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DEVELOPMENT OF A SPECTRUM SENSING PROTOCOL FOR TELEVISION WHITE SPACE IDENTIFICATION IN ENUGU, NIGERIA

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Abstract

Due to the growing need for wireless broadband, there is a continued increased request for dynamic spectrum access of TV White Spaces (TVWS) by most cellular users. The risk of high interference among Secondary Users (SUs) beyond the preferred threshold and detrimental interference to Primary Users (PUs) will be experienced when there is a high density of SUs in a TVWS network. This call for the optimization of resource allocation to lessen the level of interference among SUs, thus, protecting the PUs against detrimental interference. In this paper, a novel spectrum sensing protocol was developed for television white space identification in Enugu and its environs. The spectrum sensing algorithm was chosen over the geo-location database technique for obvious reasons as was given in the work. Performance factors of the spectrum sensing method were outlined. RF explorer was used to monitor and detect energy strength at various locations. Several path loss models were outlined after which the Longley-Rice Irregular Terrain Model was used for the physical environmental evaluation. Point measurements were taken and other subsequent computations were carried out using the spectrum measurement setup. Results show that the identification of TVWS application in a particular location within the Enugu metropolis can be determined, also a good spectrum sensor can be developed for use in Enugu, Nigeria as well as in other similar cities given the same method without interference effect with the legitimately licensed Primary users.

Keywords: *Spectrum Sensing, TV White Space, Geolocation Database, RF Explorer, Longley-Rice Irregular Terrain Model*

1. INTRODUCTION

White spaces refer to parts of the television (TV) frequency band (spectrum) that are unoccupied or not committed to any specific use at a particular time and geographical location (GSMA, 2013). This is also referred to as Television white spaces (TVWS) or interleaved spectrum, (Gomez, 2013). They are radio frequencies allocated to a broadcasting service but are

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not in use. Unused spectrum in the television broadcasting bands specified as 470 to 790 MHz in Europe and 470 to 698 MHz in the United States of America. In Nigeria, the Nigerian Communications Commission, NCC, allocated TVWS to operate on available frequencies in the 470 to 694 MHz portions of the Ultra High Frequency, (UHF), band as determined by the provided database (NCC, 2019). Within this UHF frequency band, internet access can be provided to the underserved as well as unserved regions of the country, mostly in rural service areas at broadband speeds.

In the development of TVWS, Careful interference avoidance is required especially on a secondary unlicensed basis, towards primary users like existing TV broadcasters. For the above reason, there is a need to develop an authentic database where a list of available channels could be kept for use by unlicensed TV white space devices. These developed databases are aimed at restricting unlicensed devices to available channels so that interferences do not occur. Alternatively, sensing the frequency spectrum in a geographical location is carried out. This is to constantly determine free radio signals using sensors in other to estimate the relative location of primary users, to avoid interferences with them. This is the so-called spectrum sensing technique.

As the growth in the demand for high-speed broadband multimedia services continues to rise, pressure on the use of underused spectrums also increased. Today, so many online services and applications abound. This has fundamentally necessitated the need for opening up a dedicated spectrum for both licensed and unlicensed users (Farzad, 2013). The attraction of this frequency spectrum stems from two major points namely; its propagation characteristics which are good for wireless communication with reduced losses in propagation and an increase in coverage. The next reason for the attraction is the cheapness in the procurement of infrastructure required for the implementation. This factor has particularly made it suitable for rural and underdeveloped areas, (Naroa, 2011). Additionally, the TVWS is superior in range and can penetrate opaque obstacles such as buildings, trees, and rough terrains thus increasing the desire for its use (Anderson, 2016). It can also be used alongside the surrounding TV channels.

2. LITERATURE REVIEW

According to Ezeji et al, (2019), a geo-location database is a centralized repository or local mirror that is used to identify any TVWS free channels that are available for use without interfering with other services. To ensure the protection of primary users, geo-location and sensing database systems are used. In their work, a geo-location database was used. A geo-location database is entered into and queried to ascertain which frequencies are free for a communication activity to take place by the white space devices (WSDs). Upon response, the WSD selects one of the available frequency channels with which it carries out its transmission (Carlson and Telcordia, 2015).

