Primary User Protection Contour and No-Talk Zone Characterization for TV Whitespace Spectrum Reuse in Nigeria.

Emmanuel A. Ubom, Victor E. Idigo, Ubong Ukommi

***Abstract:** To encourage secondary spectrum access within the TV broadcast bands in Nigeria, the propagation properties of TV signals on the VHF and UHF frequency ranges were empirically studied through measurements carried from two TV stations. The Pathloss exponent for the VHF band was found to be 1.9 with a characterised Pathloss equation for VHF band computed as $P_L(dB) = 84.04 + 19.03log_{10}(d)$, where (d) is the distance from the transmitter to the receiver. The UHF band Pathloss exponent was computed to be 1.8 with a Pathloss equation characterised as $P_L(dB) = 57.35 + 17.96log_{10}(d)$. The findings re-echoed the need for specific prediction model to accurately estimate the service coverage of TV stations and facilitate effective utilization of spatial TV white space as it was found that there were divergence in coverage prediction between the measured model and some of the conventional models. Using the protection view point, the protection contour in kilometers for TV signals propagating in the UHF band in Nigeria was characterized to be $dr_p = 10^{\left[\frac{P_t+32.65}{17.96}\right]}$. Where (dr_p) is the protection contour radius modeled as a function of the transmit power of the TV station in decibels with reference to one milliwatt (dBm) for co-channel and adjacent channel coverage. Similarly, the no-talk-zone in kilometers was characterized as a function of the transmit power of the secondary user device in dBm for co-channel usage to be $d_{(r_n-r_p)} = antilog\left[\frac{P_s-89.76}{17.96}\right]$ modeled as a function of the secondary user transmit power P_s. The separation distance in kilometers from the TV station to the possible secondary user transmitter beyond which no interference exist was computed to have a relationship equal to $antilog\left[\left[\frac{P_t+P_s-57.11}{17.96}\right]\right]$. This model will facilitate TVWS co-channel coexistence using the specified equation to determine the separation distances between television transmitters and secondary user transmitters.*

***Keywords:** Primary User Protection Contour, Separation Distance, Isolation Distance*

I.INTRODUCTION

It is natural that certain things thrive better in some areas of existence or operation than in other areas. For instance some plants grow well when cultivated on sandy soil than it would when planted on the rich loamy soil.

Revised Manuscript Received on August 30, 2020.

* Correspondence Author

Emmanuel Ubom, Department of Electrical and Electronic Engineering, Akwa Ibom State University, Ikot Akpaden, Mkpat Enin, Akwa Ibom State, Nigeria. E-mail: Emmanuelubom@aksu.edu.ng

Victor Idigo, Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. E-mail: Ve.idigo@unizik.edu.ng

Ubong Ukommi , Department of Electrical and Electronic Engineering, Akwa Ibom State University, Ikot Akpaden, Mkpat Enin, Akwa Ibom State, Nigeria. E-mail: Ubongukommi@aksu.edu.ng

This is to say that the performance characteristic of anything is a direct function of its habitat. The case is not different for Television (TV) signals operating on the Very High Frequency (VHF) or the Ultra High Frequency (UHF) bands who although may have very attractive propagation characteristics differ in most cases when deployed in different terrains. To properly place the propagation distance of terrains, several empirical signal strength measurement drives have been conducted and models developed for use in perceived similar terrains, but since no two terrains are exactly the same, these models sometime fails to correctly predict the propagation characteristics of the environment other than the one they were investigated for [1] and in some cases requires modification to suite specific environmental conditions. While this studies does not undermined the efforts and successes recorded by the extensive field strength measurements embarked upon by Okumura, Longley-Rice, Hata, Davidson and others to characterize the behaviour of signals at different frequencies and terrain conditions, empirical measurements remains the surest way to determine the propagation characteristics of every environment. It is in line with this believe, that this research aims to determine the propagation path loss of TV signals in the UHF and VHF band in South-South geopolitical zone of Nigeria as there is no such research result published to the best of our knowledge and therefore use the empirical results to model a frequency reuse separation distance for whitespace devices in the region. Background research showed that the mechanisms behind electromagnetic wave propagation are diverse, and are characterized by reflection, refraction, fading, scattering and shadowing [2]. Most of these characteristics are fundamentally environment specific that can be best described by the Path loss; which is an attenuation that signals suffers when propagated from the transmitter to the receiver. It has been shown that propagation path loss increases not only with frequency but with distance and in line with the environmental conditions [3]. According to [4] no single path loss model is able to predict path loss consistently, hence the need to carry out specific environment surveys to understand the effects of the terrain properties on the characteristics of propagated signals within that terrain.

II.METHODOLOGY

A. Measurements setup and data acquisition

Signal strength measurements were carried out with the help of a handheld Radio Frequency Analyser (RF-Explorer), a GARMIN GPSmap76CSx GPS receiver used to measure the radial distance from transmitter.

