Investigation of TV White Space for Maximum Spectrum Utilization in a Cellular Network Using CRT

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Abstract— *The shortage of spectrum resource availability in wireless communication network due to the rapid increase in the number of subscribers and multimedia applications has given rise to the need for effective spectrum utilization of the licensed spectrum. Cognitive Radio Technology (CRT) was adopted for the system analysis due to its dynamism in accommodating both licensed and unlicensed users within a particular spectrum band. The study framework comprised television station channels in Owerri and its environs and Mobile Telecommunication Networks (MTN) in Owerri- the capital of Imo State, Nigeria as the license and unlicensed users respectively. An outdoor twenty-four hour spectrum occupancy measurement was carried out in the frequency bands of the licensed networks using 240-960 MHz Radio Frequency Spectrum analyzer to determine the spectral usage of the licensed user. A threshold of -95 dB was used to determine the presence of the licensed users. From the results obtained, it was observed that 60.7% of the spectrum band covered was unoccupied, 31.5% was not fully occupied while 7.9% was fully occupied. Energy Detection spectrum approach was implemented by the unlicensed users for easy determination of the spectrum status and resource management. The research therefore determines the status of Radio Frequency (RF) Spectrum receivable in Owerri and its environs and proffer measures deployable in harnessing the unused RF resources using CRT.*

Key Words: RF spectrum, TV channels, Cellular networks, Cognitive Radio Technology, Primary User, Secondary User

1. INTRODUCTION

The increase in the demand for spectrum used for mobile telecommunication subscribers has necessitated the reason to maximize the Radio Frequency (RF) spectrum. This increase is as a result of varying multimedia applications deployable in wireless communication systems. To ensure fairness in addition to improved service delivery and maintenance in wireless communication systems, Radio Frequencies (RFs) are allocated and licensed to the various national regulatory bodies to corporate network operators by the international regulatory agency to avoid encroachment into adjacent operators' bandwidth. A consequent effect of this allocation is spectral shortage; such shortage is in part due to the current allocation policies by the regulatory body which allocates spectral bands for exclusive use of a single entity within a geographical area.

Studies have shown that while there is shortage of spectrum resources for future wireless technology due to the rapid increase in the number of subscribers, some of the already licensed spectrums are underutilized across time and geographical regions [1]. It becomes pertinent to balance the obvious situation and improve the wireless spectrum utilization. Confronting this rapid increase and its effects using enhanced mechanisms has become a thing of interest for researchers to investigate. One of the efficient techniques currently deployed involves the use of cognitive Radio Technology (CRT).

CRT is an intelligent wireless communication system which is aware of its RF environment, learns from it and adapts its internal states to statistical variation in the incoming RF stimuli. It actualizes this by making corresponding changes in certain operating parameter in real time [2]. By way of this concept, more devices can be incorporated in a frequency band already in use.

The paper is designed to investigate the status of the TV white space for onward spectrum maximization using CRT. The license users are the Television (TV) stations channels in Owerri and its environs while the unlicensed user is the Mobile Telecommunication Network (MTN) in Owerri metropolis in Imo State, Nigeria.

2. RELATED REVIEWED WORK

Author of [3] presented an insight into spectrum occupancy in Nigeria. They conducted an indoor spectrum occupancy measurement within the radio frequency range of 700MHz to 2.5 GHz in Gwarinpa district Abuja Nigeria; the measurement lasted for twelve hours and covered between 9am and 9pm. In their work, a threshold of -76dBm based on the noise floor level of the setup was used to decide the presence of primary users. Their results showed that large portion of the allocated spectrum was

underutilized and could be considered for deployment of cognitive radio technology. Their investigations however was specifically for indoor and the measurements were conducted for twelve hours only, further analysis for the outdoor investigations at different locations were not carried out which is necessary to actualize the mean peak and off peak performances.

According to [4], in their study discussed Non-Cooperative sensing network for spectrum sensing by secondary users. Each of the SUs transmitters carried out the task of deciding whether or not the PU transmitter is available on the scanned channel. In their study, the detection formulation was achieved using hypothesis testing where the null hypothesis is absence of the PU transmitter and the alternate implies its presence. The common lapses associated with this network were the nonflexible requirements by each SUs for reception, degradation of received signal strength and much time required for sensing to be completed by all the SUs before transmission starts.