The alternate technique is the sensing technique involving detecting radio signals using sensors to estimate the relative location of primary users to avoid interference with them. The main goal of spectrum sensing is to identify unused spectrum gaps across a broad range of frequency bands so that secondary users can utilize them to meet their quality-of-service needs. In cognitive radio (CR), spectrum sensing is a basic necessity to safeguard the primary user (PU) against harmful interference. According to Wang et al., (2010), TVWS enables the spectrum reuse paradigm to ensure interference-free broadcasting between the primary users and the secondary users applying the cognitive radio technology. Furthermore, TVWS technology was adopted after the evolution from analog television service to digital terrestrial television (DTT). This serves as a substitute to provide internet access using the free spaces in the spectrum, especially in rural areas, without causing interference to Primary Users (licensed users) of television channels transmitting at low-cost equipment and low-power levels (Avendaño et al., 2020). Thus, it is appropriate to adduce technical reasons for the choice of the method for the implementation of the TVWS technology in any particular region or country.

Facilitating the coexistence of numerous wireless devices with growing device and service complexity and global access to mobile services necessitates the use of geolocation databases or spectrum sensing techniques, as well as continuous updates regarding the available TVWS channels. (Anabi et al., 2016). This, therefore, calls for a clear distinction regarding the choice of technique for use in the implementation of the TVWS technology.

- **Choice of Implementation Technique**

Given that each strategy's peak performance depends on several variables that might not be present in all regions, neither approach can produce greater performance in every scenario, (Hope et al 2017). In areas or nations where propagation models have been thoroughly tried and tested so that their prediction results are close to actual data, with reliable Internet backbone infrastructure and centralized and comprehensive TV database information also available, the authors expected the geo-location database approach to perform better than the spectrum sensing technique. Since all these three factors are available, this applies to the developed countries in Europe and USA. This position is buttressed in Mancuso (2013) and FCC (2010) where it was observed that most implementation of TVWS technology is based on a geo-location database approach. The converse holds sway in developing countries and regions of the world. In those regions, especially in the rural areas, there is poor and unpredictable internet backbone infrastructure. At the moment, propagation models have hardly been tested there such that their behaviors are unclear. Various formats such as electronic and paper are used to store spectrum usage information which are scattered. The regulators are not yet collected into a useful integrated database that is widely available. With these prevalent settings, the use of a geo-location spectrum database approach is not likely to produce optimal results.

As a result of many tall buildings, which are also clustered, fading, shadowing as well as the hidden user problem, applicable to spectrum sensing, can be severe in the developed world. Accordingly, it is difficult to precisely detect primary TV signals using spectrum sensing alone. To users who use TV receiving antennas installed on top of their buildings, this could result in unsafe interference. Therefore, there may be poor performance of spectrum sensing in urban areas. On the other hand, rural locations, especially in poor nations, where white space could be leveraged to provide broadband access, are sparsely populated with small, ancient structures that are unlikely to significantly cause fading, shadowing, or to result in the hidden user problem. In Pietrosemoli and Zennaro, (2013), the vast majority of rural areas in emerging nations, like sub-Saharan Africa, have an untapped UHF band spectrum. Thus, in those areas, cooperative spectrum sensing lowers multi-path fading-related errors in spectrum sensing and provides a potential remedy for the hidden user issue. There are also some other metrics to be considered in deciding an approach for use. These include implementation, maintenance, and administration costs.

- **Performance Factors of Spectrum Sensing Method**

Figure 1 shows an overview of the spectrum sensing approach. It elucidates and summarizes the factors which affect its performance as has been partly discussed earlier.