The collected readings were recorded and the averages used to calculate the Path-Loss at every instance. Extensive measurements were carried out at the interval of 2km up to 20km for Akwa

Table I. Names and Parameters of Television Stations

SN	Name of Stations	Latitude / Longitude	Antenna Heights	Transmit Frequencies	Transmit Power
1	Akwa Ibom Broadcasting Corporation – AKBC-TV	N05.06931 E007.92098	304.8m	663.25 (Channel 45)	7KW
2	Nigerian Television Authority (NTA-UYO)	N05.00302 E007.90181	84.85m	224.25 (Channel 12)	3KW active during measurement

Ibom State Broadcasting Corporation (AKBC-TV) service and the Nigerian Television Authority (NTA) both in Uyo, Akwa Ibom State situated in the South-South geopolitical zone of Nigeria. The area covered in the drive area spanned from urban into the sub-urban and rural areas of the state. The parameters of the Stations covered in the drive are as presented in Table I.

The measurements were taken between the 1st and the 7th of April 2019 and the average results presented in Table II. Measurements were taken along Abak road to 4-2 Junction in Mkpat Enin LGA, also along Aka road down to Ibesikpo in Ibesikpo LGA, Uyo-Itu-Calabar road, Idoro road down to Ikot Akpabio in Etinan LGA and Oron road. The average of the measurements filtered for 2km intervals are presented in Table II and Table III for AKBC and NTA respectively.

B. Supporting equations and data presentation

In free space, the wave is not reflected or absorbed. Ideal propagation mean there are equal radiations in all directions from the radiating sources and propagation to an infinite distance with no degradation. Spreading the power over greater areas causes attenuation. "(1)" illustrates how the power flux is calculated.

$$P_d = \frac{P_t}{4\pi d^2} \qquad (1)$$

Where P_t is the transmitted power in W/m2 and P_d is the power at a distance d from antenna.

The actual power received by the antenna depends on the following: (a) The aperture of receiving antenna A_e, (b) the wavelength of received signal λ, (c) and the power flux density at receiving antenna P_r [5].

Effective area A_e of an isotropic antenna is:

$$A_e = \frac{\lambda^2}{4\pi} \qquad (2)$$

The received power is given as:

$$P_r = P_d \times A_e = \frac{P_t \times \lambda^2}{4\pi d^2} \qquad (3)$$

It has been found that the received power P_r(d) in decibel (dB) at any distance (d) from the transmitter that is transmitting with transmits power P_t (dB) is given by [6]:

$$P_r(d) = P_t - P_L(d) \qquad (4)$$

So in plane terms ***P_L(d) = Power transmitted (P_t(dB)) - Power received (P_r (dB)).***

Furthermore, substituting "(3)" into "(4)", and expanding gives the decibel value of the Path-loss P_L (dB) in "(5)".

$$P_t \times \frac{\lambda^2}{4\pi d^2} = P_t - P_L$$

$$P_L = P_t - \frac{P_t \lambda^2}{(4\pi d)^2}$$

To convert to dB:

$$P_L = 10 log_{10}\left[P_t\left(1 - \frac{\lambda^2}{4\pi d^2}\right)\right]$$

$$P_L = 10\left[log_{10}P_t - log_{10}\frac{P_t\lambda^2}{4\pi d^2}\right]$$

$$P_L = 10[log_{10}P_t - log_{10}P_t - log_{10}\lambda^2 + log_{10}(4\pi d)^2]$$

$$P_L = 10[-log_{10}\lambda^2 + log_{10}(4\pi d)^2]$$

$$P_L = 10[2log_{10}(4\pi) + 2log_{10}(d) - 2log_{10}(\lambda)]$$

$$P_L = 10[2log_{10}(4\pi) + 2log_{10}(d) - 2log_{10}(\lambda)]$$

So $P_L = 20log_{10}(4\pi) + 20log_{10}(d) - 20log_{10}(\lambda)$ (5)

Then substituting (λ (in km) = 0.3 / f (in MHz)) and rationalizing the equation produces the generic free space path loss formula, which is stated as in "(6)" [7]:

$$P_L\,(dB) = 32.5 + 20\,log_{10}\,(d) + 20\,log_{10}\,(f) \qquad (6)$$

For any distance (d), the P_L (d) is given by [7], [8], [9] and [10] as:

$$P_L(d_i) = P_L(d_o) + 10n\log_{10}\left(\frac{d_i}{d_o}\right) \qquad (7)$$

Where (n) the path loss exponent can be manually calculated using "(8)" or derived through the application of linear regression analysis technique.

Table II. Average RSS measured results captured at Uyo for AKBC-TV.