The author of [5] developed a Software Defined Radio Test bed for research in dynamic spectrum access. The SDR test bed was developed based on Universal Radio Software Peripheral (URSP) with a focus on Spectrum Probing; a seemly overlooked component of spectrum sensing according to the author. The work expanded theoretical and simulation analysis for comparing different spectrum probing. Different spectrum probing methods were implemented for an independent and cooperative network of SU. The results showed that in independent sensing, periodic probing achieved smallest delay while in cooperative probing, randomization reduces probing delay.

3. RESEARCH METHODOLOGY

A. Measurement Environments: A spectral occupancy measurement within the frequency range of 240MHz-960MHz with a span of 50 MHz apart was carried out for 24 hours using an RF Explorer Spectrum Analyzer at the following locations: Hall of Mercy in Federal University of Technology, Owerri (FUTO), Obinze, World Bank Housing Estate and Douglas road, to determine the spectral usage of the various Television stations within Owerri and its environs. These locations were selected relative to the population of residents there.

B. Measurement Equipment and Procedure: Scanning through the RF bands of TV channel was made possible by the use of the following equipment.

(1) RF Explorer Spectrum Analyzer: An RF spectrum analyzer of range 240-960MHz was used to scan the RF environment of the various measurement locations. It displayed full frequency spectrum in-band including carrier and modulated shape, activities of spread spectrum existing are also displayed. It equally showed the bandwidth to monitor collision and frequency deviation from tone.

(2) Universal Serial Bus (USB) Cable: This was used to connect the RF Spectrum analyzer to the laptop. It is relevant to establish the interface between the spectrum analyzer and the laptop which were among the devices used for recording/saving of the measurement.

(3) Laptop: An HP 630 model laptop was connected to the RF spectrum analyzer, this was used to record and capture the videos and pictures of the measurements taken and for their broader and quality display. To be able to execute the functions, an RF Explorer windows software and Camtasia Studio 8 were installed in the laptop.

(4) Power Generator: A 10 Amperes 250Volts power generator was used to ensure steady supply of voltage to the laptop and RF spectrum analyzer

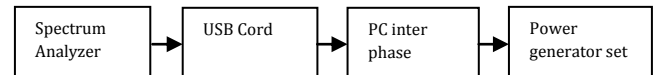Figure (1) presents the block diagram of the measurement set-up.

Fig-1: the block diagram of the measurement set-up

C. Measurement Configuration: This constitutes the software applications and the procedures used.

(1) Spectrum Analyzer Mode: The RF explorer switches automatically to spectrum mode upon start. It consists of two axes; the horizontal axis which denotes the frequency in MHz while the vertical axis represents the actual received power in decibel miliwatt (dBm). Once enabled; there is an automatic display of small marker with a look of an inverted triangle shape; mounted upon that marker are two values one on top the other indicating the peak amplitude found in the current frequency span, the upper value indicates the measured frequency in MHz while the lower value indicates the amplitude of power in dBm. Figure 2 shows the diagram of the standard mode of spectrum analyzer main screen.
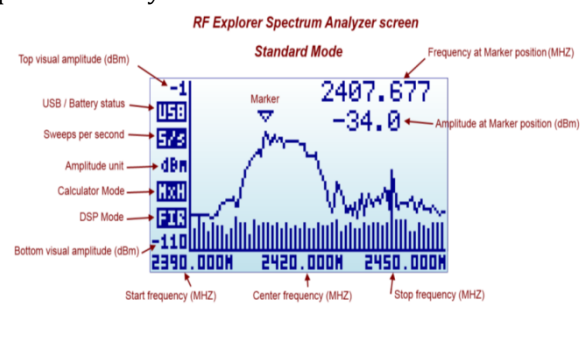