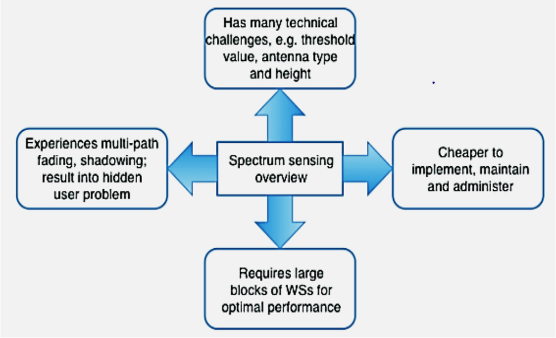


Figure 1: Spectrum Sensing Overview

As earlier discussed, due to obstacles in their path such as buildings, signals experience multi-path fading and shadowing as they propagate through the wireless medium. These effects may lead to a scenario called the hidden user problem or hidden terminal problem (Yucek and Arslan, 2010) in cases where a WSD is unable to identify a principal signal in a channel. If the sensing equipment is located indoors at ground level, where the signal is weaker than that which may be picked up by an external TV antenna on a roof, this could occur. This can lead to misinterpretation of measured data by the WSD which could start to transmit, thus causing interference to the primary user. When there are many impediments, like hills or big buildings, these impacts can be very severe.

One way to find out if a spectrum is available is to sense it with a detector. In this method, the detector has no knowledge of the locations or broadcast strengths of TV transmitters. The measurements are used to determine the amount of protection for TV viewers; if the signal level is too low for a TV receiver to use, the spectrum is assumed to be free and hence available (Hoven and Sahai (2005), Ruttik, K. (2011)). In general, the two categories of sensing techniques are energy detection and feature detection. A spectrum analyzer like the Radio Frequency (RF) Explorer can be used for energy detection, but feature extraction is more complex and sensitive because it is based on the properties of the type of signal being detected

The secondary user can accurately recognize TVWSs with the right detection threshold and be able to transmit in those bands without interfering with the major users (Brown et al, 2014). Due to its simplicity, energy detection is the commonly proposed method. It operates by calculating the energy present in a spectrum band and comparing it to a predetermined threshold value. The principal user signal is regarded as present if the energy level is over the threshold value; else, the spectrum band is considered empty.

• Review of Related Works

A set of reviews of recent works on the all-important communication paradigm of

TVWS is presented to deepen the desired knowledge as well as its applications and implementation procedure.

According to the UK Research and Innovation (2021), Internet of Things (IoT) and Machine-to-Machine (M2M) have been identified as being among five areas capable of providing real growth opportunities between government and industries. The gains of M2M would be most manifest in energy, agriculture, manufacturing, e-health, and transportation.

Kennedy et al, (2019) opined that to address spectrum scarcity and spectrum underutilization, Dynamic Spectrum Access (DSA) is currently being embraced as a solution through the use of cognitive radio. DSA permits the use of an underutilized spectrum as long as the Secondary Users (SUs) do not interfere negatively with the Primary Users (PUs). As a result of the good propagation characteristics attainable within such bands, Spectrum bands known as TV White Spaces (TVWS) have generated a lot of research and development attention. Efficient assignment of the available spectrum and power to SUs is the aim of resource allocation in cognitive access to TVWS that the interference constraints to PUs and SUs are met. An important subset of the DSA is Radio resource allocation which significantly addresses the spectrum scarcity and interference in TVWS networks.

Guo et al., 2017 in Linear Soft Combination for Cooperative Spectrum Sensing in Cognitive Radio Networks investigated the linear combination rule to minimize the probability of missed detection. The proposed rule required only the mean and variance of the local test statistics subject to an upper limit of false alarm probability. Using three typical fading scenarios namely, slow fading, block fading, and fast fading, the combination rule proposed was verified. The simulation results show that in addition to having nearly the same performance with the optimal likelihood-ratio test methods, it also outperforms the conventional linear combination procedures.

3. METHODOLOGY

The basic research methodology is incumbent on the use of the basic experimental setup shown in Figure 2.