	Signal strengths received from field measurements in intervals of 2 Km in dBm for AKBC – TV.										
SN	**50m**	**2km**	**4km**	**6km**	**8km**	**10km**	**12km**	**14km**	**16km**	**18km**	**20km**
1	-27.0	-45.5	-55.0	-57.0	-63.5	-60.0	-72.0	-74.5	-76.5	-75.5	-86.5
2	-27.0	-43.5	-54.5	-55.5	-62.0	-79.0	-73.0	-73.5	-77.5	-79.5	-97.0
3	-27.0	-47.5	-55.0	-57.0	-65.5	-67.5	-72.5	-75.0	-77.0	-76.5	-79.5
4	-27.0	-45.5	-54.0	-56.5	-61.0	-68.0	-71.5	-74.0	-73.5	-69.0	-77.5
5	-27.0	-46.0	-54.0	-54.5	-66.0	-64.5	-72.5	-75.5	-75.0	-78.0	-93.0
6	-27.0	-41.5	-55.5	-56.0	-64.0	-67.0	-71.5	-74.0	-69.5	-73.0	-96.5
7	-27.0	-43.0	-56.0	-57.5	-63.5	-66.0	-72.5	-76.5	-72.0	-75.5	-99.0

8	-27.0	-40.5	-57.5	-58.5	-62.5	-64.5	-70.5	-72.0	-80.0	-73.5	-81.5
9	-27.0	-40.0	-53.0	-56.0	-60.0	-67.0	-72.0	-74.0	-76.5	-97.0	-105.0
10	-27.0	-43.5	-55.5	-58.0	-61.5	-65.5	-73.5	-75.5	-78.5	-76.0	-93.5
Av	**-27.0**	**-43.65**	**-55.00**	**-56.65**	**-62.95**	**-66.90**	**-72.15**	**-74.45**	**-75.60**	**-77.35**	**-90.90**

Table III. Average RSS measured results captured at Uyo for NTA-UYO

	Signal strengths received from field measurements in intervals of 2 Km in dBm for NTA –UYO.										
SN	**50m**	**2km**	**4km**	**6km**	**8km**	**10km**	**12km**	**14km**	**16km**	**18km**	**20km**
1	-47.0	-79.5	-84.0	-85.5	-89.5	-91.0	-92.5	-97.5	-79.5	-87.5	-98.0
2	-47.5	-79.5	-84.0	-85.0	-88.5	-90.5	-90.5	-95.5	-82.0	-99.5	-102.0
3	-47.5	-77.5	-84.0	-84.5	-90.0	-90.5	-98.0	-99.0	-83.5	-93.0	-105.0
4	-47.5	-77.0	-86.5	-85.5	-91.0	-92.0	-99.5	-99.5	-99.0	-87.5	-102.5
5	-47.5	-79.0	-85.0	-87.0	-90.0	-93.0	-93.0	-98.0	-98.0	-93.0	-95.5
6	-47.5	-79.5	-85.5	-86.5	-89.5	-92.0	-95.5	-97.0	-97.0	-96.5	-98.0
7	-47.0	-79.0	-82.0	-88.0	-90.5	-90.5	-96.0	-98.5	-80.5	-91.0	-99.5
8	-47.0	-80.0	-82.5	-84.5	-89.0	-90.0	-87.5	-96.0	-91.0	-93.0	-97.5
9	-47.5	-80.5	-81.5	-85.0	-88.5	-91.5	-97.5	-98.5	-93.5	-96.5	-101.0
10	-49.0	-82.0	-83.0	-84.5	-89.5	-90.5	-93.0	-99.0	-94.5	-98.5	-99.0
Av	**-47.5**	**-79.35**	**-83.8**	**-85.6**	**-89.6**	**-91.15**	**-94.3**	**-97.85**	**-89.85**	**-93.6**	**-99.8**

$$n = \frac{\{P_L(d_i) - P_L(d_o)\}}{10\log_{10}(d_i/d_o)} \quad (8)$$

With linear regression, the value of the path loss exponent can be determined from the measured data, by minimizing in a mean square error sense, the difference between the measured data and the predicted path loss value of "(7)".

Let's recall from "(6)" [11]. The sum of the path loss exponents can be given by

$$E(n) = \sum_{i=1}^{k}\{L_p(d_i) - L_p'(d_i)\}^2 \quad (9)$$

Where: $L_p(d_i)$ is the measured Path loss at distance d in dB, and $L_p'(d_i)$ is predicted using "(7)" in decibel (dB) [1].