Fig-2: the diagram of the standard mode of spectrum analyzer main screen

(2). RF Explorer Windows Client: This is the software used to ensure compatibility between the RF Explorer and the Personal Computer (PC) window used. It was installed in the PC and automatically gets connected to the RF Explorer once connected together with a USB cable. RF explorer window client software turns data collected from RF spectrum analyzer into highly graphical charts and displays, given opportunity to visualize the RF

environment, monitor RF signals, troubleshoot RF issues, and detect sources of RF interference in the measurements. Figure 3 shows the RF explorer PC inter phase outlook.
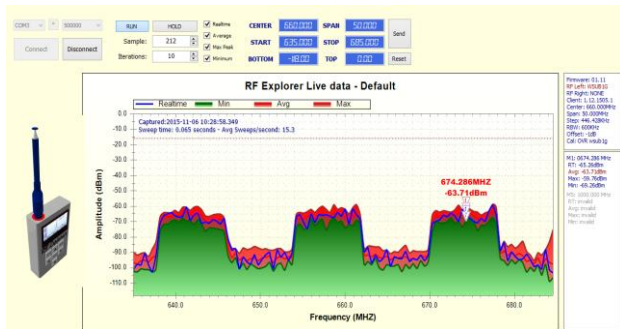

Fig-3: The RF explorer PC inter phase outlook

(3) Camtasia Record Studio: This is a software installed in the PC to ensure proper documentation and saving of the measurements' output.

(4) Threshold Decision: A close observation of measurements taken at various locations indicated that channel activity was significant at values greater than and equal to -90dBm of received signal strength displayed by the RF spectrum analyzer.

Another measure considered for choosing threshold for this study was the International Telecommunication Union (ITU) recommendation [6]. It suggests that the threshold for deciding the availability of signal in a scanned environment should be 10dBm above the ambient noise. The ambient noise for this research work based on the measurements carried out is -110 dBm.

D. The Primary Networks: The primary networks considered for this study were the TV stations in Owerri Imo state and those receivable within its environs as shown in Table 1.

Table-1:   TV stations receivable within Owerri and its environs

State	Station	Channel No	Centre Frequency (MHz)
Abia	Broadcasting Corporation of Abia State (BCA)	47	679.45
Abia	Nigeria Television Authority (NTA) Umuahia	21	471.25
Anambra	NTA Onitsha	35	583.25
Anambra	Anambra State Broadcasting Corporation (ASBC)	27	519.25
Anambra	Minaj Broadcasting International (MBI)	41	631.10
Anambra	Silver Bird	30	543.25
Imo	NTA Owerri	12	224.25
Imo	Orient Television	59	775.25
Rivers	NTA Portharcourt	10	210.25
Rivers	Rivers State Television (RSTV)	22	479.25
Rivers	Silver Bird Television	23	487.25
Rivers	Africa Independent Television (AIT)	21	471.25

E. Secondary Network: MTN Cellular network is the secondary networks. It was considered relative to its greater number of subscribers in Owerri environs when compared to other cellular networks.

F. Spectrum Sensing Technique: Spectrum sensing is the most important task that must be carried out in order to have an establishment of Cognitive Radio Network; this is because it gives the awareness of availability of white space. Actualizing greater output from this task is best done usually at the idle period of most TV stations which are 12:00 am to 6:00 am. Sensing could be done using several techniques like Cyclostationary and Matched Filter but were not deployed because of some limitations they pose such as computational complexity and large power consumption due to various receiver algorithms that needed to be executed for detection.

Energy Detection technique as illustrated in figure 4 was implemented in the study. It only depends on the power of its received signal to decide the presence or absence of the primary users and does not require a prior knowledge of the primary signal as other techniques such as Matched filter and Cyclostationary would require. It is also applicable if the power of random Guassian noise can be known. It is easily implementable in time and frequency domain with low computational complexity when compared with other reviewed techniques [7]. Decision is taken by comparing the output of the energy detector with a pre-defined threshold that depends on the noise floor. Figure 4 presents the block set-up deployed while carrying out energy detection spectrum sensing in a TV stations radio frequency spectrum.
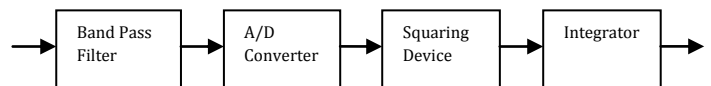

Fig-4: The block set-up of Energy Detection Technique.

