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A Review on Radiowave Propagation Models for Very High Frequency and Ultra High Frequency Band

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Abstract- Radiowave propagation model is an empirical mathematical formulation for characterization of radiowave propagation as a function of frequency, distance and other conditions. This study explains the various attenuating factors prevalent in radiowave propagation. It highlights the various types of radiowave propagation; its classification based on their propagation paths; its layers in the atmosphere, its frequency bands and propagation mechanism. The study also entails the various radiowave propagation models and their application in VHF and UHF band.

Keywords Radiowave Propagation Models, VHF Band, UHF Band, Attenuating Factors, Radiowave Propagation.

1. Introduction

Radiowave Propagation is the transfer of energy by electromagnetic radiation at radio frequencies from one point, a transmitter to another, a receiver. Radiowave Propagation comprises of two types: The Guided and Free(unguided).

Free (unguided) Radiowave Propagation occurs between corresponding antennas in the earth's atmosphere, underwater or in free space while the Guided Radiowave Propagation takes place in manmade guiding systems such as wirelines, coaxial cables, waveguides and optical fibers [1].

VHF and UHF bands belong to the free (unguided) as opposed to the guided. VHF and UHF bands are seen as the "line of sight transmission" on account of their app. VHF is defined as the portion of the radio spectrum from approximately 30MHz to 300MHz while UHF band is the portion of radio spectrum from 300MHz to 3GHz [2].

1.1. Classification of Radiowave Based on their Propagating Paths

There exists four major propagating paths of radiowave namely surface wave, space wave, tropospheric and ionospheric [3].

Surface wave. Propagates in direct contact with the earth's surface and as a result suffers severe "frequency-dependent attenuation" occasioned by absorption into the ground, "space waves on account of their being radiated from an antenna with many wavelengths above the surface are far from being attenuated as no part of it is in contact with the surface of the earth. It is, however, worthy of note that the propagation modes of both the VHF and UHF bands are exclusively tied to space wave".

Space wave. Space wave as shown in figure 1comprises two components "direct" and "reflected" and albeit it is grouped together with "surface wave" as "ground wave", their varied propagation characteristics warrant their being considered exclusively.

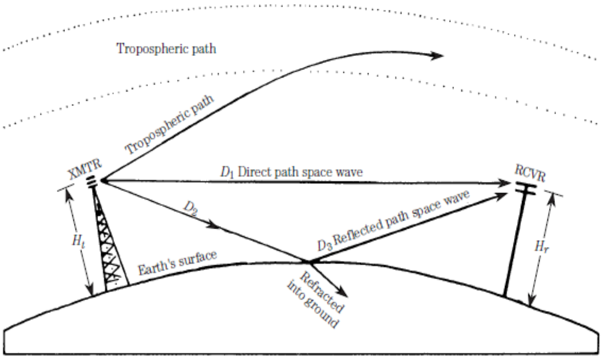

Fig. 1. Showing Space Wave Propagation [3].

Ionospheric. Ionospheric propagation is dependent on the ionization of the earth's atmosphere as a result of its being impacted upon by intervening factors such as ultra-violet radiation from the sun and cosmic rays. Ionospheric path is important to medium wave and HF Propagation but it is insignificant for VHF, UHF or microwave propagation. This phenomenon predisposes variation in electron density between day and night conditions with peaks in electron clarity that are in tandem with the height at which the evolved gases settle within the region of the upper atmosphere.

1.2. Classification of Layers in the Atmosphere

Layers in the upper atmosphere are classified into:

(i) C layer
(ii) D layer
(iii) E layer
(iv) F_1 and F_2 layers

[4] summarized their localized frequencies and heights in order of magnitude comparison as shown in Table 1.

Table 1. Showing the Virtual Height, Critical Frequency and Maximum Single-Hop Range of the Ionospheric Layers

IONOSPHERIC LAYERS	VIRTUAL HEIGHT	CRITICAL FREQUENCY	MAXIMUM SINGLE-HOP RANGE
C and D layers	60-80km	Reflects low and very low frequencies	
E layer	110km	4MHz	2350km
F_1 layer	180km	5MHz	3000km
F_2 layer	300km(day-time) and 350km(night time)	8MHz(day time) and 6MHz(night time)	3840km(day-time and 4130km(night time)

The study describes propagation of SURFACE WAVE as following the curvature of the earth due to refraction and categorizes it (Surface Wave) as being of importance at frequencies below about 2MHz with the conductivity and permittivity of the earth surface playing an important role in its propagation. This is due largely to the fact that it could introduce both displacement and conduction currents in the surface.

The study further states that at the highest frequency, these currents may penetrate depths ranging from about 1m to ten of meters at the lowest. Attenuation thus occurs as the radio wave passes over the earth surface, even in an increased dimension as the frequency increases. Hence, the limitation of the usefulness of the SURFACE WAVE to frequencies below about 2MHz.

The study equally states that the DIRECT WAVE and the GROUND REFLECTED WAVE(both of which comprise the SPACE WAVE) are at low enough frequencies(where transmitting antenna height above ground, in terms of wavelength, is small) capable of cancelling out each other; with the corollary of leaving only the SURFACE WAVE.

Nevertheless, at higher frequencies, the height of the antenna may be such that makes the SPACE WAVE comparable in magnitude to the SURFACE WAVE, which results in the PHASOR SUM. The resultant wave in this instance is referred to as the GROUND WAVE, which should not in any way be confused as SURFACE WAVE alone.

