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COMPARATIVE EVALUATION OF SPECTRUM OCCUPANCY OF THE BROADCASTING BANDS IN URBAN, SUB-URBAN AND RURAL ENVIRONMENTS

E. A. Ubom[1,*] and U. S. Ukommi[2]

[1,2] Department of Electrical and Electronic Engineering, Akwa Ibom State University, Ikot Akpaden, Mkpat Enin, Akwa Ibom State, Nigeria

*corresponding author (Phone Number: +234-803-297-8581. Email: emmanuelubom@aksu.edu.ng)

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Abstract

Wireless services are at high demand all over the world, leading to increased bandwidth requirement and exhausted spectrum. In response, efforts are on-going to find ways to allow secondary access to spectrum without causing unacceptable interference issues to the Primary Users. In the fore-front of these efforts is the attempt to allow for secondary access on the TV spectrum, hence this analysis on spectrum usage measured outdoors in three locations namely Calabar in Cross River State representing an urban environment, Eket and Asong in Akwa Ibom State representing semi-urban and rural communities in Nigeria respectively. The UHF band percentage utilizations for the three locations were 98%, 76% and 33% with available cumulative bandwidths of 8MHz, 96MHz, and 264MHz respectively. Further validation of urban spectrum condition was done at Uyo in Akwa Ibom State. Findings showed that the spectrums are relatively busy in the urban and semi-urban areas whereas the economically challenging rural areas have free spectrum that can be deployed to enhance cellular broadband services at affordable rates to uplift the living standard of the dwellers.

Keywords: Spectrum Occupancy, Channel Capacity, Spectrum Resource Occupancy.

1.0 INTRODUCTION

The traditional method of allocating spectrum channels to operators based on geographical location and type of service is presently inadequate as the demand for wireless services continue to increase due to some inherent advantages of wireless deployment especially within the African continent where the cost of fiber-cable implementation and maintenance (due to on-going infrastructural development) is not attractive. In order to match the demands, operators are constantly in need of more bandwidths and alternate spectrums for different types of services.

This proliferation of wireless services requires a more intelligent method of spectrum management, hence the attraction of the academia, product developers and spectrum managers to ways of implementing and sustaining spectral friendly coexistence ecosystem where secondary users (SUs) are permitted to share Primary users' (PUs) spectrum without causing undue difficulties to the incumbent users [1], [2], [3], [4], [5].

Primary to this study is the determination of available whitespace by the secondary devices. In this concept, White Space Devices (WSD) or secondary user radios must be able to observe the spectrum for possible unused channels and make apt, mutually beneficial decision on their operating frequency (and perhaps other parameters, like transmit power and polarization) dynamically. The advancements in Cognitive Radio (CR) and the frequency hopping techniques have contributed immensely to the possibility of PU and SU coexistence as the CR has the capability to study the spectrum through sensing and determine the channels that are free for use and dynamically hop out as soon as the PU switches ON transmission [4, [6], [7].

To buttress the possibility of secondary access deployment adapting cognitive radio technology, it has become a necessity to know the current spectrum usage of our environs. For this reason, many spectrum occupancy measurements have been performed worldwide [2], [8] [9], [10], [11], [12], [13], [14], [15],

[16], [17], [18], [19], driven to determine how frequently one specific frequency band is used and the frequency bands that remain unused. It is therefore pertinent that we look at spectrum utilization in Nigeria with specific interest to determining the availability of spectrum for secondary access in the TV broadcasting spectrum range allocated by the Nigerian Communications Commission’s (NCC) National Frequency Allocation Table [20].

2.0 MATERIALS AND METHODS

2.1 MEASUREMENT SETUP AND EXPERIMENTAL FRAMEWORK

The measurements were taken at the highest points at Calabar in Cross River State considered to be of an urban scenario, Eket in Akwa Ibom State with a semi-urban characteristics and Asong in Mkpat Enin LGA of Akwa Ibom State as a typical rural terrain. The choices were made primarily to showcase the spectrum conditions of typical urban, semi-urban and rural communities in Nigeria and which is generalizable to represent the situation in most urban, semi-urban and rural communities in Nigeria.

