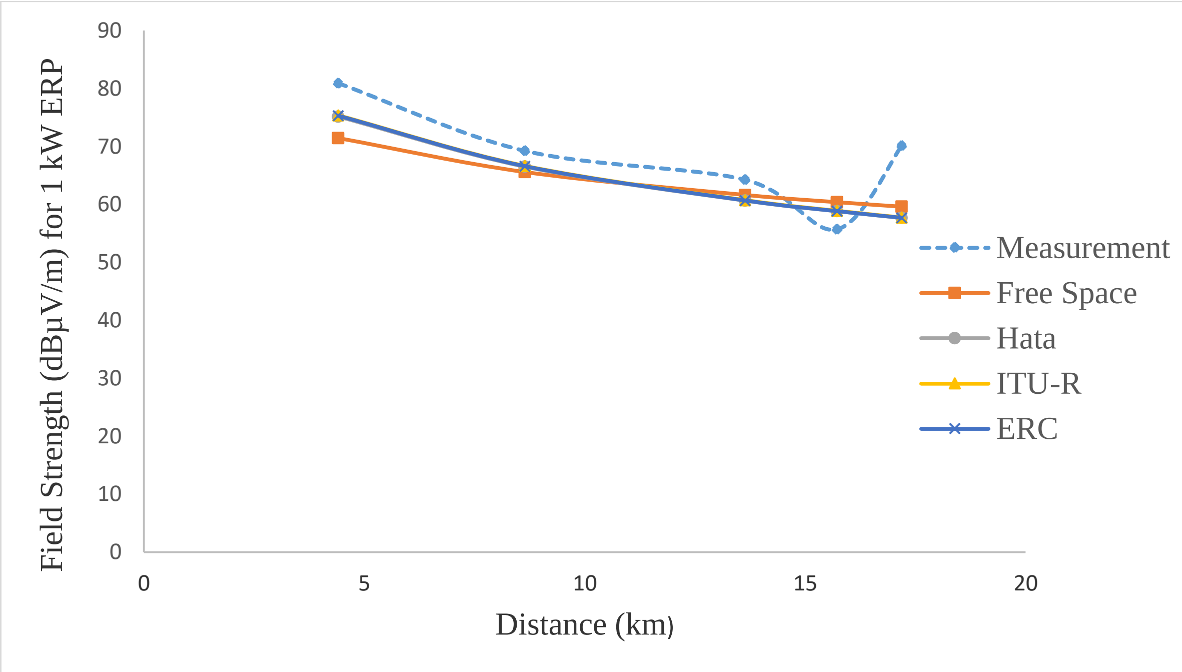


Figure 4.23: Generalised field strength models for route B

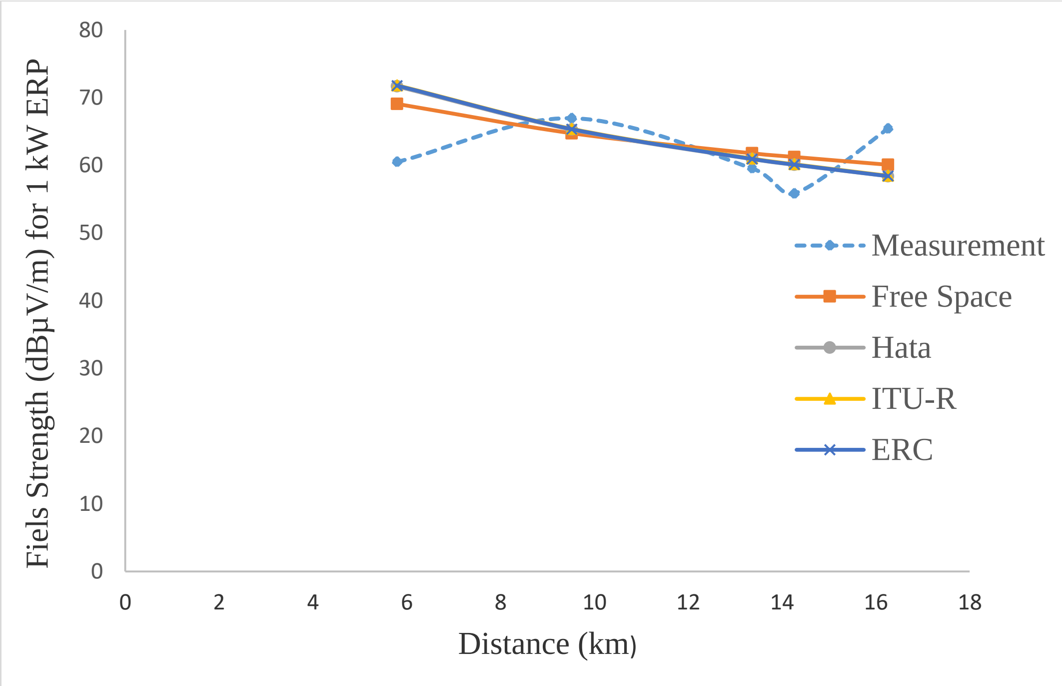


Figure 4.24: Generalised field strength models for route C

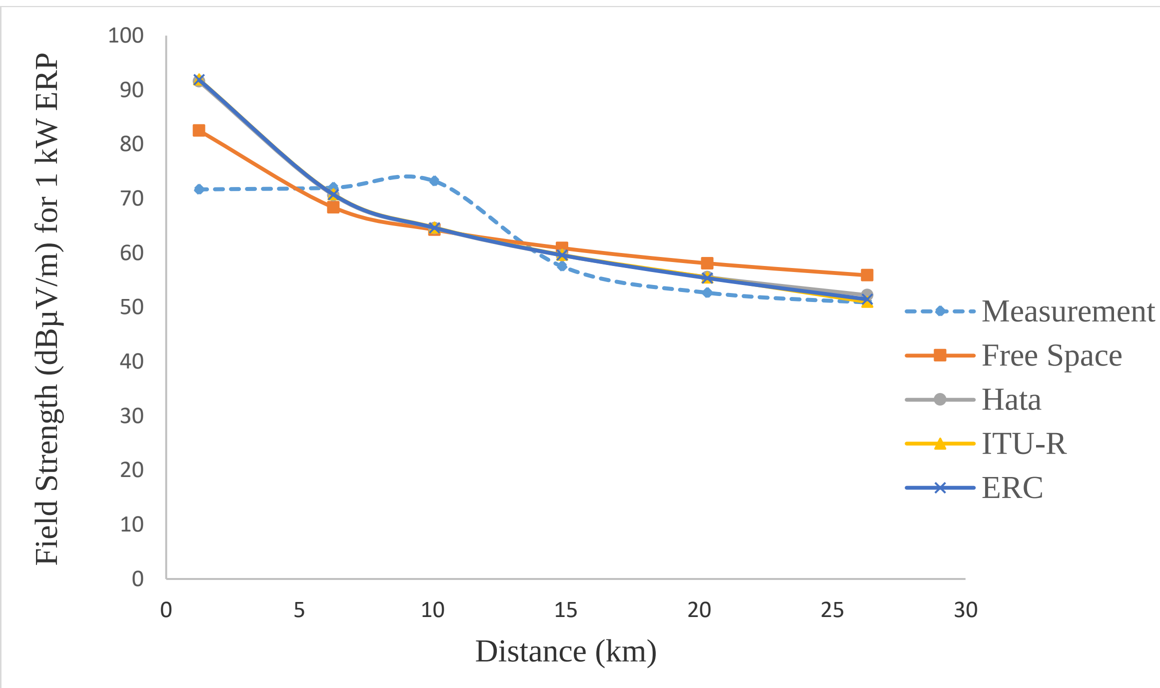


Figure 4.25: Generalised field strength models for route D

Table 4.13: Root mean square error of the generalised field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	5.81	3.47	3.30	3.35
B	6.95	6.59	6.52	6.55
C	5.31	6.27	6.32	6.31
D	6.78	9.03	9.08	9.07
Average	6.21	6.34	6.30	6.32

4.2.2 Signal coverage area

The contour map of the signal coverage for BSES Ado Ekiti transmitting station in Ekiti State is shown in Figure 4.26 and the signal coverage is given in Tables 4.14 to 4.15 as percentages of the entire landmass of the state as well as the local government area. Tables 4.16 to 4.18 shows some of towns and villages within the coverage area in terms of primary, secondary and fringe coverage areas. It is obvious that the television station does not have an optimum coverage area for the State. The television station covers 24.73 % of Ekiti State.