1.3. Classification of Radio wave Based on Frequency Bands

[1] sees radiowaves as being classified either by frequency bands or by propagation mechanisms

Table 2 shows a decimal based division of the entire radio spectrum into frequency bands

Table 2. Showing a decimal based division of the entire radio spectrum into frequency bands

Frequency Band	Frequency Range	Wavelength	Propagation Modes
Extra Low Frequency(ELF)	<3kHz	<100km	Ground wave
Very Low Frequency (VLF)	3-30kHz	<10km	Earth-Ionosphere guided
Low Frequency(LF)	30-300kHz	<1km	Ground wave
Medium Frequency(MF)	0.3-3MHz	<100m	Ground wave/ sky wave for short/long distances
High Frequency(HF)	3-30MHz	<10m	Sky wave
Very High Frequency(VHF)	30-300MHz	<1m	Space wave
Ultra-High Frequency(UHF)	0.3-3GHz	<100cm	Space wave
Super High Frequency(SHF)	3-30GHz	<10cm	Space wave
Extra High Frequency(EHF)	>30GHz	<1cm	Space wave

1.4. Classification of Radio wave Based on Propagation Mechanism

By propagation mechanisms, the study outlines radio waves as comprising of two types, namely: the “guided” and the “free(unguided)”; and went on to characterize “ground waves” and “sky waves” as evolving based on SPATIAL AREA THROUGH WHICH THE PROPAGATING PATHS OF RADIO WAVES ARE TRAVELLING. Accordingly, the study sees “sky waves” (or ionospheric waves) as radio waves that propagate obliquely toward, and is then returned from the ionosphere. Sky waves are usually localized in the spatial region between the ionosphere and the earth’s surface as shown in figure 2. The study outlines “ground waves” as radio waves that propagate from a source in the vicinity of the surface of the earth as opposed to having its propagating path in the ionosphere. The study also sees two ground wave modes: “surface waves” and “space waves” as existing independently. This varies slightly from the position of [2] which sees “ground waves” as consisting of “surface waves”, “direct waves” and “ground-reflected waves”. While highlighting “ground waves” and “sky waves” as those based on spatial area, [1] outlines four radio waveforms as falling into the category of THOSE EVOLVING UNDER THE MECHANISM BETWEEN THE TRANSMITTING AND RECEIVING ANTENNAS. They are:

i. Direct radio waves(or simply direct waves)
ii. Reflected radio waves(or reflected waves)
iii. Scattered(or secondary) radio waves
iv. Diffracted radio waves (or simply diffracted waves).

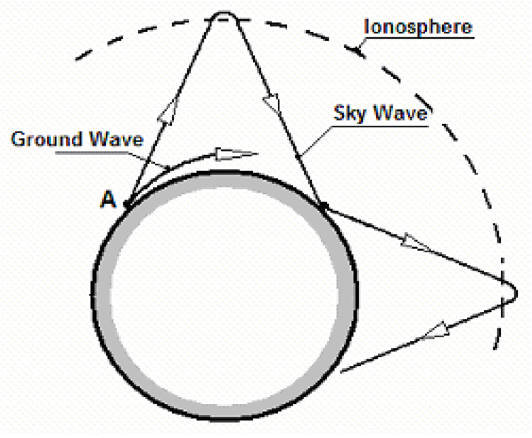

Fig. 2. Showing Sky Wave Propagation [1]

Direct Radio Waves. The study went on to define “direct radio waves” as those propagating from a transmitting to a receiving point over an unobstructed ray path. It exemplified it succinctly with a radio wave that propagates via an earth-to-space (uplink), space-to-space, or space-to-earth (downlink) path of the satellite communication system as shown in figure 3.

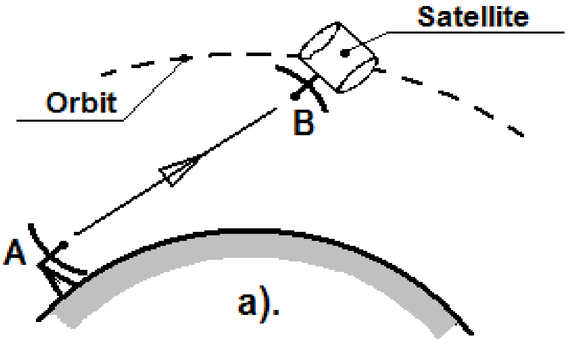

Fig. 3. Showing a direct radio wave [1]

Reflected Radio Waves. Reflected radio waves are those waves that travel to the receiving point via a reflection from an object, which has large dimensions compared to the wavelength [1,5]. Occasioned by impedances between the air and the encountered object, a part of the energy is reflected whilst the remaining part is refracted into the other medium. Figure 4 shows an ideal representation of this occurrence.

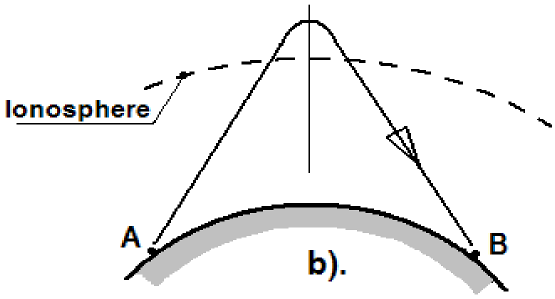

Fig. 4. showing a reflected radio wave [1]

A Scattered (Or Secondary) Radio wave. Scattered (or secondary) radio waves is referred as scattering, which it construes as related to reflection and could be referred to as diffuse reflection [6]. Its occurrence causes the energy of the radio wave to be distributed in all directions. According to [1], the phenomenon of scatter propagation through the irregularities of the ionosphere is peculiar to the VHF frequency band as shown in Figure 5.