Substituting "(7)" in (9) for $L_p'(d_i)$

$$E(n) = \sum_{i=1}^{k}[L_p - L_p(d_o) - 10\log_{10}(\frac{d}{d_o})]^2 \quad (10a)$$

Differentiating "(10a)" w.r.t. n,

$$\frac{\delta E(n)}{\delta n} = -20\log_{10}(d)\sum_{i=1}^{k}[L_p - L_p(d_o)10\log_{10}(\frac{d}{d_o})] \quad (10b)$$

Equating $\frac{\delta E(n)}{\delta n}$ to zero,

$$0 = -20\log_{10}(d)\sum_{i=1}^{k}[L_p - L_p(d_o) - 10n\log_{10}(\frac{d}{d_o})$$

$$\sum_{i=1}^{k}[Lp - Lp(do)] - 10n\log_{10}\frac{d}{do} = 0$$

$$\sum_{i=1}^{k}[Lp - Lp(do)] - \sum_{i=1}^{k}[10n\log_{10}(\frac{d}{do}) = 0$$

$$\sum_{i=1}^{k}\{L_p - L_p(d_o)\}\sum_{i=1}^{k}\{10n\log_{10}(\frac{d}{do})\} = 0$$

$$\sum_{i=1}^{k}\{L_p - L_p(d_o)\} = \sum_{i=1}^{k}\{10n\log_{10}\frac{d}{do}\}$$

$$n = \frac{\sum_{i=1}^{k}[L_p - L_p(d_o)]}{\sum_{i=1}^{k}[10\log_{10}(\frac{d_i}{d_o})} \quad (11)$$

Equation (11) was used in the MATLAB code for the calculation of the pathloss exponents (n). For AKBC- UYO, the reference path loss calculated from the received signal strength at $d_0 = 0.05km$ was $L_p(d_0) = 95.45dB$. The Transmitted power of the station in dB was $P_t = 38.45dB$ and similarly for NTA – UYO, the reference path loss calculated from the received signal strength at $d_0 = 0.05km$ was $L_p(d_0) = 112.27dB$. The Transmitted power of the station in dB was $P_t = 34.77dB$

III. PRESENTATION OF RESULTS

A. Pathloss characterisation

Plots of the received signal strength (RSS) against the measured distances (d) are shown in Fig I for AKBC UYO and NTA UYO.

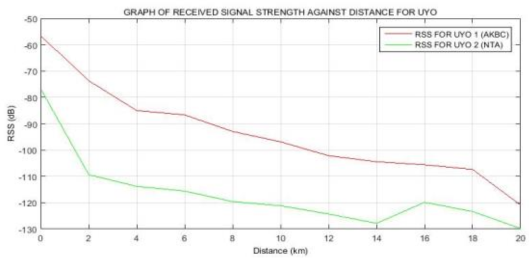


Fig I. Graph of the RSS against Distance for AKBC and NTA (Uyo).

From "(11)", the Path loss exponent for AKBC UYO and NTA UYO are, $n =$

1.796 (UHF) and n = 1.903 (VHF) respectively.

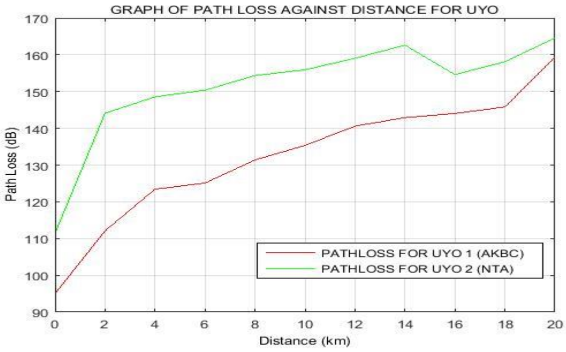


Fig II. Graph of the Pathloss against Distance for AKBC and NTA Uyo.

From "(7)" standard equation for measured pathloss therefore becomes,

$$For\ AKBC\ \ P_L\,(dB) = 24.94 + 17.96log_{10}(d) \quad (12a)$$

$$For\ NTA\ \ P_L\,(dB) = 79.94 + 19.03log_{10}(d) \quad (12b)$$

To determine the shadowing constant the mean square error method of "(13)"was used

$$\text{Mean Square Error,} \quad X_\sigma = \sqrt{\frac{\sum(P_m - P_r)^2}{N}} \quad (13)$$

It was derived that the actual pathloss values for the two stations were;

$$For\ AKBC\ \ P_L\,(dB) = 57.35 + 17.96log_{10}(d) \quad (14a)$$

$$For\ NTA\ \ P_L\,(dB) = 84.04 + 19.03log_{10}(d) \quad (14b)$$

The graphs of pathlosses against distances are shown in Fig II. A comparison of these pathloss results with popular models namely, Okumura Hata, Cost 231-Hata and Cost 231-Walfish Ikegami as presented in Fig III for AKBC and Fig IV for NTA Uyo, it is seen that the measured pathlosses were far lower than what was predicted by the popular models.