The test apparatus comprises an affordable handheld device “RF-Explorer 3G Combo”, fitted with Nagoya NA-773 wide band telescopic antenna and a whip narrow band antenna capable of detecting a wide range of frequencies that satisfied the measurement drive. To capture and store the real-time data for future analysis, the RF-Explorer was connected to an RF-Explorer for Windows PC client software running on a Dell laptop through a USB cable. The RF-Explorer has already been proven to be very efficient in spectrum efficiency advocacy and measurements [21].

The measurement setup and Picture of the measurement activities are as shown in Figure 1 and Figure 2. The measurements were taken between October 2018 and May 2019. Each measurement was repeated every three hours for a week (Monday to Sunday) in each location to cover possible daily broadcasting pattern of stations, and the maximum held signal strength within 15 minutes integration time for each measurement filtered out for presentation. Measurements were taken at Uyo in September 2021 to compare with Calabar urban.

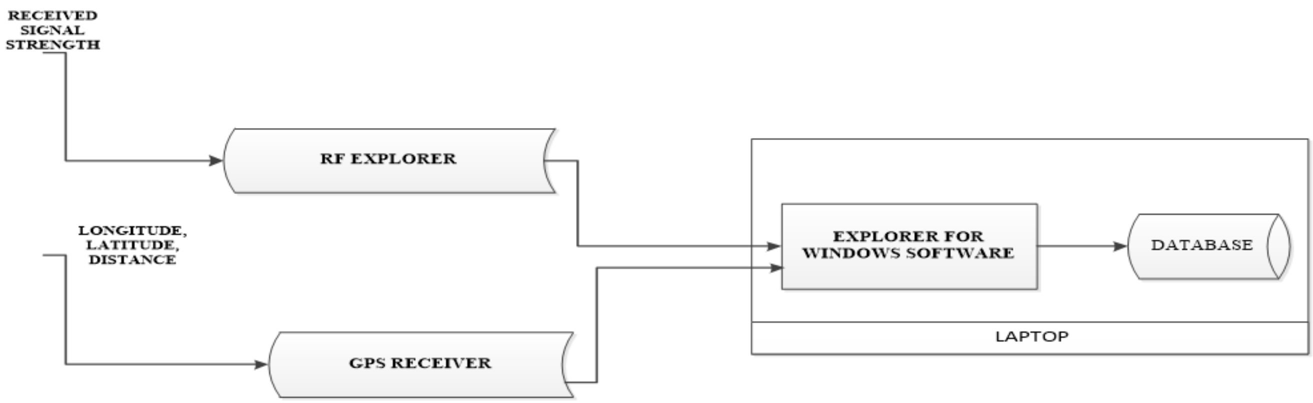

Figure 1: Testbed Setup

Frequency selection for the measurements was informed by the Nigerian Communications Commission’s (NCC) National Frequency Allocation Table [20] targeted at the assigned TV broadcasting bands. The breakdown of the selected frequency bands and location wise noise thresholds is shown in Table 1.

Table 1: Frequency Bands of Interest and Noise Thresholds

Frequency Bands for Broadcasting	**Pre-set Noise Thresholds in dBm**			
	Calabar	**Eket**	**Asong**	**Uyo**
174MHz – 230MHz (VHF)	-88	-90	-96.5	-89
470MHz – 862MHz (UHF)	-85	-89	-94	-86.5
Location Coordinates	N04.95548’ E008.35631º	N04.64792’ E007.94435º	N04.64661’ E007.82185º	N04.99950’ E007.92721º
Measurement Altitudes (AGL)	18.002 meters	9.077 meters	6.334 meters	75.104 meters

Determination of noise strength was necessary as the noise floor parameter is used to distinguish between noise and signal. The effect of a bad noise floor threshold setting either leads to the recognition of noise as valid signal or consideration of weak signals as noise. Either way, the efficacy of the measurement drive is jeopardized. To predict the best noise level, the RF-Explorer was used to scan known frequency channels assumed to be idle in line with the NCC national frequency allocation table. The detected noise levels represent the amount of background noise in the measurement environment. Since the noise floor changes with frequency [12], different band of interest were measured distinctively. The noise floor decision thresholds were selected and additional 2dB added to the actual noise level using the M dB criterion [15] and the resultant noise level computed as shown in Table 1.