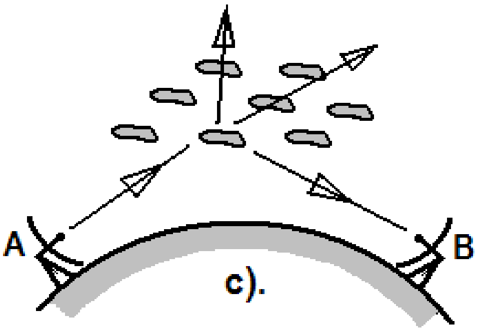

Fig. 5. Showing Scattered Radio Waves [1]

Diffracted Radio Waves (Or Diffracted Waves). Diffracted radio waves is defined as electromagnetic wave that has been modified by an obstacle or spatial inhomogeneity in the medium by means other than a reflection or refraction [1].[5] concurs with this assertion when it sees the phenomenon as occurring when the obstructing object is large compared to the wavelength of the radio wave. [1] sees it as occurring when h≤λ as shown in figure 6.

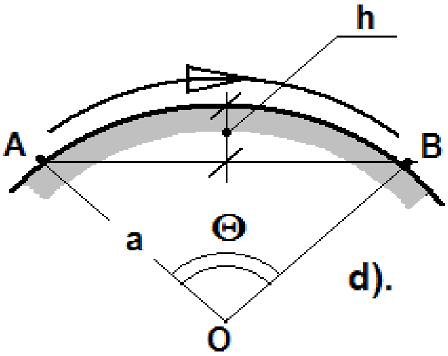

Fig. 6. Showing Diffracted Radio Waves [1]

In much the same vein, [3] outlines four major propagation paths: “surface wave”, “space wave”, “trospospheric” and “ionospheric.” While the study sees the ionospheric path as important to medium-wave (MW) and HF propagation, it sees it as insignificant for VHF, UHF or microwave propagation.

2. Dynamics of Attenuating Factors prevalent in Radiowave Propagation

Several attenuating factors are prevalent in radiowave propagation namely: Shadowing Effects, Multipath distortion, Picket Fencing, Path loss, Diffraction, Multipath Spread, Noise and Interference.

Shadowing Effect. “Shadowing” is the loss of field strength typically contributed to a diffracted wave emanating from an obstacle between transmitter antenna and receiver antenna [7, 8]. VHF and UHF waves exhibit a tendency of being attenuated with every rule of distance [2]. This is just as ridges and hills could form shadows of VHF and UHF waves. The study, however, gave an exception concerning sharp ridges or other kinds of abrupt barriers usually caused by diffraction.

Multipath Distortion. Multipath distortion has to do with a situation where VHF and UHF waves are reflected off of dense surfaces like rocks or conductive earth, just like a beam of light can be reflected of a wall or a ceiling [2]. It sometimes occurs with several paths between a transmitting and receiving antenna as evinced in Figure 7.

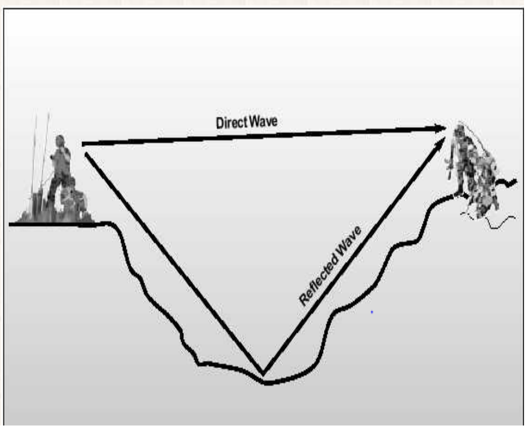

Fig. 7. Showing wave reflections caused by multipath distortion [2]

Figure 7 shows a direct LOS path between two radios that is inclusive of a reflected path from the bottom of a valley between them. The two paths are of different length with the direct path being the shorter of the two. And since radio waves travel at a constant velocity, the direct path wave arrives at the receiver before the reflected path. Thus, the same broadcast information reaches the receiver at two different times. It is much like echoes in an acoustically poor room. It is hard to understand what is being said if the echoes are close enough to each other.

Picket Fencing. Picket fencing is a form of multipathing that is common to vehicular mounted radios [2]. Its occurrence is usually associated with interference or reflections of signals from man-made objects such as buildings, houses, and other structures. Picket fencing is prevalent with VHF and UHF.

Path Loss. Path loss is the loss in power density experienced by a wave as it traverses the path between the transmitter and the receiver [9]. It is also major component in the analysis and design of the link budget of a telecommunication system [10].

Diffraction. Diffraction is an exception to the rule where ridges and hills form shadows of VHF and UHF radio waves [2]. It occurs when VHF and UHF waves are subjected to having a portion of their waves bend around on reaching very sharp ridges and continue propagation as if a very low power radio was placed at the top of the ridge. Figure 8shows VHF and UHF Diffraction.