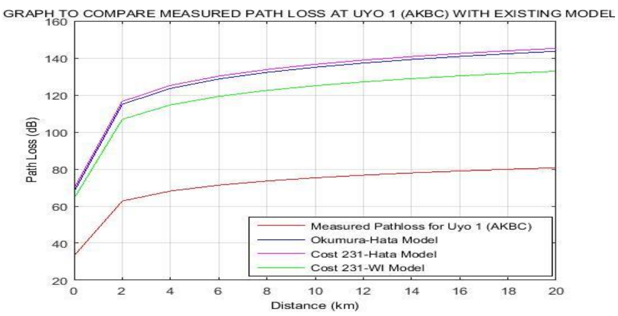


Fig III. Models for AKBC Uyo

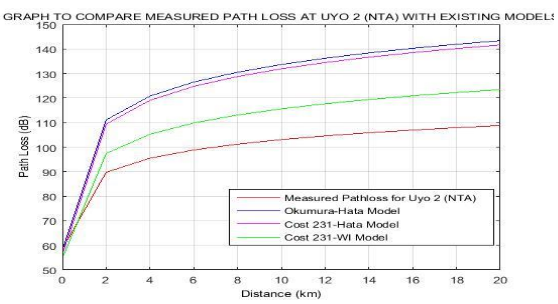


Fig IV. Comparison of Measured Pathloss and Existing Models for NTA Uyo

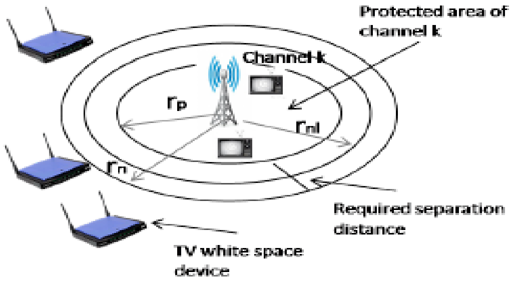


Fig V. Protection Radius, Separation Distance and the No-Talk Radius Consideration for PU protection

B. Characterisation of TV primary users protection contour for Nigeria

The main deterrent to the use of TV whitespaces for secondary access has been hinged on Primary User (PU) rights. The Secondary User (SU) can only operate on a TV channel if it will not cause unwanted interference to the TV service users and also not render the channel unusable due to the summation of interferences from many SUs. Many ideas have been proposed to protect the PUs such as transmit power control, protection contours, pollution consideration and the location probability method. This work applies the protection viewpoint in the determination of the protection contours in the UHF band for Nigeria.

Considering the determined path loss characteristics for TV signals in Akwa Ibom State, it is possible to calculate the TV coverage protection region and no talk zone beyond which the same PU channel can be reassigned by the geolocation database to a secondary user.

According to [11] and shown in Fig V. Fig VI shows the protection viewpoint for PUs, the distance r_p is the protection radius and the coverage area allocated to the PU services where the signal to interference noise ratio (SINR) of the PU receiver is not below the TV receiver sensitivity threshold (∆). The r_n called the no talk zone is defined as the distance from the PU transmitter up to which no secondary user can transmit. $r_n - r_p$ is called the separation distance, it offers more protection to the PU receiver such that if an SU transmit at that distance $r_n - r_p$ from the PU receiver, the received signal would not fall below the SINR threshold (∆). An established relationship exist for the r_p for in-band usage and can be found in [11], If P_t is the transmit power of the PU transmitter in dBm, $P_{L(r_p)}$ is the Pathloss in dB for the distance r_p from the PU transmitter, the threshold SINR in decibels with reference to one milliwatt (dBm) is ∆ and $N_o$is the noise power given as $10log_{10}(KTB)$ in dBm, then

$$P_t - P_{L(r_p)} - N_o = \Delta \quad (15)$$

$$P_{L(r_p)} = P_t - \Delta - N_o \quad (16)$$

Recalling "(14a)" which gives the pathloss equation for AKBC UYO TV signals propagating in the UHF band as

$$P_L\,(dB) = 57.35 + 17.96log_{10}(d)$$

And equating it to "(16)", where d = dr_p and the pathloss is the pathloss for the distance (dr_p) $is\ P_{L(r_p)}$, then

$$P_{L(r_p)} = 57.35 + 17.96log_{10}(dr_p)$$

Making dr_p the subject of the equation, we

$$P_{L(r_p)} - 57.35 = 17.96log_{10}(dr_p)$$

$$log_{10}(dr_p) = \frac{P_{L(r_p)} - 57.35}{17.96}$$

$$dr_p = antilog\left[\frac{P_{L(r_p)} - 57.35}{17.96}\right] \quad (17)$$

But $P_{L(r_p)} = P_t - \triangle - N_o$ in "(16)"

And N_o= $10log_{10}(KTB)$ where K= Boltzmann's constant of $1.38x10^{-23}J/K$ and T = Temperature in Kelvin and B=Bandwidth in Hz. Taking atmospheric temperature in Nigeria as 27^o and the UHF channel bandwidth to be 8MHz So the N_o is given as

N_o= $10log_{10}(1.38x10^{-23}x\ 300x\ 8x10^6)$

N_o= $10log_{10}(3.312x10^{-14}) = -134.8 \equiv -135\ dBm$

And the maximum tolerable interference which is the threshold SINR ($\triangle$) for PU receivers is given as 45dBm [11].