Flowchart for implementation of the Energy Detection Technique is shown figure 7.
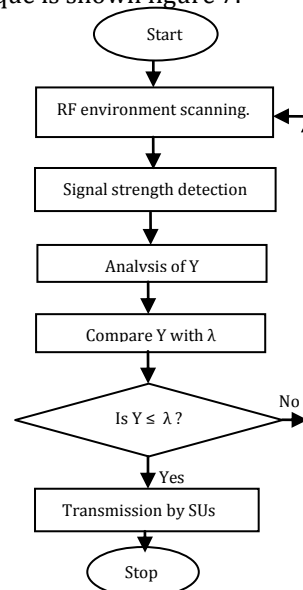

Fig-5: The flowchart implementation of Energy Detection Technique

Decentralized Coordinated Cooperative network topology consisting of six cognitive radios (CRs) was deployed in this study as illustrated in figure 5(a)
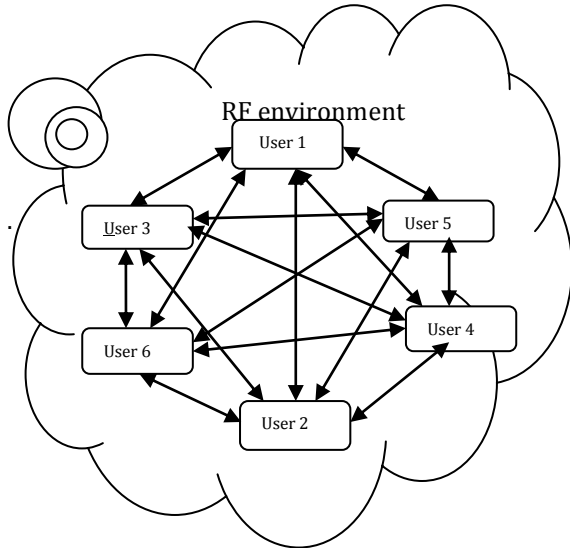

Fig-5(a): Distributed Coordinated Topology

Spectrum sensing was carried out by each of the co-existence CRs which enabled acquaintance with the RF environment and aided observations; each of the users analyzed its observations and exchanged that among themselves directly, therefore no controller or fusion centre was required for such. From the updates obtained by each of the SUs, decisions on whether or not the availability of the PUs were taken, if the spectrum is deemed free of PUs, transmission by SUs would be initiated and continued until completed otherwise spectrum mobility.

The reason for collaboration was to reduce the large sensitivity requirement for individual cognitive users assuming there was no cooperation among them. This topology is a typical example of Star topology network where on the event of damage of any link, the whole system would be unaffected. Also it was preferred because of the improved performance it has in the presence of fading, shadowing and noise uncertainty. Algorithm used for the network communication is illustrated below. The flow chart for implementation of the Distributed Co-ordinated network are shown in figures 5 (b)

- Observation by each CRs.
- Analysis of observation by each CRs.
- Exchange update.
- Decision would be taken. if the PUs are absent, then share the spectrum and transmit.
- Else, spectrum mobility by CRs
- Else Else, transmission continues.
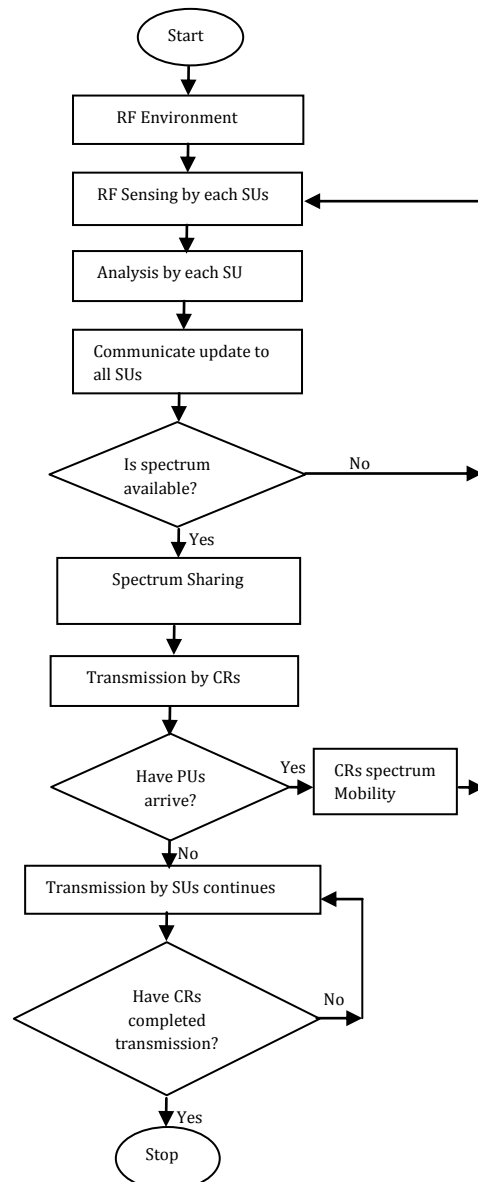- Transmission completed by the CRs
- Stop.