Figure 2: Measurements at 21 Stories Dakada Building Uyo

2.2 SPECTRUM SURVEY FRAMEWORK

Spectrum usage can be quantified using the metric called "spectrum occupancy" and a spectrum is said to be utilized if a signal stronger than or equal to a pre-set threshold power level is detected on the channel [18]. The duty cycle (DC) of the signal which provides the probability that a channel is occupied within a specified period of the testing time can also be used to ascertain the amount of time in which the spectrum is used compared to when it is free.

Arithmetically:

$$DC = \frac{Occupied\ period}{Observation\ period} \times \frac{100}{1} \quad (1)$$

Where the occupied period refers to the total time in which signal above the threshold was detected on the channel and the total observation period depicts the total time of measurement activities. The alternative is the method of spectrum resource occupancy (SRO) [22] which takes into consideration the total number of channels that are in use with respect to the total number of channels that are measured. SRO, also known as "band occupancy" was used in this work and is given by Eq. (2).

$$SRO = \frac{Channels\ occupied}{Channels\ measured} \times \frac{100}{1} \quad (2)$$

The received signal strength $r\ (t)$ is represented as

$$r(t) = S(t) + N(t) \quad (3)$$

Where $S(t)$ is the transmitted signal and $N(t)$ is the sum of all noise sources and unwanted signals measured within the environment. Hypothetically;

$$r(t) = \begin{cases} S(t) + N(t) & H_1 \\ N(t) & H_0 \end{cases} \quad (4)$$

H_1 indicates a busy channel as signal is on that channel and is thereby marked as occupied while condition H_0 will indicate an unused channel and therefore considered available. As some of the broadcast channels may not be on air for 24 hours daily, maximum signal detected on such channel at any iteration was used to determine the state of such channel.

3.0 RESULTS AND ANALYSIS

A practical aim of occupancy measurements is to achieve accurate results with minimum measurement effort [22]. To achieve this, the maximum detected signal on the measurement drive were filtered and used to detect busy channels, if at any time within the measurement, the received signal strength exceeded the noise threshold, and the channel was marked busy. Multiple points within each sub-channel were measured to ensure signal detection at the smallest possible occupancy bandwidth.

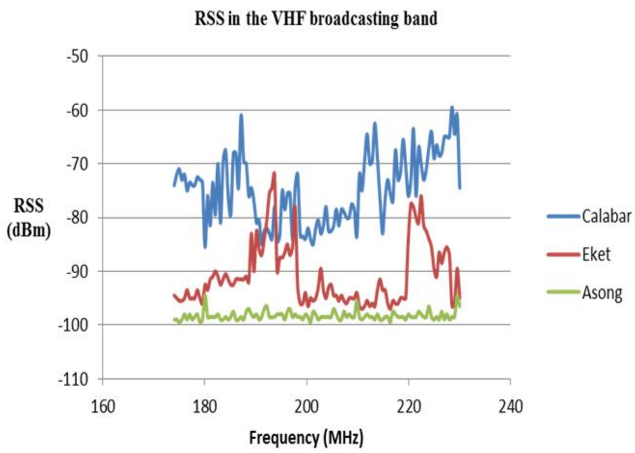

Figure 2: Maximum Received Signal Strength in the VHF Band

Figure 2 and Figure 3 capture the plots of RSS against the measured frequency in the VHF and UHF bands respectively. The RSS level was compared to Table 1 noise threshold and busy or idle channel detected.

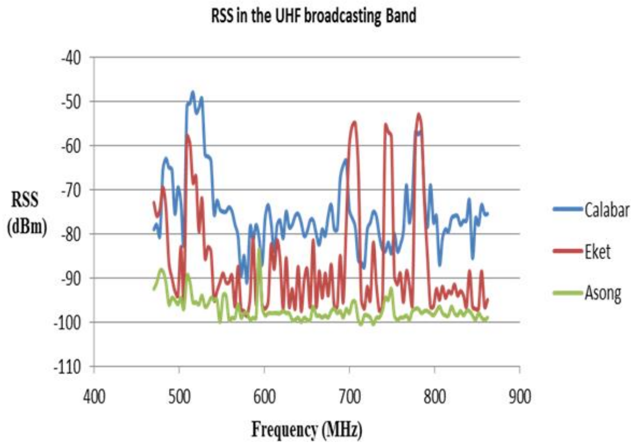

Figure 3: Maximum Received Signal Strength in the UHF Band

3.1 LOCATION-WISE SPECTRUM OCCUPANCY ANALYSIS

The VHF and UHF spectrum analysis reports are shown in Figure 4 through Figure 10 for the three respective locations representing urban, semi-urban and rural settings.