Substituting in the equation $P_{L(r_p)} = P_t - \triangle - N_o$

$$P_{L(r_p)} = P_t - 45 - (-135) = P_t + 90$$

Then "(15)" becomes $(dr_p) = antilog\left[\frac{P_t + 90 - 57.35}{17.96}\right]$

$$dr_p = antilog\left[\frac{P_t + 32.65}{17.96}\right]$$

Or simply $\boldsymbol{dr_p = 10^{\left[\frac{P_t + 32.65}{17.96}\right]}}$. (18)

This gives the equation of the PU protection contour as a function of PU transmits power P_t when propagating within the UHF band in rural Nigeria. From "(18)" Table IV is deduced, which gives the protection distance of the PU (coverage area) as the transmit power increases as shown in Fig VI.

Table IV. Table of Relationship between Transmit Power and Protection Distance of a TV station.

PU TX Power (KW)	Protection Distance (KM)
1	33.72352479
2	49.67137049
3	62.29901037
4	73.16094808
5	82.87413278
6	91.76019542
7	100.0126123
8	107.7587405
9	115.0878124
10	122.0652876
11	128.7409128
12	135.1535669
13	141.334336
14	147.3085494
15	153.0971774
16	158.7178196
17	164.1854218
18	169.5128075
19	174.7110796
20	179.7899289

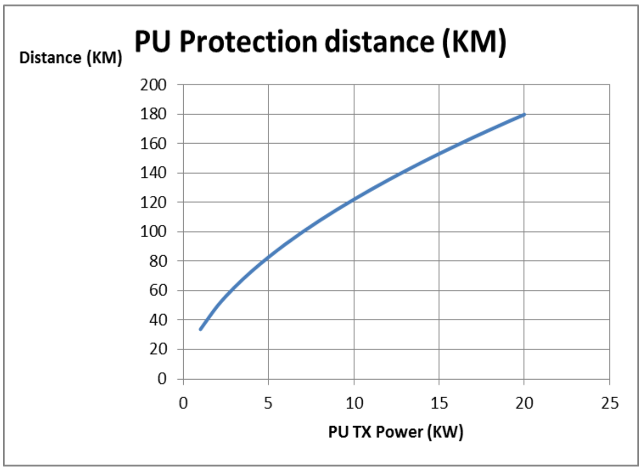


Fig VI: Display of the Relationship between PU Tx Power and the Protection Distance in Nigeria.

C. Computation of separation distance $(\mathbf{r_n - r_p})$

In [11], the separation distance can be determined by using "(19)"

$$P_s - P_{L(r_n - r_p)} = \varphi \quad (19)$$

Where P_s is the transmit power of the secondary user equipment and φ is the fading constant derived as the standard deviation of the measured pathloss from the predicted pathloss values and given in this case for UHF propagation using AKBC measured data as $X_\sigma = \sqrt{\frac{\sum(P_m - P_r)^2}{N}} = \sqrt{\frac{11556.01}{11}} = 32.41dB$

Since the pathloss of the UHF for any distance can be deduced from "(14a)"

$$P_{L(d)} = 57.35 + 17.96log_{10}(d)$$

Therefore pathloss for $d_{(r_n - r_p)}$ = $57.35 + 17.96log_{10}\left(d_{(r_n - r_p)}\right)$ and

$$P_{L(r_n - r_p)} - 57.35 = 17.96log_{10}\left(d_{(r_n - r_p)}\right)$$

$$log_{10}\left(d_{(r_n - r_p)}\right) = \frac{P_{L(r_n - r_p)} - 57.35}{17.96}$$

But $P_s - P_{L(r_n - r_p)} = \varphi$ (requirement for separation distance).

So $P_{L(r_n - r_p)} = P_s - \varphi$ and as such

$$log_{10}\left(d_{(r_n - r_p)}\right) = \frac{P_s - \varphi - 57.35}{17.96}$$

Substituting $\varphi = 32.41dB$ (derived from "(13)").