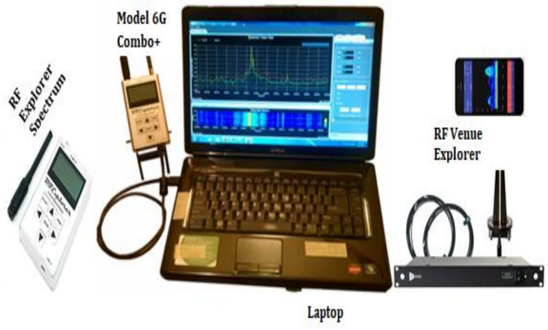


Figure 2: Basic Experimental Setup

This setup comprises a laptop computer unit, a radio frequency explorer, RF Venue Explorer Pro, Model 6G Combo+, B & H Photo-Video-Audio. To connect to the laptop, CP2102 USB device was used internally to connect to the PC. The setup in Figure 2 was used for data generation and collection resulting from measurements got from different locations in the form of a drive test arrangement. This was a physical environmental evaluation result.

Physical Environmental Evaluation

Since it has been established from the preceding section that the choice of propagation depends on certain metrics as none of the propagation methods performs better than the other, spectral measurements were then carried out to determine the fundamental statistics for different locations. Thus, in this work, **Longley-Rice Irregular Terrain Model** was used in the evaluation established in this work.

The model, which was originally developed in the 1960s was meant to predict properties of propagation losses in a communication link between the transmitter and receiver. Cumulative distribution was used to describe the predicted propagation loss due to the stochastic nature of radio wave propagation. Using the path geometry of the terrain profile and atmospheric refraction, it calculates the median transmission loss. Two modes of prediction are available namely, area prediction and point-to-point prediction. Due to the level of detail incorporated in the model, its application was in the form of a computer program capable of accepting the required parameters with which it was used to compute the expected path loss. Radio Mobile Network Planning was used. Due to the irregularity of the terrain, the Friis transmission equation was used as shown:

$$Pr(d) = Pr(dr) + 20 * log(dr/d) \quad (1)$$

where Pr(d) = the received power;

d = the distance from the transmitting primary user (NTA Enugu) which was the same radial where do is calculated;

Pr(dr) = the received power at a close-in-reference-distance;

dr = the reference distance.

Transmitter Used and its Frequency

Nigerian Television Authority, NTA, Enugu, operates on a frequency of 8 VHF with a transmitter of 10kW, Rhode and Schwartz digital transmitter.

Points of Measurements

Measurements were taken at ten locations having different distances from the transmitter of NTA Enugu which is the reference transmitter. Table one shows the values of the sites' height above average terrain (HAAT), as determined using the GLOBE 1 km Base elevation database. Enugu is sitting on global coordinates of 6° 26' 28.75" N and 7° 29' 55.79" E. This means that it has a Latitude of 6° 26' 28.75" and a Longitude of 7° 29' 55.79" which also translates to a latitude of 6.459964 and a longitude of 7.548949.

Table 1: GPS coordinates of measurement sites and their distances from the TV transmitter

Name of site	Lat.	Long.	HAAT(m)	D_{km} (km)
SITE 1 FGC Enugu	6.12	7.41	9	0.82
Maryland	6.08	7.25	8	0.93
CIC Enugu	6.31	7.35	11	1.05
Enugu North	6.45	7.54	9	1.14
Ameachi Road	6.10	7.45	12	1.42
Garki Enugu	6.09	7.39	12	1.83
Trans-Ekulu	6.23	7.42	51	1.86
Umuchigbo Nike	6.40	7.20	41	2.14
Emene Enugu	6.38	7.42	21	2.26
CCSS Ngwo	6.32	7.18	140	2.43

The geographic map shown in Figure 3 shows these sites from where measurements were taken.