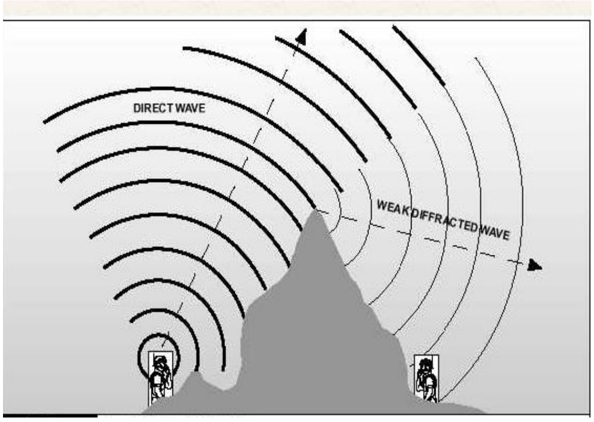

Fig. 8. Showing VHF and UHF Diffraction. [2]

Multipath Spread. Multipath spread is defined as the range of timed differences that it takes for radio signals to reach the receiving antenna when they arrive from several routes, which may include one or more sky wave paths and/or a ground-wave path [2]. This effect according to the study could be minimized by selecting a frequency that is as close as possible to the maximum usable frequency (MUF).

Noise and Interference. Receiver noise and interference comes from both external and internal sources [2]. While the internal noise originated from within the circuits of the receiver, other sources of noise within the radio that are of prominence are the power supplies and frequency synthesizers. External noise, however, comes from sources outside the radio and often exceeds internal receiver noise. The study went on to outline natural and man-made sources of noise and went on to highlight the VHF and UHF bands as being above atmospheric noise. Unintentional radio interference and intentional radio interference were also highlighted; with “collocation interference” as being typical of the former, while using “jamming” or deliberate interference as an example of the latter.

3. Radiowave Propagation Models

Radiowave propagation model is defined as an empirical mathematical formulation for characterization of radio wave propagation as a function of frequency, distance and other conditions [11, 12, 13 and 14].

It plays an important role in planning analysis and optimization of radio network. Hence, the imperative of developing effective propagation models for wireless communication systems. Radio Propagation models are not only used as mitigation measures, but used to predict the behavior of radio propagation in different environments. [15] categorized radio propagation models as falling into three categories, namely:

a) Statistical Models

b) Deterministic Models and

c) Empirical Models.

Statistical Propagation Models. Their study outlines statistical propagation models as originally devised to provide estimations of signal field strengths (or signal power) in cases where there is insufficient knowledge of the terrain profile. Being models derived from data obtained from extensive measurements in different environments, they require a limited number of parameters (eg. effective antenna height, time and/or location variability, type of ground).

Deterministic (Geometrical) Propagation Models. Their study outlines Deterministic models as making use of the laws governing electromagnetic wave propagation with a view to estimating the field strength(or signal power)directly from the path profile(which has to do with terrain and clutter between the transmitter and receiver). They are usually site specific and can be associated with indoor or outdoor propagation environments. Notable examples of it are the Fresnel model, Recommendation ITU-R P.525-2/526-4.

Empirical Propagation Models .Their study outlines Empirical path loss models as incorporating the benefits of deterministic and statistical models and is widely used for the planning and optimization of cellular networks. This model takes all environmental influences implicitly regardless of whether they could be separately recognized or not.

Their creation is hinged on fitting appropriate mathematical functions to extensive sets of measured path loss data with no due regard to base these functions on physical models of dominant propagation mechanisms. Wireless, Propagation and Network Engineers sees the simplicity and computational efficiency of this model as its main advantage.[16] and [17] sees the possibility of splitting empirical models into two subcategories namely, time dispersive and non-time dispersive; with the time dispersive models providing information about time dispersive characteristics of the channel such as delay spread of the channel during multipath. Examples of it are: Free space, Okumura-Hata, Cost 231, Ericsson propagation models, Recommendation ITU-RP. 1546, Okumura, Egli, ECC-33, SUI, Lee, Macro, COST-231-Walfisch-Ikeagami and Dual-slope, etc.

Okumura Model. This model is one of the most widely and frequently used wireless macroscopic propagation models applied to suburban and urban environments[18]. It is designed for use in frequency range of 150MHz to 1920MHz and are mostly used in urban propagation environment.

The model can be represented mathematically as:

$$PL = FPL + A(f,d) - G(h_{te}) - G(h_{re}) - G(Area) \tag{1}$$

$$where$$

$$FPL = Free\ space\ path\ loss\ in\ dB$$

$$C\ is\ the\ speed\ of\ light\ in\ \frac{m}{s}$$

$$f\ is\ the\ frequency\ in\ Hz$$

$$h_{te}\ is\ the\ effective\ height\ of\ the\ transmitting\ antenna\ in\ metres$$

$$h_{re}\ is\ the\ effective\ height\ of\ the\ receiving\ antenna\ in\ metres$$

$$d\ is\ the\ distance\ between\ the\ transmitting\ and\ the\ receiving\ antenna\ in\ metres.$$

$$G(Area)\ is\ the\ correction\ factor\ gain\ in\ dB\ and$$

$$A(f,d) is\ the\ median\ attenuation (in\ dB) which\ is\ a\ function\ of\ frequency\ and\ distance.$$

$$FPL = 20\log\left(\frac{4\pi df}{c}\right) \tag{2}$$

$$G(h_{te}) = 20log\left(\frac{h_{te}}{200}\right) \text{for} h_{te} \text{between 30m and 100m} \tag{3}$$

$$G(h_{re}) = 20log\left(\frac{h_{re}}{200}\right) \text{ for h\_re between 3m and 10m} \tag{4}$$

$$G(h_{re}) = 10log\left(\frac{h_{re}}{200}\right)\text{for}h_{re} \text{ less than 3m} \tag{5}$$