Therefore

$$\left(d_{(r_n - r_p)}\right) = antilog\left[\frac{P_s - 32.41 - 57.35}{17.96}\right]$$

Or

$$\boldsymbol{d_{(r_n - r_p)} = antilog\left[\frac{P_s - 89.76}{17.96}\right]} \quad (20)$$

Retrieval Number: J74390891020/2020©BEIESP
DOI: 10.35940/ijitee.J7439.0891020
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication

Where P_s is the transmit power of the secondary device. This equation provides a means of determining the separation distance from the PU protection contour after which SU devices can coexist on the same channel.

Table V: Table depicting SU keep away distance in km from the PU Protection Contour

SU Tx-Power (dBm)	SU No talk zone (KM)
5	1.9082E-05
10	0.056523256
15	0.107305902
20	0.20371361
25	0.386737674
30	0.734197527
35	1.393828544
40	2.646097184
45	5.023451657
50	9.536711916
55	18.10485705
60	34.37095006

As can be seen from Table V and Fig VII, the keep away no talk distance increases as the SU transmit power increases. Meaning with adequate power management, coexistence between the PU and SU on same channel is possible if attention is paid to the distance separation.

In total the distance between the PU and the SU which is the sum of the $\boldsymbol{dr_p} + \boldsymbol{d_{(r_n - r_p)}}$ and beyond which co-channel and adjacent channel interference will not hinder the reuse of the spectrum is given by

That is $antilog\left[\frac{P_t+32.65}{17.96} + \frac{P_s-89.76}{17.96}\right] = 10^{\frac{P_t+P_s+32.65-89.76}{17.96}}$ (21)

So $\boldsymbol{d_{(r_n)}}$ (the distance from PU transmitter to SU transmitter) = $\boldsymbol{antilog}\left[\left[\frac{P_t+P_s-57.11}{17.96}\right]\right]$. This is to be known as the isolation Distance.

IV. CONCLUSION

This research work studied the propagation properties of TV signals on the VHF and UHF frequency ranges. The emphasis on the use of a reliable prediction technique to accurately estimate the service coverage of TV stations for effective utilization of spatial TV white space was herein re-echoed. The Pathloss exponent for the VHF band was found to be approximately 1.9 and a characterised Pathloss equation for VHF band computed as $P_L\,(dB) = 84.04 + 19.03log_{10}(d)$, where (d) is the distance from the transmitter to the receiver. The UHF band Pathloss exponent was computed to be approximately 1.8 with a Pathloss equation characterised as $P_L\,(dB) = 57.35 + 17.96log_{10}(d)$. The research also found that there where divergence in coverage prediction between the measured model and the conventional models namely the Okumura-Hata Model, the Cost 231-Hata Model and the Walfisch Ikegami Model.

The protection view point was used to determine the protection contour for TV signals propagating in the UHF band in South-south Nigeria. The contour radius (dr_p) was found to be $dr_p = 10^{\left[\frac{P_t+32.65}{17.96}\right]}$ modeled as a function of the

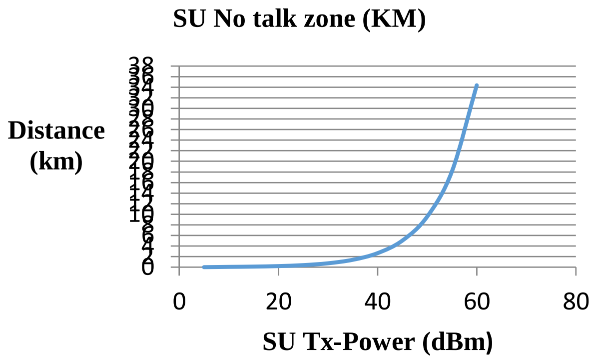


Fig VII: Display of the relationship between SU Tx Power and the Separation Distance.

transmit power P_t of the TV station in dBm for co-channel and adjacent channel access.

Similarly, the no-talk-zone separation distance was also computed as a function of the transmit power of the secondary user device in dBm for co-channel usage to be $\boldsymbol{d_{(r_n-r_p)} = antilog\left[\frac{P_s-89.76}{17.96}\right]}$.

The propagation characteristics of the VHF and UHF TV signals were successfully characterized for use in Nigeria and the distance between the PU and the SU that will allow for harmonious co-existence was deduced as $\boldsymbol{10^{\frac{P_t+P_s-57.11}{17.96}}}$. This model will facilitate TVWS co-channel coexistence using the specified equation to determine the separation distances between television transmitters and secondary user transmitters.