3.1.1 Result Presentation for Calabar Urban, Cross River State

Figure 4 present the VHF band signal strength waterfall with the red colour signifying the presence of a strong signal on the channel, the green signifies a weak signal while blue represent no signal traces. The signal strength is on the vertical coordinate, while the frequency and the time of measurements are on the other coordinates. Only a fragment of the iteration points in the channels were seen to be green (weak signals) with strong signals in part of the channel's bandwidth measured and were considered as busy.

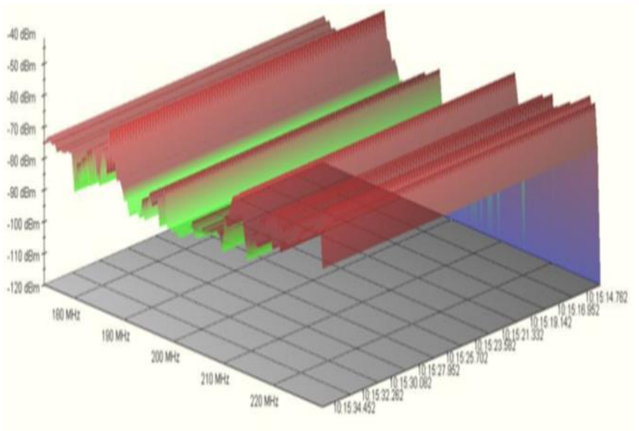

Figure 4: Waterfall of Usage in the VHF Band at Calabar

Figure 5 shows the channels in which signals were detected above the highly conservation pre-set noise threshold for the Calabar urban settlement. To determine the SRO, Eq. (2) was deployed to compute the SRO of the NCC assigned 7 channels VHF band for broadcasting [20]. The % utilization and available bandwidth was found to be:

No of measured channels = 7
No of occupied channels = 7
No of free channels = 0
% Utilization = 100%

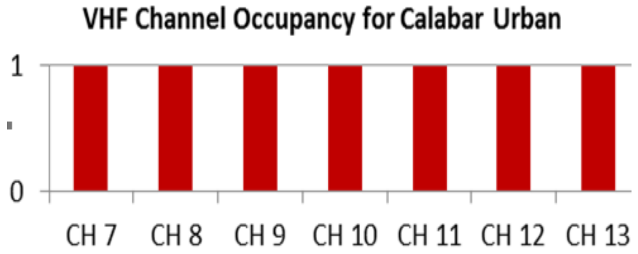

Figure 5: VHF Occupancy Chart for Calabar Urban Area

Similarly the UHF 49 channels were scanned throughout the measure period and the waterfall displayed in Figure 6, and the occupancy chart in Figure 7. Weak signals were spotted on most of iteration points within the channel bandwidth along with some strong signals thereby declaring such channels as busy. Only one channel had very weak signals (below the threshold) throughout the channel bandwidth and was declared idle.

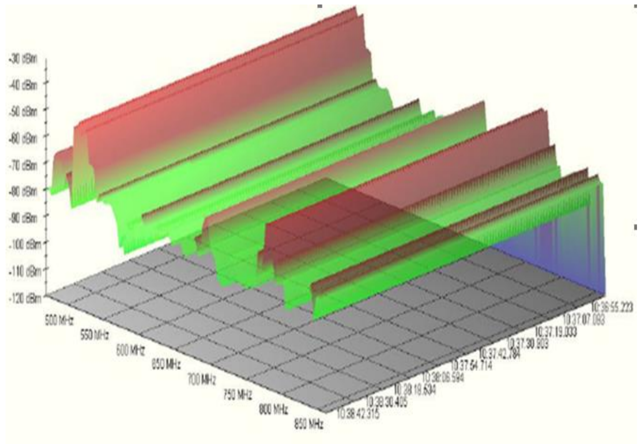

Figure 6: Waterfall of Usage in the UHF Band at Calabar

The SRO from Eq. (2) for the 49 channels measured showed

No of measured channels = 49
No of occupied channels = 48
No of free channels = 1
% Utilization = 98%
Available bandwidth $= 1x8 = 8MH_z$