The coverage area of the transmitting station shows that only 3.72 % of the state has primary coverage area and 7.29 % of the state is within the secondary coverage area while 13.72 % of the state lies within the fringe coverage areas of the television station. From Figure 4.26, it is observed that some local government areas of the state are not serviced by the station and the towns that fall within this area are: Moba, Ilemeje, Ekiti East and Emure; and few areas within Efon and Ijero local government areas because of their topographic features. Therefore, there is need for repeater station at certain intervals to provide good reception of television signal coverage for all parts of the state.

In summary, Table 4.19 gives an overview of percentage of coverage areas of the two television stations relative to the total land mass of Ekiti State.

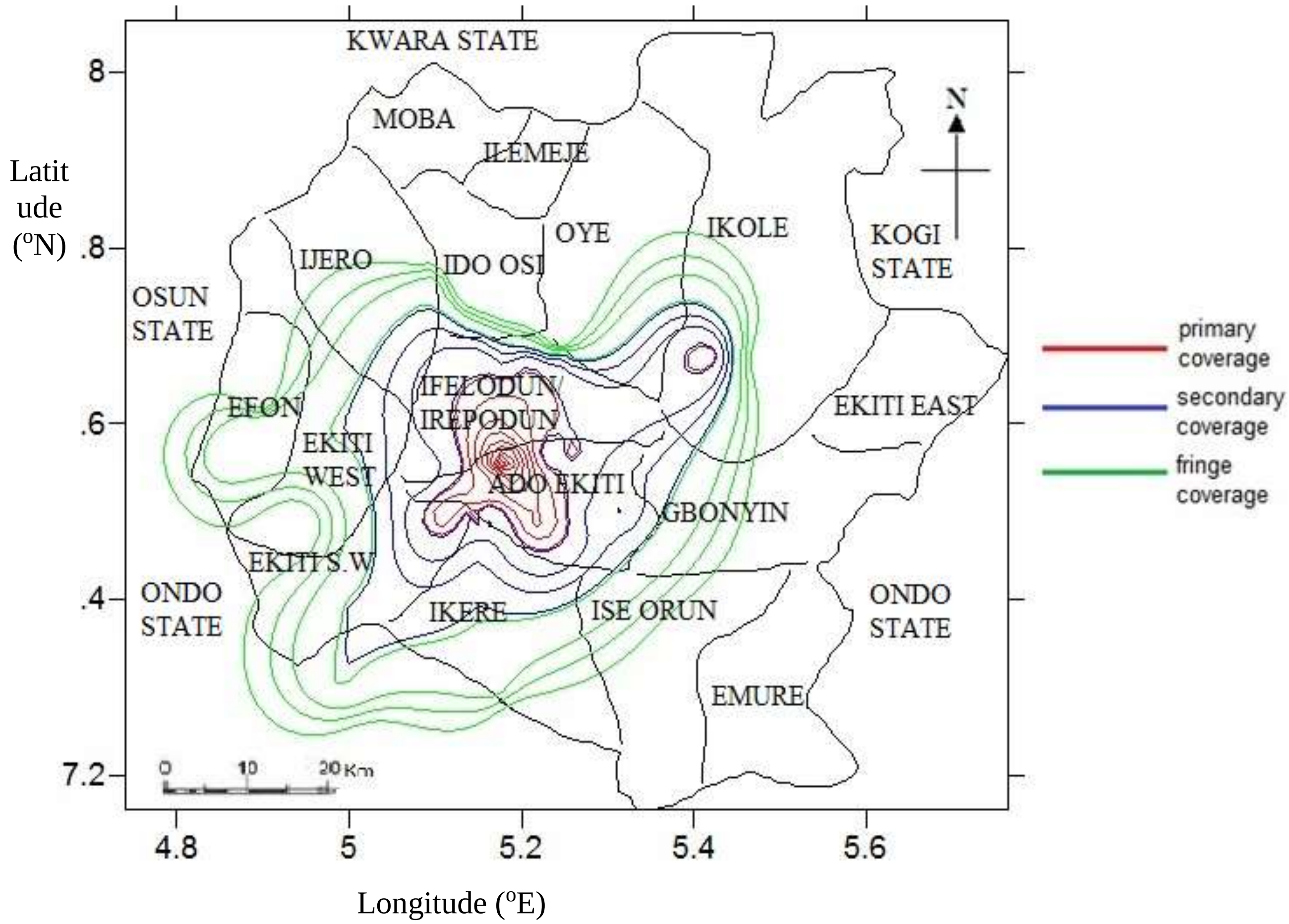


Figure 4.26: Coverage area of BSES UHF channel 41 transmitting station in Ekiti State

Table 4.14: The percentage of the coverage area of BSES television transmitting station relative to total landmass of Ekiti State

Station	% of primary coverage area	% of secondary coverage area	% of fringe coverage area	Total % of coverage area
Broadcasting Service of Ekiti State, channel 41	3.72	7.29	13.72	24.73

Table 4.15: The percentage of each local government areas covered by the Broadcasting Service of Ekiti BSES channel 41, transmitting station in Ekiti State

