# INVESTIGATION OF RADIO FREQUENCY LICENSED SPECTRUM UTILIZATION IN NIGERIA: A STUDY OF RUMUOKWUTA, PORT HARCOURT, NIGERIA

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## *ABSTRACT*

*This study was carried out to investigate the spectrum utilization of the licensed Radio Frequency (RF) spectrum in Rumuokwuta, Port Harcourt. An outdoor measurement of spectrum occupancy was carried out in a high-rise building situated at Rumuokwuta urban area in Port Harcourt, Nigeria using RF explorer spectrum analyzer and a personal computer laptop system. Spectrum activities in the band of 240-960 MHz were monitored for 24 hours. The frequency band was subdivided into 24 sub bands each with a span size of 30 MHz. Scanning of bands was made efficient using a python script that scans a range, analyzed the frequencies and signal strengths for 112 data points, saves data in CSV file format, scans the next range until the 24 ranges were scanned. The process was repeated to achieve 15 iterations. With a noise floor of -110dBm, a threshold of -95dBm was used to determine the presence of signal, hence the spectrum occupancy of measured bands. Results showed that out of the 24 investigated sub bands; only one band was completely occupied with spectrum occupancy of 100%. 12 bands were partially occupied while 11 were completely free. The average spectrum occupancy for the whole band was obtained as 11.64%. This showed good location for dynamic spectrum access and cognitive radio deployment, especially in Television White Space (TVWS).*

## *KEYWORDS*

*Cognitive radio, Dynamic spectrum access, RF spectrum, TV white space & Wireless communication.*

## 1. INTRODUCTION

The Radio Frequency (RF) spectrum is a natural scarce resource that requires optimum utilization. It is that portion of electromagnetic spectrum which ranges from 3 Hz to 300 GHz that is used for communication purposes [1]. The enormous pressure on it has caused significant scarcity on the availability of the RF resource [2][3][4]. Spectrum occupancy measurement carried out in various parts of the world showed underutilization of the resource [5][6][7] in the frequency range of 2.4-2.7 GHz The locations cut across rural, suburban and urban areas. From their investigations, rural locations have the least duty cycle of approximately 0%. This is apparently due to very small or no wireless connectivity. The result showed absolute unoccupied bands. The occupancy levels for suburban regions were better compared to the rural locations. The urban locations have the highest occupancy level.

As the very first occupancy measurement campaign in Nigeria, [8] considered an insight into spectrum occupancy in Nigeria. The objective of the study was to carry out an indoor spectrum occupancy measurement within the region of 0.7 GHz to 2.5 GHz in Gwarimpa, Abuja, Nigeria.

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Each band was studied for 12 hours daily; from 9am to 9pm. An Aarona spectrum analyzer and Omnilog 90200 antenna with a frequency range of 0.7-2.5 GHz were used in the measurement. A decision threshold of -76dBm was used to determine the active and idle states of a licensed user. The measurement showed that the cellular bands have the highest degree of utilization at 26% and 25.56% for the 2G and 3G cellular standards respectively. 2-2.2 GHz band has the least utilization level. As expected, the result showed spectrum white space that could be exploited through cognitive radio.

The Radio Frequency (RF) spectrum is a natural scarce resource that requires optimum utilization [1]. However, to optimize the scarce resources, spectrum sharing through adaptive power allotment has been proposed by many authors. This is a way forward in achieving spectrum optimization. Cognitive radio network allows primary and secondary resource user to share the same frequency band while ensuring minimal interference [9][10][11]. The TVWS network can be made to share the spectrum as a secondary user to provide internet services.

## 2. REVIEW OF LITERATURES

In recent years, spectrum management has been a major concern for researchers. This is due to the rising demand for wireless connectivity. The astronomical growth in number of mobile subscribers, as well as the high demand for multimedia access spurs interest in querying the efficiency of present radio frequency management. The command and control method of spectrum management has shown to be ineffective. Researches on spectrum management showed that high proportion of assigned radio frequency band is unused. The spectrum usage of licensed radio spectrum varied from 15% to 85% in the United States of America [12]. This conventional system of spectrum management would need to be replaced by a more intelligent system that accesses the spectrum dynamically.

Dynamic Spectrum Access (DSA) is basically the process and system of accessing spectrum white space of a licensed user referred to as Primary User (PU) by an opportunistic user known as the Secondary User (SU). The idea of Cognitive Radio (CR) was first presented in [13]. Mitola analyzed CR as a radio that is aware of its environment and can adjust its parameters to respond to environmental changes. For safe deployment of CR without harmful interference and infringement on the right of the licensed user, it is therefore necessary to have the knowledge about the degree of utilization of a particular band to ascertain which band(s) would be suitable for DSA.