Fig-5 (b): the flowchart implementation of Distributed Coordinated network
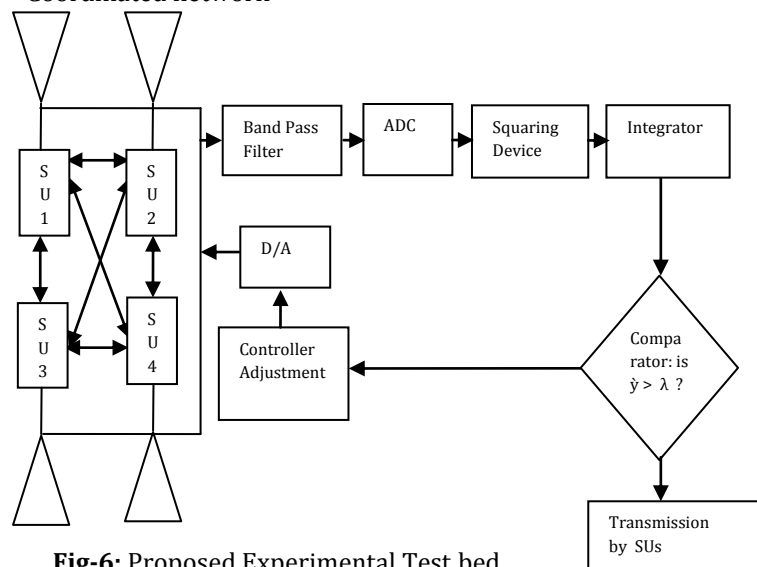

Fig-6: Proposed Experimental Test bed

G. System Parameters

(1) Antenna Two discone antennas embedded into one structure that cooperate well with cell phones were deployed. One was omini- directional and used for scanning the required RF band while the other was more directional and reconfigurable and used for tuning to the required frequency used by the secondary users.

(2) Band Pass Filter (BPF): The BPF considered was a second order Butterworth filter; it was such that is sensitive and selective to the desired frequency among other frequencies available in the frequency spectrum.

(3) Analogue to Digital Converter (ADC): To ensure compatibility with components of system used before and after controller, ADC and Digital to Analogue Converter (DAC) were deployed to ensure that time varying signals from the band pass filter were converted to discrete form and versa without altering the essential contents of the signal. It was also necessary to achieve improved signal to noise performance.

(4) Squaring Device: For effective performance of the integrator circuit, the input to the integrator must be a square wave; otherwise it does the work of low pass filter. For this conversion, a 555timer integrated circuit configured as Schmitt trigger was deployed to perform the task.

(5) Integrator: An integrator used was to ensure that continuous varying input signal from band pass filter was summed up into an output signal represented in time integral of the input, hence determines the observational interval. Mathematically represented as $y = \int x \, dt$ where x and y are the input and output of the system.

(6) Comparator: This was used to compare the output from the integrator with the predefined threshold value of (λ = -95 dBm). The value was considered relative to the study and determined whether or not the transmission by SU would be successful else a feedback error message would be send back to the local oscillator through the controller.