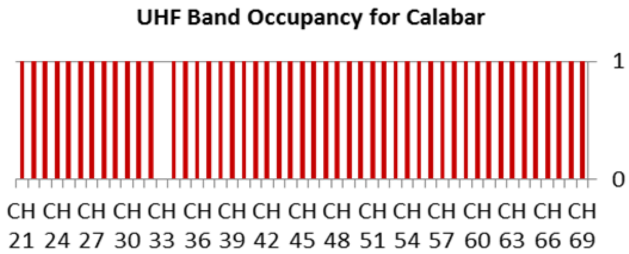

Figure 7: VHF Band Occupancy Chart for Calabar

3.1.2 Result Presentation for Eket Semi-urban Environment in Akwa Ibom State.

Figure 8 and Figure 9 depicts the Eket semi-urban VHF channels waterfall display and the VHF occupancy chart. Although weak signals are seen on the waterfall, strong enough signals above the threshold were spotted in most of the iterations points within the channels thereby declaring them as busy.

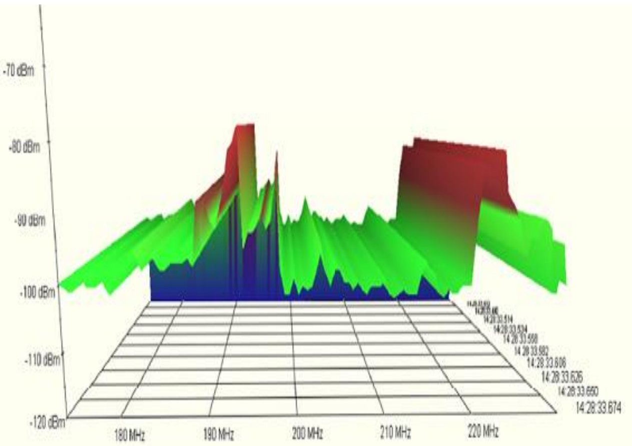

Figure 8: VHF Occupancy Waterfall Display for Eket Semi-urban Environment

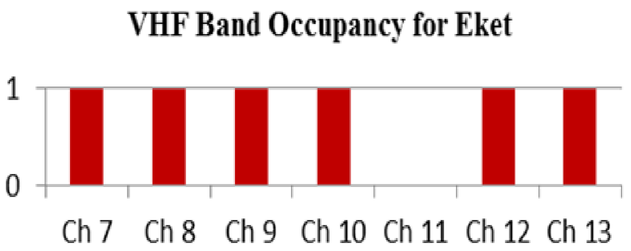

Figure 9: VHF Band Occupancy Chart for Eket

Applying Eq. (2) to the measured signal strengths from the semi-urban town of Eket, the VHF's occupancy was calculated as follows;

No of measured channels = 7
No of occupied channels = 6
No of free channels = 1
% Utilization = $approx. 86\%$
Available bandwidth = $1x8 = 8MH_z$

Similar measurements carried out for the UHF band at Eket are shown in Figure 10 and Figure 11. Here twelve of the forty nine channels had signals measured below the threshold with some completely free (blue coloured on the waterfall) and were considered as idle.