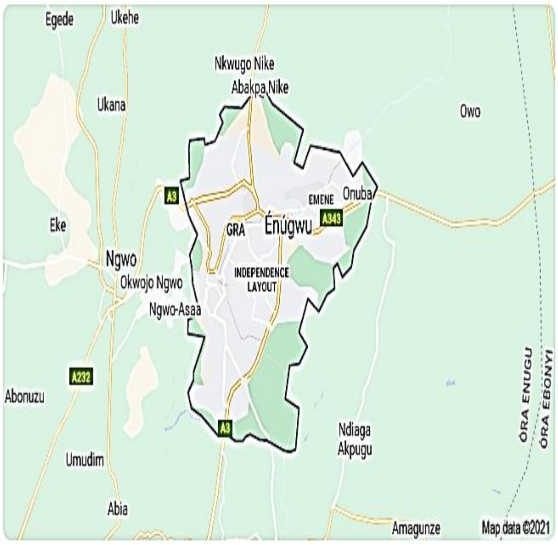


Figure 3: Geographic Map showing Measurement Points

Setup of Spectrum Measurements

A hand-held RF Explorer model WSUB1G with a measurement frequency range of 240 MHz to 960 MHz was used to conduct outdoor spectrum measurements in the UHF frequency band at the selected sites. The RF Explorer was linked to an Android phone that was running the RfTrack application, which immediately began measuring the spectrum after the RF Explorer was connected. Figure 4 shows a complete spectrum sensing setup from which results generated were tabulated in tables as subsequently presented. In the setup shown in Figure 4, USRP N210 was used as arranged in conjunction with the general experimental setup shown earlier in Figure 2. Spectrum monitoring was done at each site, for 6 hours from 08:00 in the morning to 14:00.

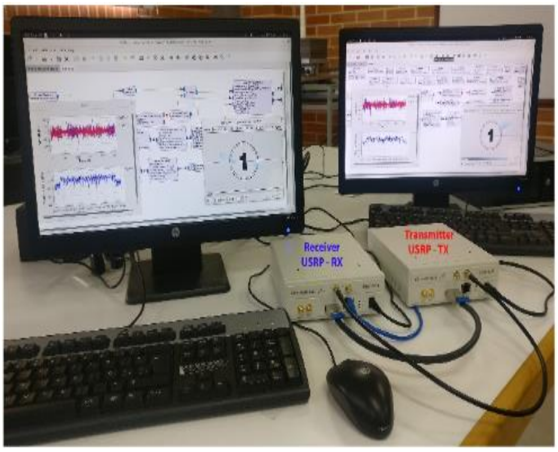
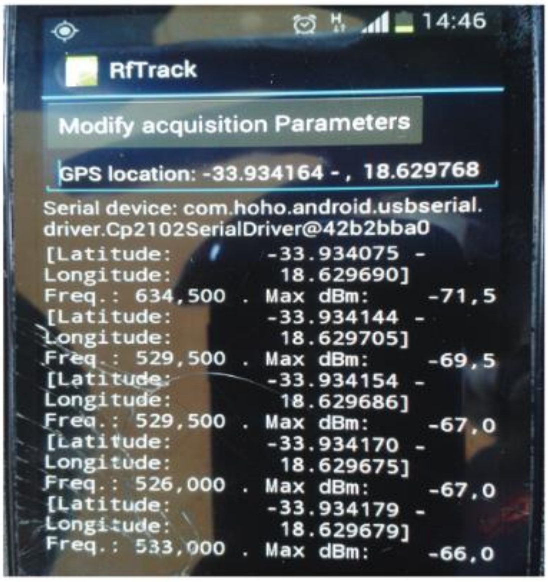


Figure 4: Experimental Set-up for digital video transmission using USRP N210

The display is shown in figure 5



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GPS location: -33.934164 - , 18.629768
Serial device: com.hoho.android.usbserial.
driver.Cp2102SerialDriver@42b2bba0
[Latitude:        -33.934075 -
Longitude:         18.629690]
Freq.: 634,500 . Max dBm:      -71,5
[Latitude:        -33.934144 -
Longitude:         18.629705]
Freq.: 529,500 . Max dBm:      -69,5
[Latitude:        -33.934154 -
Longitude:         18.629686]
Freq.: 529,500 . Max dBm:      -67,0
[Latitude:        -33.934170 -
Longitude:         18.629675]
Freq.: 526,000 . Max dBm:      -67,0
[Latitude:        -33.934179 -
Longitude:         18.629679]
Freq.: 533,000 . Max dBm:      -66,0
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Figure 5: Monitored Measurement Display

To determine the received signal power, measurements were taken at each site where the TV transmitter broadcast (Rx). The Friis transmission equation was used to estimate the power received at further locations along the same approximate radial from the average value of the observed power at the closest site to the BS transmitter (SITE1) as shown in equation 1.