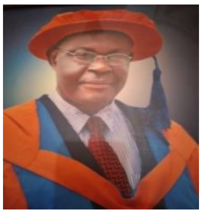
REFERENCES

1. E. A. Ubom, V. E. Idigo, A.C.O. Azubogu, C.O. Ohaneme, and T.L. Alumona, "Path loss Characterization of Wireless Propagation for South – South Region of Nigeria". International Journal of Computer Theory and Engineering, Vol. 3, No. 3, June 2011 pp. 360-364.
2. V.H. MacDonald, "The cellular concept," The Bell Systems Technical Journal, vol. 58, no. 1, 1979, pp. 15-43.
3. S. Faruque, "Propagation prediction based on environment classification and fuzzy logic approximation". In Proceedings of the International Conference on Communications, ICCC/SUPERCOMM'96, Dallas, TX, USA, 23–27 June 2002.
4. N. Faruk A.A. Ayeni and Y.A.Adediran, "On the Study of Empirical Path Loss Models for Accurate Prediction of TV Signal for Secondary Users". Progress in Electromagnetics Research B, Vol. 49, 2013, pp 155–176.
5. Z. Nadir, N. Elfadhil, and F. Touati, "Pathloss Determination using Okumura-Hata Model and Spline Interpolation for Missing Data for Oman", Proceedings of the World Congress on Engineering 2008 Vol I WCE 2008, July 2 - 4, 2008, London, U.K. Page 422-425.
6. K. Mano, "Coverage estimation for Mobile Cellular Network. From Signal strength Measurements" submitted PhD Dissertation to Department of Electrical Engineering, The University of Texas at Dallas, 1999. Accessed on the 26th of June 2018 @ citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.58.4998&rep=rep1&type=pdf.
   http://www.awe-communications.com/Propagation/Rural/HO/index.htm. Accessed 22nd of June 2019.

7. A. R. Mishra, "Advanced Cellular Network Planning and Optimisation" – Wiley 2007.
8. R. Nave, "Blue sky and Rayleigh Scattering". Hyperphysics. Georgia State University.http://hyperphysics.phy-astr.gsu.edu/HBASE/atmos/blusky.html]
9. M. Awad, K. T. Wong & Z. Li "An Integrative Overview of the Open Literature's Empirical Data on the Indoor Radiowave Channel's Temporal Properties" IEEE Transactions on Antennas & Propagation, vol. 56, no. 5, 2008, pp. 1451-1468.
10. G. Naik, S. Singhal, A. Kumar, and A. Karandikar, "Quantitative assessments of TV Whitespaces in India" , 2015 available online @ http://www.dynamicspectrumalliance.org/assets/Quantitative%20Assessment%20of%20TV%20White%20Space%20in%20India_02032015.pdf

AUTHORS PROFILE

Emmanuel A. Ubom is a telecommunications engineer with 18+ years of experience in the full cycle of planning, implementation, commissioning, operations and management of fixed wireless and mobile telecommunication networks, optical networks, Enterprise Services and Systems Integration. He is currently a Lecturer in the Department of Electrical and Electronic Engineering, Akwa Ibom State University. His research interest is in the areas of wireless communications, signal propagation, spectrum management, green energy and signal processing with many published papers. He is a PhD in Communications Engineering candidate and holds a MEng in Electronic and Computer Engineering at Nnamdi Azikiwe University. He is a registered engineer with the Council for the Regulation of Engineering in Nigeria (COREN) and member of the Institute of Electrical and Electronic Engineers (IEEE), USA and the International Association of Engineers (IAEng.).



Victor Idigo is currently a Professor of Electronics and Computer Engineering in the Department of Electronics and Computer Engineering, Faculty of Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. He has MSc and PhD in Communications Engineering. His research interests are: mobile communications systems, geolocation system design and implementation, electronic control systems design and implementation, system modelling and simulation with many published papers and books to his covers. He is a registered engineer by the Council for the Regulation of Engineering in Nigeria (COREN), a member of the Nigerian Society of Engineers (NSE), member, Institute of Electrical and Electronic Engineers (IEEE), USA and member of the International Association of Engineers (IAEng.).

Ubong Ukommi, obtained Masters degree (MSc) in Mobile and Satellite Communications, and PhD in Electronic Engineering from the University of Surrey, United Kingdom respectively. He has made contribution towards advancement of engineering and technology through presentations and publications of research findings in reputable journals and conference in London, UK, California, USA and Abuja, Nigeria. He is a member of international and national professional organisations including Institution of Electrical and Electronics Engineers, New York, USA, Institution of Engineering and Technology, UK, Nigerian Society of Engineers, Nigeria. Having completed his Masters programme, he worked for Viewsat Limited, UK, as a team member consulting, developing and reviewing engineering designs, project implementation and upgrading of telecommunications facilities for improved quality of experience. Ubong, is also involve in the activities of Association of Consulting Engineers in Nigeria. He is a registered member of the Council for the Regulation of Engineering in Nigeria (COREN), where engineering practice and policies are formulated and regulated for best practice and development. Currently, Ubong is working for Akwa Ibom State University, Nigeria, where he is actively engage in Lecturing, Research and Development programme. He also consults for Government Projects and Engineering Organisations in Nigeria.