G (Area) =33dB for urban, 27dB for sub-urban and 13dB for medium urban

Okumura-Hata Model for Urban Areas. It is a furtherance of the Okumura model in a variant referred to as Okumura Hata model which is the most widely used radio frequency propagation model for predicting the behavior of broadcast transmission, cellular transmissions in built up areas, point-to-point and it is based extensively on the empirical measurements taken. [18]

The model can be represented mathematically as

$$PL = 69.55 + 26.16\log f - 13.82logh_T - a(h_R) + [44.9 - 6.55logh_T]\log d \tag{6}$$

where PL is the pathloss in dB f is the frequency of transmission in MHz h_T is the height of transmitting antenna in meters h_R is the height of the receiving antenna in meters a(h_R)is the receiving antenna height correction factor and d is the distance between the transmitting g and the receiving antenna in kilometers.

For large city with the frequency of transmission, f ≥ 400MH.

$$a(h_R) = 3.2[\log(11.75h_R)]^2 - 4.97 \tag{7}$$

For large cities with frequency of transmission f≤400MHz

$$a(h_R) = 8.2[\log(1.5h_R)]^2 - 1.1 \tag{8}$$

For suburban environments (150MHz≤f≤1500MHz)

$$a(h_R) = (1.1\log f - 0.7)h_R - (1.56logf - 0.8) \tag{9}$$

Okumura Hata Model specification can be represented below as:

Carrier frequency: 150MHz≤f≤1500MHz

Transmitting antenna height: 30m≤h_T≤200m

Receiving antenna height: 1m≤h_(R)≤10m

And distance between the transmitting and receiving antennas: 1km≤d≤20km.

COST-231 Hata Model. COST is defined as the European Cooperative for Scientific and Technical research; which is widely used for predicting path loss in mobile wireless systems [18,19,20]. COST-231 Hata model is an extension of the Okumura-Hata model designed to be used in frequency ranging from 500MHz to 2000MHz.It is also used for prediction of path loss in different environments such as rural, urban and sub-urban. A basic path loss equation in dB for COST-231 Hata model can be represented as:

$$PL = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_T) - a_{hm} + \left(44.9 - 6.55log_{10}(h_T)\right)log_{10}d + C_m \tag{10}$$

Where PL is the pathloss in decibel f is the frequency in MHz d is the distance between the transmitting and the receiving antennas in kilometres h_T is the transmitting antenna height above ground level in metres a(h_m) is the correction factor in dB Cm is defined as 0db for suburban and 3dB for urban environment a(h_(m))is represented mathematically for urban environment and suburban or rural(flat)environmentas:

For urban environment with f ≥ 400MHz

$$a(h_m) = 3.20(log_{10}(11.75h_R))^2 - 4.97 \tag{11}$$

For urban environment with frequency of transmission f≤400MHz.

$$a(h_m) = 8.2[\log(1.5h_R)]^2 - 1.1 \tag{12}$$

For suburban or rural environment (150MHz≤f≤1500MHz)

$$a(h_m) = (1.1log_{10}f - 0.7)h_R - (1.56log_{10}f - 0.8) \tag{13}$$

Where h_R is the receiving antenna height above ground level.

Egli Model. Egli model is a terrain model used for radio frequency propagation gotten from real-world data on VHF and UHF television in large cities [18]. It is used to predict the total path loss for a point-to-point link, and is also used for outdoor line-of-sight transmission. [13] outlines Egli model as applicable at frequency from 40MHz to 900MHz.Egli model is suitable for communication where the transmission goes over an irregular terrain. It can be represented mathematically as:

$$L = G_T G_R \left[\frac{h_T h_R}{d^2}\right]^2 \left[\frac{40}{f}\right]^2 \tag{14}$$

Egli model can also be represented mathematically [21, 22] as:

For h_R≤10m

$$\text{Path loss} = 20logf + 40\log d - 20logh_T + 76.3 - 10logh_R \tag{15}$$

For h_R≥10m

$$\text{Path loss}=20logf + 40\log d - 20logh_T + 85.9 - 20logh_R \tag{16}$$

Where

$G_T\ is\ the\ gain\ of\ the\ transmitting\ station\ antenna$

$G_R$is the gain of the receiving antenna

$h_T\ is\ the\ height\ of\ the\ transmitting\ antenna\ in\ metres$

$h_R\ is\ the\ height\ of\ the\ receiving\ antenna\ in\ metres$

$d\ is\ the\ distance\ between\ the\ transmitting$

$and\ the\ receiving\ antennas\ in\ metres$

$f\ is\ the\ frequency\ of\ transmission\ in\ MHz.$

Ecc-33 Model. ECC model is an extension of Okumura Model formulated by Electronic Communication Committee (ECC) in the European Conference of Postal and Telecommunications Administrations (CEPT) [22, 23]. It is the most widely used model based on Okumura model, with a frequency range of 700MHz to 3.5GHz and for distance between 1 and 10Km.