Equation (1) has earlier been established for irregular terrain.

Using equation (1), measured and calculated values were compared.

Site 1 (FGC Enugu)

Pr (d) = Pr (do) = -80.39 dBm = Reference Power.

Site 2 (Maryland)

The following definitions need to be made considering the distances.

do = 0.82km

d = 0.93km

Applying equation 1, the following was obtained:

Pr (d) = -80.39 dBm + 20 * log (0.82/0.93)

= -80.39 dBm + 20 * log (0.881720430…)

= -81.48 dBm.

Thus, calculated Pr (d) = -81.48 dBm

Measured – Calculated

= -97.30 dBm – (-81.48dBm)

= -15.82dBm.

Following the above procedures, table 2 was generated.

Table 2: Comparison between Calculated and Measured Power

Site Name	d_{Km} (km)	Measured (dBm)	Calculated ($Pr_{(d)}$(dBm)	Measured - Calculated (dBm)
SITE 1	do = 0.82	Pr(do) = -80.39	Reference power	-
SITE 2	0.93	-97.30	-81.48	-15.82
SITE 3	1.05	-86.45	-82.54	-3.91
SITE 4	1.14	-93.34	-83.25	-10.09
SITE 5	1.42	-94.52	-85.16	-9.36
SITE 6	1.83	-92.52	-87.37	-5.15
SITE 7	1.86	-92.58	-87.50	-5.08
SITE 8	2.14	-96.43	-88.72	-7.71
SITE 9	2.26	-97.75	-89.20	-8.55
SITE10	2.43	-91.77	-89.83	-1.94

Table 2 shows a reasonable agreement between measured and calculated values thereby confirming the adequacy of the square law dependence of power loss with distance given the absence of obstacles in the trajectory. With the presence of obstacles, the multiplication factor with the logarithm can be as high as even 40 instead of 20. Graphs of dkm versus calculated values as well as measured power when plotted were used to show the possibility of allowing the presence of a secondary user, (SU) within sites where the measurements were taken.

4. RESULTS AND DISCUSSIONS

From the data presented in table 2, the graphs shown in Figures 6, 7, and 8 were produced for further analysis. Considering the graphs of Figures 6, 7, and 8, corresponding to the measured receiver power, calculated receiver power, and the difference between the measured and calculated receiver power respectively, the observations and inferences are hereby analyzed and presented.

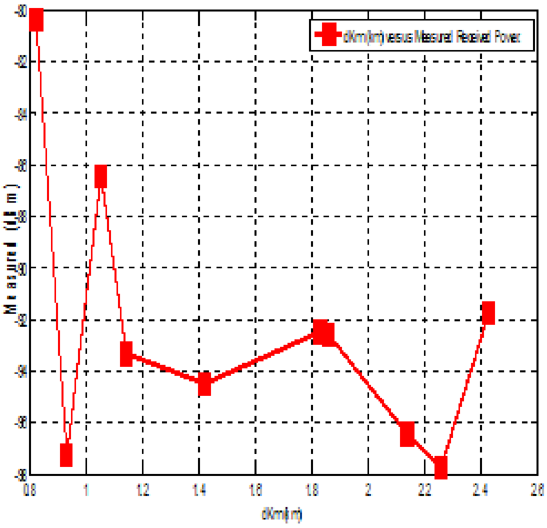

Figure 6: Graph of Measured Received Power (dBm) Versus Site Distances (km)