### 2.1. Traditional Spectrum Management System

Spectrum is a finite resource and therefore its continuous use depends on how efficiently spectrum bandwidth is used within a given portion of the radio spectrum and geographical location. Traditionally, the spectrum management system is a command and control approach where a user has an exclusive right to operate within a certain band. This is to ensure that the activities of spectrum users are devoid of interference. The spectrum management system has been in existence for several years since licensing became part of spectrum resource control[14]. It has been a wide practiced system by every spectrum administrator as well as management authorities. In this management approach, a spectrum manager outlined certain rules and constraints that determine how, where and when spectrum can be used, as well as who has access to the resource. In this management model, different services are sometimes allocated to different frequency bands, although for some frequency bands, more than a radio service is allocated. The traditional spectrum management system is a hierarchical management system with International Telecommunication Union (ITU) at top hierarchy. ITU oversees radio spectrum management internationally and ensures compliance at the national level. The next in hierarchy is the national planning process and down to licensing and interference management. Basically, the traditional management system uses three managerial tools which include spectrum allocation, spectrum assignment and interference management.

### 2.2. Dynamic Spectrum Management System

The limitations of the traditional fixed management system are enough to embrace a system that would access spectrum dynamically [2]. The old spectrum management system does not consider spectrum white space and as such renders the system ineffective. The dynamic spectrum management system is a proposed spectral management system that relies on dynamic spectrum access which showed the dependent of spectrum on location, time, measurement conditions, and equipment [15]. Dynamic spectrum management system births dynamic spectrum access which is a recent spectrum sharing paradigm in which a licensed user, otherwise known as Primary User (PU) shares the licensed band with an opportunistic user known as the Secondary User [16][17]. With DSA, SUs search for the spectrum bands dynamically, and temporarily access them for wireless communications. To avoid interference to PUs, SUs continuously monitor the spectrum bands and yield to PUs whenever the latter start using the band [18].

### 2.3. Spectrum Sensing

Spectrum is a limited wireless communication resource, and licensed spectrum can only be used by the paid company owners. Cognitive radio (CR) is a new model of using a licensed spectrum when not use in an unlicensed manner [19]. The motivation for cognitive radio is to carry out analyses of various spectrum or channel utilization to detect vacant and occupied spectrum. It immediately switches to the vacant spectrum while avoiding the licensed occupied spectrum thereby avoiding interference with the licensed channel. To ensure interference free, the secondary user must keep monitoring the primary user and be able to sense weak PU signals. The Cognitive radio should be able to switch to another available channel on sensing PU signal in occupied channel [20].

Spectrum sensing is a key component of DSA. Sensing is so important that a slight neglect in the process of DSA could cause huge effect to the PU. For a SU to transmit there would be need to sense the spectral environment of the PU. Sensing ensures adequate white space before the SU can share the spectrum band with the PU.Spectrum sensing could be implemented locally or could be carried out via cooperative sensing. Sensing is done locally if and only if a SU senses the spectrum environment independently and selects an unused band.

In order to improve sensing by providing accurate detection technique, as well as combating fading, shadowing and other channel impairments, cooperative sensing has been proposed in this study. Cooperative sensing improves accuracy in detection through cooperation among SUs, hence the name [21].

### 2.4. Reviewed Work

In [22], the authors focused on evaluation of spectrum usage for GSM band in indoor and outdoor scenarios for dynamic spectrum access. They presented the current spectrum usage of GSM band in Pune, India. A fibre optic cable was used as an interface between a Rohde and Schwarz spectrum analyzer and a Dell laptop computer. A 0.7-3 GHz band AOR DA 500 antenna was used in the campaign. Four different scenarios were considered. The first scenario was an outdoor measurement taken in suburban India. The second case scenario was an indoor measurement carried out in outskirts of the city of Pune, India. The third and fourth scenarios were conducted in the busy places of Pune. Results and analysis showed that though there is an underutilization for both uplink and downlink frequencies for GSM900 and GSM1800, the downlink band occupancy is higher than uplink band occupancy.

The authors in [23] conducted spectrum investigation for TV white space In the band of 240-960 MHz. Part of the investigation were carried out in suburban Hall of Mercy, FUTO, Owerri; Obinze; while the rest were carried out in two different locations of Oweri metropolis. With a noise floor of -110dBm, they chose -95dBm as a suitable threshold. The measurement was done outdoor in four different locations. The result of their investigation showed that 7.8% of the spectrum was fully occupied, 31.5% was moderately occupied while 60.7% was unoccupied. Obviously the result showed high percentage of unused spectral portion which will be a promising band for cognitive radio deployment. However, their investigation lacks automation of frequency scan, as a result; it requires manual changing of frequency range which could have caused measurement error.