LGA	Approximate distance (km)	% of Primary coverage area	% of Secondary coverage area	% of Fringe coverage area	Total % of coverage area
Oye	14.79	0	8.90	17.00	25.90
Ikole	30.2	1.09	6.59	11.53	19.21
Gbonyin	14.25	0	6.12	25.30	31.42
Ise Orun	32.17	0	2.10	15.78	17.88
Ado Ekiti	7.67	45.5	24.24	2.60	72.34
Ikere	19.32	0.58	18.82	19.20	38.60
Ekiti South West	22.99	7.24	22.46	46.70	76.60
Ekiti West	21.74	0	11.37	26.94	38.31
Efon	33.43	0	0	38.70	38.70
Ijero	25.38	0	9.94	22.80	32.74
Irepodun/Ifelodun	4.47	23.3	28.57	2.59	54.46
Ido Osi	22.36	0	4.76	16.10	20.86

Table 4.16: Some of towns and villages within primary coverage area

LGA	Latitude(°N)	Longitude(°E)	Elevation (m)	Approximate distance (km)	Town/Villages
Ado Ekiti	7.665	5.241	382	1.23	Ado, EKSU
Irepodun/Ifelodun	7.6497	5.268	370	3.63	Afao
Ekiti South West	7.611	5.129	527	14.86	Ilawe, Igbara
Ikole	7.795	5.545	525	32.52	Ikole

Table 4.17: Some of towns and villages within secondary coverage area

LGA	Latitude(°N)	Longitude(°E)	Elevation(m)	Approximate distance(km)	Town/Villages
Ado Ekiti	7.618	5.207	426	7.7	Ado, Federal poly
Oye	7.788	5.245	573	12.64	Oye, Ayegbaju
Gbonyin	7.618	5.352	369	13.14	Ijan
Ikere	7.552	5.215	405	14.13	Ikere town,Oke-Ikere
Ekiti South West	7.564	5.099	405	20.49	Igbara Odo
Ekiti West	7.685	5.089	496	17.57	Aramoko
Irepodun/Ifelodun	7.678	5.192	449	6.06	Afao, Iyin
Ido Osi	7.787	5.243	561	12.51	Ifaki, Ora Ekiti
Ijero	7.836	5.687	505	22.15	Ijero town
Ikole	7.795	5.545	525	32.52	Ikole
Ise Orun	7.423	5.645	390	30.5	Ise