(7) Controller: This is an adaptive adjuster used for the system. It works based on the algorithm developed relative to the system desired output.

Algorithm for Controller Adjustment using Fuzzy rules

Process Variable (input to the controller): Power of the received signal ($\grave{y}$).

Control variable (output from the controller): Rescan or Transmission

Operator's Control rules: IF $\grave{y} < \lambda$, THEN Transmission.

: IF $\grave{y} > \lambda$, THEN Rescan.

System: Energy Detection for one input, one output and two rules

Values for control rules: IF $\grave{y} < \lambda$ [0 0.5]= Transmission.

: IF $\grave{y} < \lambda$ [0.5 1.0]= Rescan.

4. ANALYSIS OF SPECTRAL OCCUPANCY

For the frequency range captured during measurement, a measure of spectrum occupancy for each frequency channel in each location is done in order to ascertain percentage occupancy of each channel for the period measurements. Duty cycle which is described as the percentage of time a frequency band or channel is occupied over a given period of time. It is utilized to indicate how often signals are perceived during a sample period of scanning. It is given as

$$\text{Duty Cycle (DC)(\%)} = \frac{\text{Occupied Period (Oc.P) (hours)}}{\text{Total Observation Period (hours)}} \times \frac{100}{1}$$

Occupied period is dependent on measurement, total measurement period =24 hours. Another estimate necessary for consideration is the Spectrum Resource Occupancy (SRO), it is given as

$$\frac{\text{Number of Occupied Channels (NOC)}}{\text{Total Number of Channel Measured (TnCm)}} \times \frac{100}{1}$$

Total number of channels measured = 89, Number of unoccupied channels = 54, Number of channels not fully occupied = 28, Number of channels fully occupied = 7.

Therefore, number of occupied channels (both fully and non-fully occupied channels inclusive) equals to 7+28 = 35. Hence

$$SRO = \frac{NOC}{T_n C_m} x \frac{100}{1} = 39.3258\%$$

While the percentage of unoccupied resource equals

$$100 - 39.3258 = 60.6742\%$$

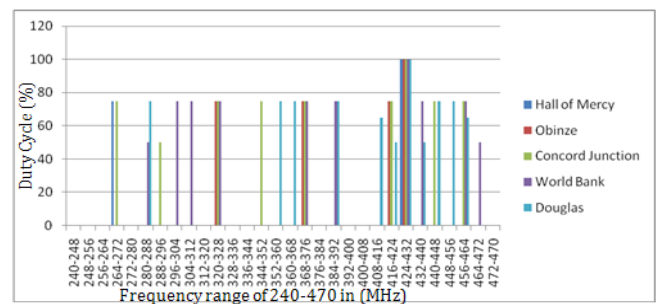Figures 7(a), (b), (c) and (d) present the occupancy distribution of the measurement.

Fig-7(a): The bar chart representation for the frequency range of 270-742 MHz versus the duty cycle (%).
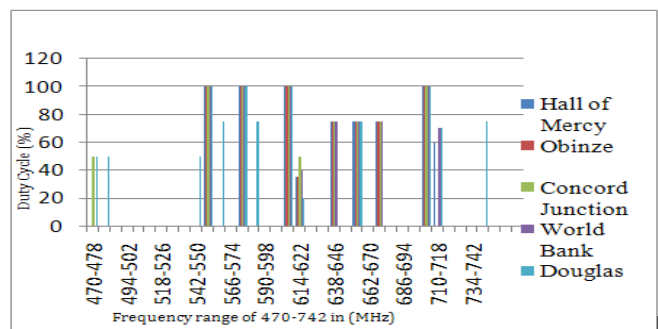