The path loss model is expressed as follows:

$$PL = A_{fs} + A_{bm} - G_t - G_r \qquad (17)$$

Where

$A_{fs} = Attenuation\ due\ to\ free\ space$

$A_{bm} = Median\ path\ loss$

$G_t = Transmitter\ antenna\ height\ gain\ factor$

$G_r = Receiver\ antenna\ height\ gain\ factor$

They are defined independently as:

$$A_{fs} = 92.4 + 20log_{10}(d) + 20log_{10}(f) \qquad (18)$$

$$A_{bm} = 20.41 + 9.83log_{10}(d) + 7.89log_{10}(f) + 9.56[log_{10}(f)]^2 \qquad (19)$$

$$G = log_{10}\left(\frac{h_t}{200}\right)\{13.958 + 5.8(log_{10}d)^2\} \qquad (20)$$

For medium environment:

$$G_r = [42.57 + 13.7log_{10}][log_{10}(h_r - 0.586)] \qquad (21)$$

$Where\ f\ is\ in\ GHz\ and\ d\ is\ in\ km$

$(distance\ between\ the\ transmitting$

$and\ receiving\ antenna)$

$For\ large\ city$:

$$G_r = 0.759h_r - 1.862 \qquad (22)$$

$Where\ h_{r\ and}\ h_t\ are\ the\ receiver\ and\ transmitter$

$antenna\ height\ in\ metres.$

University Interim (SUI) Model. SUI model is formulated by IEEE 802.16 Broadband Wireless Access working group in Standford University with a proposed frequency band below 11GHz consisting of channel model [23]. It is an expansion of Hata model with frequency greater than 1900MHz and is used for prediction of path loss in sub-urban, urban and open environments.This model is categorized into three different groups namely A-C with each group having its own characteristics.

Group A is associated with a hilly environment that has moderate-to-heavy foliage densities and has maximum path loss. It is suitably for populated compact urban area.

Group B is associated with hilly environment that has rare trees or flat environment with heavy or moderate densities. It is suitable for sub urban area.

Group C is associated with flat environment with light tree densities and has the minimum path loss. It is suitable for open area.

The different groups are described mathematically as:

Cells < 10km in radius;

Receiver antenna height=2-10m

Base station antenna height=15-40m

High coverage requirement (80-90%)

The median path loss for SUI model is expressed mathematically as:

$$PL = A + 10\gamma log_{10}\left[\frac{d}{d_o}\right]X_f + X_n + S \qquad (22)$$

Where

$$A=20\log\left(\frac{4\pi d_o}{\lambda}\right); \qquad (23)$$

$$\Gamma=a-bh_t + \frac{c}{h_t}; \qquad (24)$$

$d_o - 100m$

10m<$h_b < 80m$;

8.2dB<S<10.6dB

Where

d=Distance between transmitter and receiver antenna (m)

λ= Wavelength (m)

f≤2000MHz

γ= path loss exponent

$h_t = Height\ of\ transmitter\ and\ receiver\ antenna(m)$

$A = free\ space\ path\ loss$

$S = A\ long\ normally\ distributed\ factor\ and\ a - c\ are\ constants.$

$h_t = Determine\ the\ path\ loss\ exponent\ for\ environment\ type.$

Frequency correction factors and transmitter antenna height are represented mathematically as:

$$X_f = 6.0log_{10}\left(\frac{f}{2000}\right) \qquad (25)$$

$$X_b = -10.8log_{10}\left(\frac{hr}{2000}\right);\ \text{(Type A and B environment)} \qquad (26)$$

$$X_h = -20.0log_{10}\left(\frac{hr}{2000}\right);\ \text{(Type C environment)} \qquad (6.5)$$

$$S=0.65(log_{10} f)^2 - 1.3\log(f) + \alpha \qquad (27)$$

A=5.2 for environment A and B

A=6.6Db for environment C.

Free Space Propagation Model. Free space propagation model is a model used to predict received signal strength when the transmitter and receiver have an unobstructed line-of-sight and a clear path between them [7]. It predicts that received power decays as a function of the Transmitter- Receiver separation distance raised to some power (ie power law function). The free space power received by a receiving antenna is separated from a radiating transmitter antenna by a distance d is given by Friss free space equation and is stated as:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \quad (28)$$

Where P_t *is the transmitted power*

$P_r(d)$ *is the received power*

G_t *is the transmitter antenna gain*

G_r *is the receiver antenna gain*

d *is the Transmitter*

− Receiver seperation distance in metres

λ *is the wavelength in metres.*

$$PL(dB) = 10\ log \frac{P_t}{P_r} \quad (29)$$

$$PL(dB) = -10 log \left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right] \quad (30)$$

It can be expanded to give:

$$PL(dB) = -10 log_{10}(G_r) - 20 log_{10}\left[\frac{(c*10^{-3})}{4\pi * f * 10^6}\right] - 20 log_{10}\left(\frac{1}{d}\right) \quad (31)$$

$$PL(dB) = -G_t(dB) - G_r(dB) + 32.44 + 20 log_{10}\left(\frac{d}{km}\right) + 20 log_{10}\left(\frac{f}{MHz}\right) \quad (32)$$

C is the speed of light

Ericson Propagation Model. Ericson propagation model is a software for network planning engineer provided by Ericson Company used to predict path loss [15]. It is a modified mode of Okumura-Hata model used to allow room for change in parameters based on propagation environment.