Table 4.18: Some of towns and villages within fringe coverage area

LGA	Latitude(°N)	Longitude(°E)	Elevation(m)	Approximate distance (km)	Town/Villages
Ado Ekiti	7.618	5.235	426	7.7	Ado poly
Oye	7.799	5.314	565	15.72	Oye Ekiti 2
Gbonyin	7.626	5.386	387	16.26	Orun, Ijan
Ikere	7.388	5.26	383	31.76	Ikere-Akure road
Ekiti South West	7.47	5.064	359	30.2	Ilawe-Igbaraoke
Ekiti West	7.725	5.018	514	25.94	Erio
Irepodun/Ifelodun	7.669	5.125	570	13.57	Igede
Ido Osi	7.845	5.186	573	20.15	Ido
Ijero	7.836	5.686	505	25.38	Ijero
Ikole	7.795	5.545	525	32.50	Ikole
Ise Orun	7.470	5.465	395	32.17	Ise Orun
Efon	7.68	4.925	513	35.68	Efon

Table 4.19: Percentage of the coverage areas of the two television stations relative to the total land mass of Ekiti State

Stations	% of primary coverage area	% of secondary coverage area	% of fringe coverage area	Total % of coverage area
NTA Ado Ekiti, VHF channel 5	13.53	11.53	15.06	40.16
BSES, UHF channel 41	3.72	7.29	13.72	24.73

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The generalised field strength models for the two television stations for Ekiti State are obtained by using the average of the RMSE of the four routes as the correction factor for each models. The average values of RMSE of the generalised field strength models for the four routes are taken as the RMSE value for Ekiti State. The correction factors used for all the field strength models for NTA (175.25 MHz) channel 5 are as follows: -37.87 for free space, -2.78 for Hata, -2.30 for ITU-R P and 7.04 for ERC Report 68 models with average RMSE of 6.28 dBµV/m for free space, 7.54 dBµV/m for Hata, 7.69 dBµV/m for ITU-R and 7.70 dBµV/m for ERC Report 68 model respectively while correction factors used for modified and generalised field strength models for BSES (631.25 MHz) channel 41 are: -25.48 for free space, 9.85 for Hata, 10.21 for ITU-R P.529-3 and 16.25 for ERC Report 68 models with generalised average RMSE of 6.21 dBµV/m for free space, 6.31 dBµV/m for Hata, 6.30 dBµV/m for ITU-R P.529-3 and 6.32 dBµV/m for ERC Report 68 models respectively. Thus, the generalised free space prediction model have the lowest RMSE for the four routes considered for the two television stations. So, the generalised free space model gives more accurate prediction for field strength models in Ekiti State compared to other models considered.

The coverage areas of the two television transmitting stations shows that 17.25 % of the entire land mass of Ekiti State has television signal strong enough to override ordinary interference in the locality at all times, and this comprise the primary coverage area. About 18.82 % of the state also enjoys good television signals but not strong enough to overcome interference completely at all times, this is within the secondary coverage area. But the service provided in this area may be adequate in rural areas where the noise level is low. Also, 28.78 % of the state is in fringe service areas. In such area, the service can neither be guaranteed nor protected against interference, and an antennas with high gain and heights higher than the surrounding buildings and obstacles are needed to receive good signals. About 64.85 % of the entire land mass of Ekiti State has television signal coverage. It is also observed that, Emure and Ekiti East local government areas are completely out of the two television stations.

The rate of attenuation of VHF and UHF signals is very high in Ekiti State. This may be as a result of high loss of television signal due to diffraction by some physical features like hills and vegetation covering a large portion of the entire land mass and irregular elevation of the surface of the ground.

In summary, it is therefore needful for the two television stations to increase their transmitting power or build some repeater stations along Emure, Ekiti- East, and Moba, if they are to cover the entire state effectively.

5.2 Recommendations

(i) The government should endeavor to site booster stations across the state to achieve optimum coverage of the entire land mass. This is necessary to ensure that government policies and programmes are well disseminated. These booster stations will be needed in the following local government areas of the state where the signal strength recorded had become weak such as Efon- Ekiti West areas, Moba- Ilemeje areas, Ikole- Ekiti East areas, Ise Orun- Emure areas and part of Ikere area

(ii) For further study, the period of data collection for this work should be extended to cover a period of one year, so that all the seasons within the year could be captured, which include rainy season, dry season and harmatan season. This will reveal the variation of signals with seasons and how these seasons affect the coverage area of the signals.

(iii) Some weather parameters such as temperature and pressure should be measured alongside with electric field strength of the signals to study the correlation between VHF/UHF television signals and the surface refractivity.

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