Spectrum occupancy measurement in the frequency range of 2.4-2.7 GHz in nine various locations in Kwara State of Nigeria for 12 hours were carried out in [24]. The locations cut across rural, suburban and urban areas. From their investigations, rural locations have the least duty cycle of approximately 0%. This is apparently due to very small or no wireless connectivity. The result showed absolute unoccupied bands. The occupancy levels for suburban regions were better compared to the rural locations. The urban locations have the highest occupancy level. For duty cycles of 0.08% and 0.95% for suburban locations and 18.56% and 22.56% for urban locations, it is crystal clear that the radio frequency spectrum bands used in those locations are highly underutilized. The result showed good environment for cognitive radio technology. The measurements were done in so many locations, nevertheless, it were not done for a long period of time.

In [25], the authors carried out a survey on the availability of TV white spaces in Eastern Nigeria. The measurement was done in the analog television band of the UHF using a resolution bandwidth of 20 KHz. The ambient noise of their spectrum analysis was measured as -100dBm with a flat average noise level of - 114dBm and frequency range of 100 MHz. They investigated the TV white space in two different locations of Eastern Nigeria. Results showed that the spectral usage of the UHF frequency band within the study region is 32%. Again, the result, which is not different from other campaigns, is a good location for dynamic spectrum access. While the graphical representation of the TV white space was clearly presented, the research lacks clear methodology as evident in the Resolution Bandwidth (RBW) of 20 KHz which does not conform to the 100 MHz frequency range.

A new paradigm of converting radio spectrum wastage to wealth was proposed in [26]. Analysis of spectrum occupancy verification in three different urban cities of Nigeria was carried out. The investigation was done in the spectral range of 80-2200 MHz. The locations considered are Ado-Ekiti, Akure and Ikeja, which are the capitals of Ekiti, Ondo and Lagos state respectively. The three western Nigerian states were chosen due to population density, industrial activities and socio-economic developments. Their verification showed variation in the usage of each frequency band with location. It also showed that though a specific frequency is much more utilized in a particular location, it is underutilized in a different location. The results generally showed that the total spectrum occupancy for the three locations ranges from 0.08%-64.4%. The limitation of this work is the use of very high average threshold of 70.64 in Ado-Ekiti measurement location.

It is obvious from the aforementioned section that spectrum occupancy measurement is rich in literature. However, there are noticeable gaps in the measurement of spectrum occupancy. None of these works considered several measurement iterations to obtain the mean (actual) value of spectrum occupancy. Again, some of the work done has high resolution bandwidth as adjacent frequencies could hardly be resolved. While this research work seeks to provide spectral activities in Port Harcourt, Rivers State, Nigeria, it also aims to breach other research gaps in spectrum occupancy measurement

This research aims to investigate for the first time the level of spectrum usage within the band of 240 MHz to 960 MHz in Rumuokwuta, Port Harcourt, Rivers State, Nigeria, using RF Explorer and efficient python script. Unlike previous work, the spectrum activities were monitored for 24hours instead of 12hours. This is full day coverage. The Rumuokwuta area of the state was considered because the population and the high level of commercial activities. In this area, there are no commensurate available and low cost quality internet services to match the demand. Therefore, result of this research will aid in the deployment of TVWS for internet provision in the rural and suburban areas of the state.

## 3. METHODOLOGY

The methods adopted in this work are discussed in the following sections.

### 3.1. Conducting Spectrum Occupancy Measurements for Outdoor Scenario

The spectrum occupancy measurements were done outdoor in a high rise building in a residential apartment in Rumuokwuta, Port Harcourt, Rivers State, Nigeria using RF Explorer spectrum analyzer, python script and personal laptop computer. This site is positioned at latitude N4o48’36” and longitude 6o55’12”. Port Harcourt, with an estimated population of 1,865,000 is a densely populated city with various commercial activities in southern Nigeria. The location site has direct line of sight with several telecommunication systems, sub systems and base stations. The site was strategically chosen, being an urban setting with obvious high level of wireless connectivity. This location being in direct line of sight with various transmitters ensures measurements of signals that have suffered little or no form of channel impairments. The ambient noise of the spectrum analyser was determined and a threshold value of -95dBm was gotten based on noise floor.