Fig-7(b): The bar chart representation for the frequency range of 270-742 MHz versus the duty cycle (%)
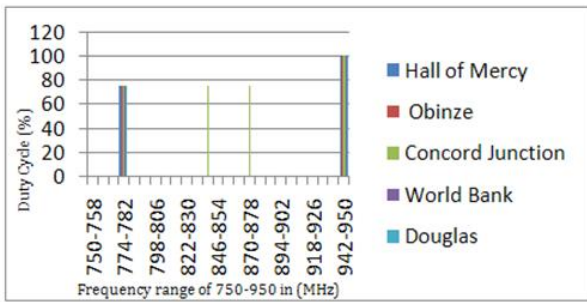
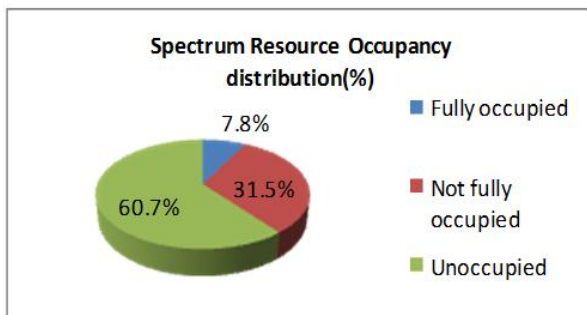Fig-7(c): The bar chart representation for the frequency range of 270-742 MHz versus the duty cycle (%).

Fig-7(d): The pie chart demonstration of occupancy distribution of the measurement

5 RESULTS DISCUSSION

About 89 channels were captured in measurements. From the results of figures 7(a), 7(b), 7(c) and 7(d), it can be observed that 7.8 % of the spectrum was fully occupied, 31.5% was partially occupied while 60.7% which is of greatest portion of the channels measured was not occupied at all. For an instance, within ranges of 240-264 MHz, 486-542 MHz and 782-838 MHz etc, the bands were idle. While within the ranges of 280-312 MHz, 606-622 MHz and 774-782 MHz etc the bands were not fully occupied. Also within the ranges of 424-432 MHz, 550-558 MHz and 942-950 MHz etc, the bands were fully occupied.

From the results obtained, it was observed that CRT is well suited for adoption and implementation in the study environments considering the greater portion of the idle state.

Another observation made from the measurement results at various locations was that even though the results obtained at those locations are related, each location has a unique dB loss relative to its environment. For example, measurement results at Concord junction location showed that noise level decreased from -100 and -110dB and the signal level increased from the usual level of -90 to -80dB. This was because that particular environment was apparently noise free and very close to Orient transmission antenna which enhanced reception when compared with other locations.

6. CONCLUSION

A spectrum occupancy measurement within the range of 240 -290 MHz was carried out to determine the spectral status of the licensed bands of various TV stations in Owerri capital city and its environments in Imo State, Nigeria. A threshold value of λ = -95 dBm was used in deciding the presence of primary user above noise level and below which the spectrum band was deemed free and can be utilized by the secondary users. The measurement results showed that 60.7 % of the spectrum was unoccupied, 31.5% was not fully occupied while 7.9% was fully occupied indicating lots of spectrum utilization opportunity. The empirical characterization of the environment showed that it is an excellent environment for deployment of CRT for optimal RF utilization for MTN network.

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BIOGRAPHIES

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Damian Obioma Dike is an Associate Professor at Federal University of Technology Owerri Nigeria. He obtained his PhD in Electrical Engineering at Tennessee Technological University, USA 2008. He has worked in various international Engineering firms such as Cummins Inc (Power Generation), USA as a senior project Engineer, as a coordinating consultant engineer to JENCEL Consults limited etc. His research interest includes integration of modeling programming and simulation tools for power systems, distribution system modeling and protection, power system studies and automation, converter modeling FACTS and system integration.

Dr. Gordon Ononiwu - Received his B.Eng, in Electrical and Electronic Engineering from the Federal University of Technology (FUTO), Owerri, his M.Sc in Computer Systems Engineering from Halmstad University in Sweden, and his PhD in Computer Engineering from FUTO. He is a senior Lecturer at the department of Electrical and Electronic Engineering of the Federal University of Technology, Owerri. He is a fellow of the Swedish Institute (SI), and also an International Faculty Fellow (2015/2016) at the Massachusetts Institute of Technology (MIT). He was a guest scholar at the Centre for Research on Embedded Systems (CERES) in Sweden (2009 - 2011). He is a member of Nigerian Society of Engineers and is registered by COREN. His research interest is in the field of embedded systems engineering.