Path loss in Ericsson propagation model is represented mathematically as:

$$PL(dB) = a_0 + a_1 \log(d) + a_2 \log(h_b) + a_3 log(h_b) \log(d) - 3.2 \log(11.75 h_r)^2 + g(f) \quad (32)$$

Where

$$g(f) = 44.49 \log(f) - 4.78 \log(f)^2 \quad (33)$$

h_b *is the transmission antenna height(metres)*

h_r *is the receiver antenna height(metres)*

f *is frequency in MHz.*

Lee Model. Lee model is a model proposed by W.C.Y Lee in 1982extensively used pathloss model due to its simplicity and prediction accuracy [10, 23]. It is used in predicting area to area path loss by specifying different parameters from various environments. It is used by system engineers because its parameters can be adjusted easily to the environment in use by adding field calibrated measurement.

Path loss of this model is given by:

$$a_0 = a_1 a_2 a_3 a_4 a_5 \quad (34)$$

$$PL_{Lee} = P_{LO} + \beta log\left[\frac{r}{1..6km}\right] + 10 log\left[\frac{f}{900MHz}\right] - a_0 \quad (35)$$

Where

a_1 *is the transmitter antenna height(m)/30.48m*

a_2*is receiver antenna height(m)/3m*

a_3 *is the transmitting antenna gain with respect* $\frac{\lambda}{2})$

a_4*is transmitter power/10W*

$a_5$is the receiver antenna gain correction factor

Macro Model. Macro model is based on Hata model and corrects each factor that influences propagation path loss [25]. This model is calibrated by changing parameters to fit propagation conditions better.

Path loss is given by the following formula

$$PL_{macr0} = K_{off} + K_{lgd}.l_{gd} + Kh_R.h_R + K_{l_{gh_R}}.l_g h_R + Kl_g h_T.l_g h_T + Kl_g h_T lgdl_g h_T.l_g d \quad (36)$$

Where

K_{off} *is a constant which regulates the absolute value of path loss;*

K_{lgd} *regulates path loss dependence on the distance*

Kh_R *is the correction factor for receiver antenna height gain*

$K_{l_{gh_R}}$ *is the Okumura − Hata multiplying factor for* h_R

$Kl_g h_T$ *is the transmitting antenna height gain factor*

$Kl_g h_T lgd$ *is the Okumura*

− Hata multiplying factor $l_g h_T.l_g d$

Cost 231-Walfisch-Ikegami Propagation Model. COST 231-Walfisch-Ikegami Propagation model is a combination of the models from J. Walfisch and F. Ikegami [20]. This model was developed by COST-231 project and is also called Empirical COST-Walfisch-Ikegami. It is applicable to the frequency range of 80 to 2000MHz. Its model accuracy is quite high because in urban environments especially the propagation over the rooftops is the most dominant part. It considers only the buildings in the vertical place between the transmitter and the receiver. This model distinguishes between two situations namely: the “line of sight (LOS)” and the non-line of sight (NLOS)”situations.

Equation for path loss prediction (LOS situation) is:

$$PL(dB) = 42.6 + 26 \log\left(\frac{d}{km}\right) + 20 log\left(\frac{f}{MHz}\right) \quad (37)$$

NLOS Situation

$$PL_{LOS} = \{L_{FSL} + L_{rts} + L_{msd}\ for\ urban\ and\ sub\ urban$$
$$L_{FS}\ if\ L_{rts} + L_{msd} > 0\} \quad (38)$$

Where

L_{FSL} *is free space loss*

L_{rts} $is\ roof\ top\ to\ street\ diffraction$

L_{msd} $is\ multiscreen\ diffraction\ loss$

Dual Slope Model. This model is based on a two ray model which is commonly used in transmitting antenna with several wavelengths or more above the horizontal ground plane. It is suitable for the Line of Sight (LOS) propagation regions [26]. [27]outlines the following equations to show the relationship between received power, path loss and field strength:

$$P_r = \frac{P_t G_t G_r}{PL} \quad (39)$$

$$P_r = \frac{P_t G_t G_r ht^2 hr^2}{d^4} \quad (40)$$

$$E\left(\frac{V}{m}\right) = \sqrt{\frac{30 P_t G_T}{d(LOS)}} \quad (41)$$

4. Conclusion

The study has given an extensive detail of the various type of radiowave propagation and also its classification based on its propagation paths, layers in the atmosphere, based on its frequency band and its propagation mechanism. It also elaborated on the attenuating factor prevalent in radiowave propagation. Radiowave propagation models and its application in VHF and UHF Band was also discussed in this study.

References

[1] A.S. Saakian, “Radiowave Propagation Fundamentals”, Artech House, 2011.

[2] Harris, “Radio Communications on the Digital Age: VHF/UHF Technology”, Harris Corporation, USA, vol. (2), 2000.

[3] J. J. Carr, “Practical Antenna Handbook”, 4th Edition. McGraw-Hill, 2001.

[4] J. J. Biebuma, “Telecommunication System Design”, Celwill Nigeria Ltd, Idaminabo Close, Abuloma, Port Harcourt, 2014.

[5] O. Ayekomilogbon, O. Famoriji, and O. Olasoji, “UHF Band Radio Wave Propagation”, Mechanism in Forested Environments for Wireless Communication Systems, vol. 3(7), pp 11-16, 2013.