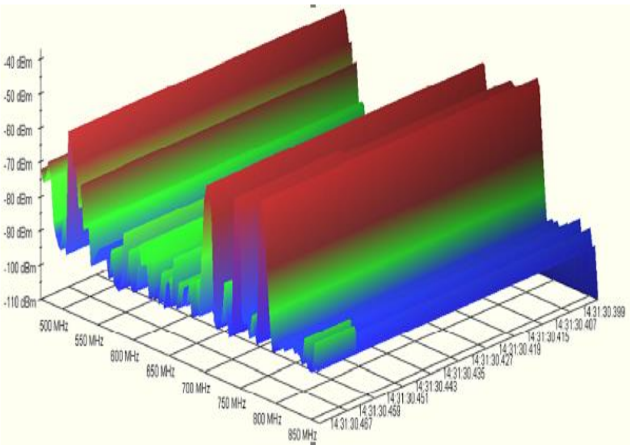

Figure 10: Waterfall Whitespace Display for the Eket UHF Band

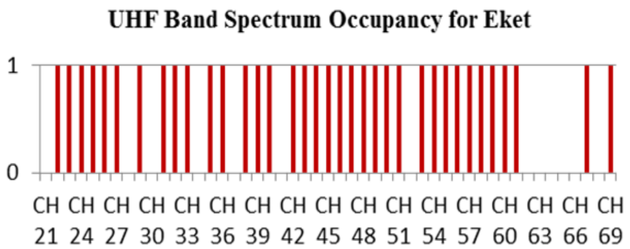

Figure 11: UHF Band Spectrum Occupancy

In line with Eq. (2), the SRO was calculated;

No of measured channels = 49
No of occupied channels = 37
No of free channels = 12
% Utilization = $approx. 76\%$
Available bandwidth = $12x8 = 96MH_z$

3.1.3 Result Presentation for Asong Rural Settlement in Akwa Ibom State

Figure 12 is the waterfall plot of the RSS amplitude against measured frequency points in the VHF band measured at Asong in Mkpat Enin LGA of Akwa Ibom State. Figure 13 is the band occupancy chart. The channel utilization in the typical rural challenging area measured showed considerable channel availability for provision of the much needed cellular broadband services.

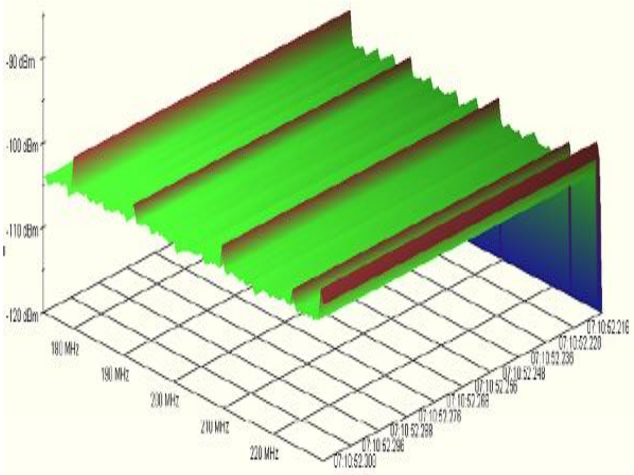

Figure 12: Waterfall of VHF Band Plot for Asong

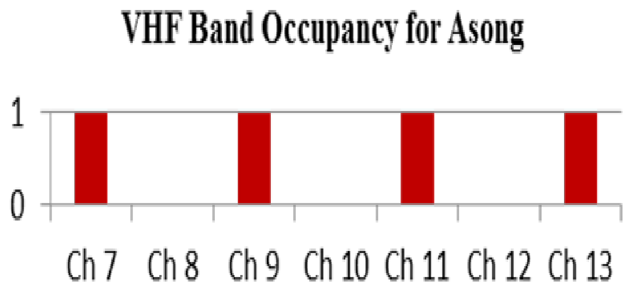

Figure 13: The VHF Band Occupancy for Asong

As stated for Calabar and Eket, the SRO was calaculated using Eq. (2) and the results summarised for Asong VHF broadcasting band;

No of measured channels = 7
No of occupied channels = 4
No of free channels = 3
% Utilization = $approx. 57\%$
Available bandwidth = $3x8 = 24MH_z$

Similarly, the UHF band was also monitored and the plots of Figure 14 and Figure 15 are the waterfall and spectrum resource occupancy respectively.

The 49 UHF channels were also measured at Asong as shown in Figures 14 and 15 and the SRO calculated

No of measured channels = 49
No of occupied channels = 16
No of free channels = 33
% Utilization = $approx. 33\%$
Available bandwidth = $33x8 = 264MH_z$

Measurements carried out at Uyo portrayed similar outcome as in Calabar and thereby goes ahead to confirm the status of spectrum occupancy in urban areas of the country. Figure 16 and 17 shows the RSS against frequency and the waterfall for the VHF band spectrum scan while Figure 18 and 19 display the RSS and waterfall for the UHF band.