The graph of Figure 6 is the measured receiver power versus the distances of the measurement locations designated as SITES 1 to 10 in table 2. From the graph, it is observed that at different distances corresponding to different sites, the measured receiver power differs as well. This showed that the available spectrum frequencies that could be used by secondary users, SUs, are available. At this realization, the deployment of SUs is feasible without any fear of possible interference with the licensed primary user, PU. In particular, both the receiver power at the antenna input of the RF spectrum analyzer and the power recorded by the same RF spectrum analyzer at SITE 1 is the resultant effect of the antenna gain and return loss of NTA Enugu at a transmitting frequency of 201 MHz by the TV transmitter. This is seen when equation (1) was applied to calculate the received power. A comparison shows that there is a difference between the measured and calculated power values. In the figures of the different values in table 2, since all the values are close to 0 in magnitude, there is a good reception as sensed by the RF explorer thus indicating that no interference effect would be produced by the use of any secondary user should any transmission of signals be carried by them.

Let the graph of Figure 6 be considered now.

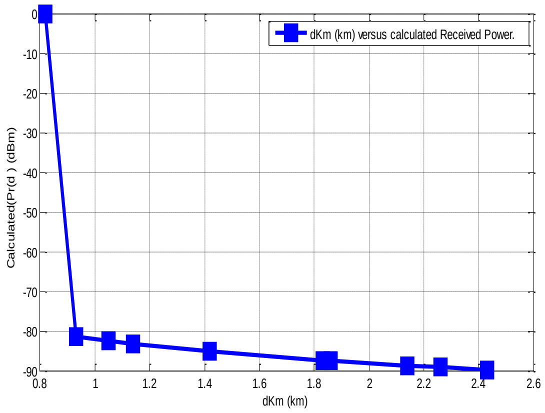

Figure 7: Site Distances (km) Versus Graph of Calculated Received Power (dBm)

The same condition as above also holds as true when the graph of Figure 7 was analyzed. This graph is an extension of the graph in Figure 8. It is supposed to make the graph of Figure 8 more understandable.

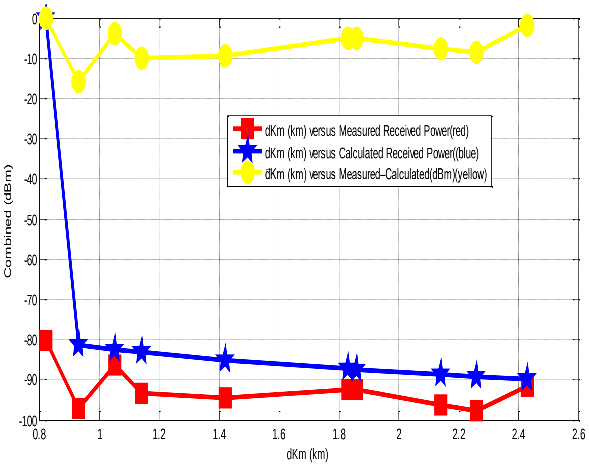

Figure 8: Graph of Site Distances (km) Versus Measured, Calculated and Measured-Calculated Received Power (dBm)

Figure 8 shows the graphic presentation during spectrum sensing protocol and process. The essence is to clearly show the operational relationship between the reception at the sites and the power generation as NTA Enugu transmits as a reference TV broadcasting point. Thus, at the difference, between zero to minus twenty dBm (0 to -20 dBm), signals for the operation of SUs can be guaranteed without the effect of interference against the PUs which is a condition for TV White Space utilization.

An extension of this analysis is the application of the earlier metrics briefly mentioned in this paper to measure path loss in each SITE. This is only meant to show which metric will bring about a better result in the event of spectrum sensing method for the identification and development of TV White Space in Enugu bearing in mind its environmental peculiarities in a developing country with a poorly developed network of infrastructure for efficient assessment of geo-location database contents.

5. CONCLUSION

Given the above protocol, a good, workable, and efficient spectrum sensing protocol can be developed for TV White Space identification and effective utilization in Enugu without interference effect with the legitimately licensed Primary users.

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