[6] O. T. Ayekomilogbon, J. Famoriji, and O. Y. Olasoji, “Evaluation and Modelling Of UHF Radio Wave Propagation in a Forested Environment”, International Journal of Engineering and Innovative Technology (IJEIT), vol. 2(12), pp 101-106, 2013.

[7] V. Armoogum, K. M. S. Soyjaudah, N. Mohamudally, and T. Fogarty, “Propagation Models and Their Applications in Digital Television Broadcast Network Design and Implementation”, Trends in Telecommunications Technologies, pp 165-185, 2010.

[8] S. R. Sauders, Antenna and Propagation for Wireless Communication Systems. Wiley, 2005.

[9] IEEE Standard Definitions of Terms for Radio Waves Propagation. IEEE Antenna and Propagation Society. New York, USA, IEEE Std 211, 2018.

[10] J. J. Biebuma, and B. O. Omijeh, “Path loss Model Using Geographic Information System (GIS)”, International Journal of Engineering and Technology, vol. 3(3), pp 269-275, 2013.

[11] T. Rick, and R. Mathar, “Fast Edge Diffraction-Based Radiowave Propagation Model for Graphics Hardware”, Proceeding Of The 2nd IEEE International ITG Conference On Antenna (INICA), Munich, Germany, 2007.

[12] K. J. Parmar, and V. D. Nimavat, “Comparative Analysis of Path Loss Propagation Models on Radio Communication”, International Journal of Innovative Research of Computer and Communication Engineering, vol. 3(2), pp 840-844, 2015.

[13] S. Bolli, and M. Z. A. Khan, “A Novel LMMSE Based Optimized Perez-Vega Zamanillo Propagation Path Loss Model In VHF/UHF Bands for India”, Progress in Electromagnetic Research, vol. 63, pp 17-33, 2015.

[14] J. J. Popoola, and A. T. Adesanya, “A Versatile Wave Propagation Model for Very High Frequency Broadcasting Band in Vegetation and/or Rocky Environment”, International Journal of Engineering Science and Application, vol. 2(1), pp 18-26, 2018.

[15] C. Temaneh- Nyah, and J. Nepembe, “Determination of a Suitable Correction Factor to a Radio Propagation Model for Cellular Wireless Network Analysis”, Fifth International Conference on Intelligent Systems, Modelling and Simulation, IEEE Computer Society, pp 175-182, 2014.

[16] H. R. Anderson, “Fixed Broadband Wireless System Design: The Creation Of Global Mobile Communication”, John Wiley & Sons, Inc., New York, NY, 2003.

[17] P. K. Sharma, and R. K. Singh, “Comparative Analysis of Propagation Path Loss Models with Field Measured Oata”, International Journal of Engineering, Science and Technology, vol. 2(6), pp 2008-2013, 2010.

[18] A. A. Poonle, and O. J. Owolabi, “Path Loss Modelling Of UHF Radio Wave Propagation in Ado-Ekiti, Nigeria”, ABUAD Journal of Engineering Research and Development (AJERD), vol. 2(1), pp 90-102, 2019.

[19] J. C. Ogbulezie, N. A. Akonjom, S. A. Ojomu, A. O. Ezugwu, and I. E. Igajah, “A Review of Path Loss Models for Uhfradiowaves Propagation: Trends and Assessment”, International Journal of Research in Engineering and Science, vol 4(7), pp 67-75, 2016.

[20] G. Sati, and S. Singh, “A Review on Outdoor Propagation Models in Radio Communication”, International Journal

of Computer Engineering & Science, vol. 4(2), pp 64-68, 2014.

[21] M. Garah., L. Djouane, H. Oudira, and N. Hamdiken, Indonesian Journal of Electrical Engineering and Computer Science. vol. 3(1), pp 126-135, 2016.

[22] R. Mardeni, and K. F. Kwan, “Optimization of Hata Propagation Prediction Model in Suburban Area in Malaysia”, Progress in Electromagnetic Research C, vol. 13, pp 91-106, 2010.

[23] C. V. Ebhota, J. Isabona, and V. M. Srivastava, “Base Line Knowledge on Propagation Modelling and Prediction Techniques in Wireless Communication Networks”, Journal of Engineering and Applied Sciences, vol. 13(7), pp 1919-1934, 2018.

[24] T. S. B. Nazmat, F. Nasir, I. P. Segun, A. S. Muhammed, A. O. Abdulkarim, and T. C. Carlos, “Path Loss Predictions For Multi-Transmitter Radio Propagation In VHF Bands Using Adaptive Neuro-Fuzzy Interference System”, Engineering Science and Technology, an International Journal, Elsevier, pp 679-691, 2018.

[25] J. Milanovic, S. Rimac-Drlje, and I. Mayerski, “Radio Wave Propagation Mechanisms And Empirical Models For Fixed Wireless Access Systems”, Technical Gazette, pp 43-52, 2010.

[26] T. K. Sarkar, J. Zhong, K. Kim, A. Medouri, and M. Salazar-Palma, “A Study of Various Propagation Models for Mobile Communication”, IEEE Antennas and Propagation Magazine, vol. 45(3), pp 51-82, 2003.

[27] T. S. Rappapot, “Wireless Communication Principles and Practice,” 2nd Edition, New York. Pearson Education., 2002.