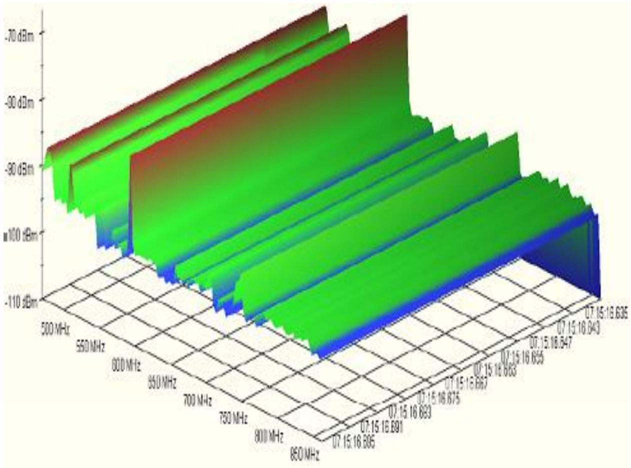

Figure 14: Waterfall Imaging Showing the RSS per UHF Frequency for Asong

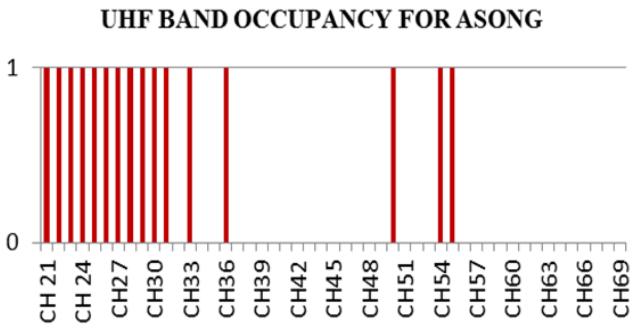

Figure 15: UHF frequency band occupancy for Asong village

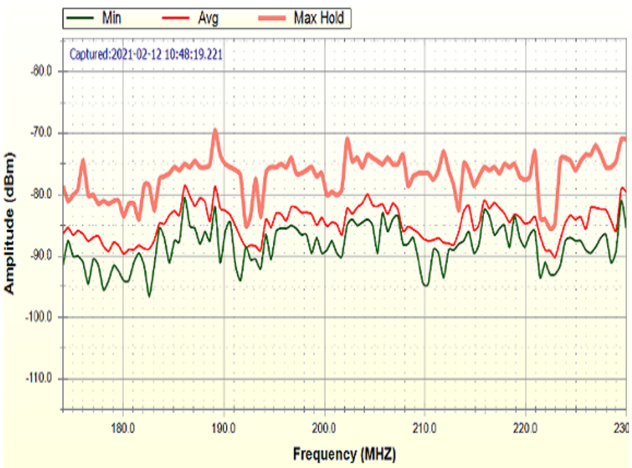

Figure 16: RSS versus Frequency for Uyo VHF Band

From Figure 19, Uyo UHF band can be said to be highly utilised as high signal is spotted at some point on most of the channels. This result is very similar to that of Calabar as seen in figure 6.

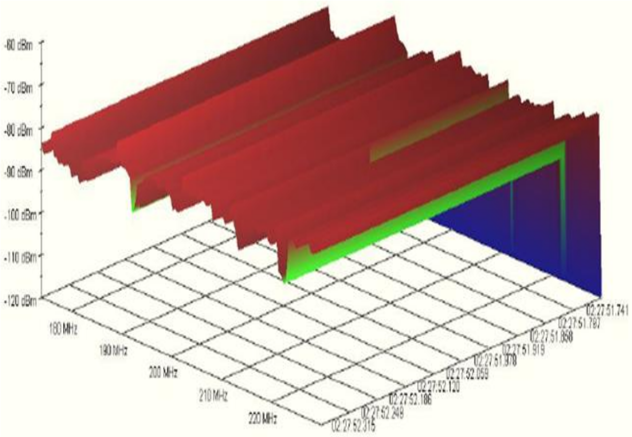

Figure 17: Waterfall Display for the Uyo VHF Band

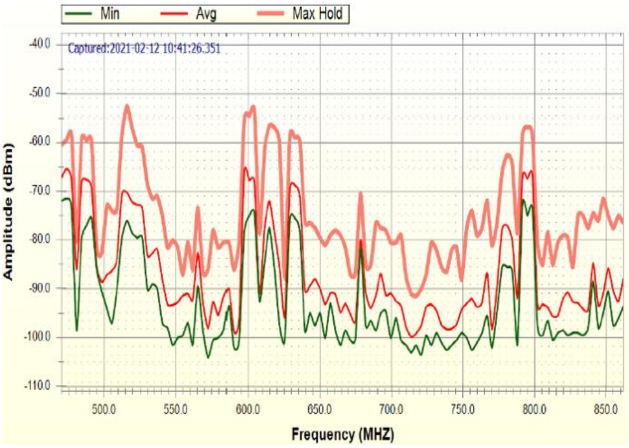

Figure 18: RSS versus Frequency for Uyo UHF Band

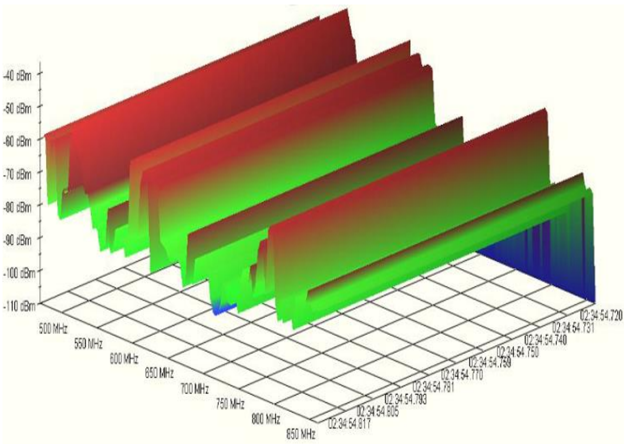

Figure 19: Waterfall Whitespace Display for the Uyo UHF Band

4.0 CONCLUSION

The results presentation in section 3 confirms the availability of TV-whitespaces (TVWS) within the UHF band in the economically challenging rural areas of our nation presently underserved by the cellular network operators that could be used to provide secondary access for the provision of broadband cellular services. The analysis presents a busy VHF band and UHF bands in the urban and semi-urban communities measured which portrayed possible difficulties in the deployment of TVWS secondary access in the urban and semi-urban cities in Nigeria. Although the VHF band of the challenging areas also recorded low utilization, the number of channels within the VHF band may not provide a good bandwidth aggregation for robust cellular network services, hence the need to concentrate on the UHF band.

The urban measurement at Calabar showed 100% signal unavailability in all the VHF channels measured, while the UHF band had 98% utilization. The VHF channels in the semi-urban area of Eket in Akwa Ibom state also recorded 86% utilization with a free 8 MHz channel and 76% utilization on the UHF band with available channel bandwidth of 96MHz. Asong (a rural area) on the order hand, recorded 57% utilization in the VHF band with 24MHz available and 33% utilisation in the UHF band with a whooping 264MHz available for rural broadband services deployment.

Although the measurements were very conservative in the set-up of noise thresholds intentionally to avoid declaring any channel with the weakest possible signal as idle, it is evident from the results that there abound huge spectrum resources that could be deployed to enhance cellular network operations in the challenging rural areas of the nation. There is therefore a need for a new rural areas spectrum licensing regime that will encourage deployments on the TVWS at an attractive amount (lightly licensing) to enhance broadband cellular services at lower services rates.

The rural areas of Akwa Ibom State for instance, host almost 1,000,000 citizens [23] and reducing the cost of service to them will contribute to the general improvement of their living condition by enabling newer forms of communication through use of emails, chats and real-time videos, fostering online communities through access to social communities, fuelling economic growth through the use of e-commerce, and facilitating entertainment, access to telemedicine resources, remote learning and public/e-government facilities and information. This can considerably reduce rural to urban migration and enhance productivity in our farming and fishing settlements.

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