For additional functionality of the RF Explorer spectrum analyzer, as well as efficient, broader, automatic and quality display of the spectrum analysis, a Dell laptop computer was connected to the spectrum analyzer with a USB cord as an interface. The system enables wider view of spectrum environment, data capturing/saving, automation of tasks and additional features and programmability. The experimental setup for data measurement and aggregation is as shown in Fig. 1.

Fig. 1. Measurement setup

Installed in the PC is python programming, version 3.5.0. The software is responsible for automation. The RF explorer spectrum analyzer is designed to be configured manually, with a maximum scanning range of 100 MHz. This limitation means a script is needed to repeatedly scan the spectrum from 240 to 960 MHz for 24 hours.The 24 frequency bands analyzed in this work are 240-270MHz, 270-300MHz, 300-330MHz, 330-360MHz, 360-390MHz, 390-420MHz, 420-450MHz, 450-480MHz, 480-510MHz, 510-540MHz, 540-570MHz, 570-600MHz, 600-630MHz, 630-660MHz, 660-690MHz, 690-720MHz, 720-750MHz, 750-780MHz, 780-810MHz, 810-840MHz, 840-870MHz, 870-900MHz, 900-930MHz and 930-960MHz.

The step by step procedure or the algorithm designed to perform scanning, analysis and data aggregation is outlined below.

*1. Import modules from python 3.5.0 library.*
*2. Initialize global and local variables.*
*3. While WholeDay < (Iteration×24); continue; else; Go To 26.*
*4. Define RF Explorer object and sets its properties.*
*5. Connect system to module using RFEObj.ConnectPort(COMPort,DataRate).*
*6. Reset RF Explorer using RFEObj.SendCommand(“r”).*
*7. Wait for reset notification.*
*8. Wait for unit to stabilize using time.Sleep().*
*9. Send a request command for RF Explorer configuration.*
*10. Wait for the arrival of configuration and model details.*
*11. Process received configuration using RFEObj.ProcessReceivedString(True).*
*12. Update device configuration with new start, stop and span frequencies*
*13. While (StopFreq <= MaxStopFreq and StartFreq < StopFreq); continue;*
*14. Process all received from RF Explorer spectrum analyzer.*
*15. Save data to appropriate CSV file for a new sweep and start frequencies.*
*16. Set new range of frequencies.*
*17. If (StopFreq > MaxStopFreq); StopFreq = MaxStopFreq;*
*18. If (StartFreq < StopFreq); continue; else; Go To 21.*
*19. Update device with new settings.*
*20. Wait for fresh configuration to arrive.*
*21. Increment RoundOf Data.*
*22. Print round of saved data on console.*
*23. If WholeDay < (Iteration×24); time statement.*
*24. RFEObj.Close(); ##Close port.*
*25. Wait for the processing of the next round of data.*
*26. Compute total elapsed time.*

Scanning started with the first frequency range and data saved in CSV file format; after which the next range was scanned until the 24 iterations were completed.Investigation started from 9.00am on 27-09-2017 to 9.00am on 28-09-2017.For each band, 112 data points were resolved with a Resolution Bandwidth (RBW) of 268 KHz. Each frequency range with 112 data points was further subdivided into 8 frequency ranges for efficient computation.Spectrum Resource Occupancy (SRO) for each range is calculated as in equation 1.

$$Spectrum\ Resource\ Occupancy(SRO) = \frac{NOCAT}{TNMC} \times \frac{100}{1} \quad (1)$$

Where: NOCAT is the Number of Channel Above Threshold and TNMC is the Total Number of measured Channels

### 3.2. Estimation of Spectrum Utilization Level of the Measured Spectrum

Python script, as discussed in the previous section was employed to manipulate and automatically change the settings of the digital device. The software changes the range of frequency to be scanned at uniform time interval. A 112 data points comprising frequencies and corresponding amplitudes of 24 frequency ranges were dumped in CSV file. The process was repeated until 15 sets of 112 data points were saved in each of the 24 files for 24 hours. The comma separated value files were latter converted to Microsoft Excel files with .xlsx as the file extension. For a range of frequencies with 268 KHz as resolution bandwidths, 15 columns, each with 112 amplitudes with corresponding frequencies were entered in excel worksheet. The tool allows the computation of average amplitude in dBm which gives the mean amplitude for each sweep step. The average values of the signal strength were further segmented for efficient computation. Each segment consists of 14 sweep steps, which give rise to a total of 8 segments. The tool compares these values with the threshold value to determine the extent of spectrum usage. Plots of Spectrum Resource Occupancy versus frequency band were obtained. For more visualization of spectrum usage level, various degrees of spectrum usage were shown with the use of a pie chart.

### 3.3. Identification of Potential Bands Suitable for CR

The tool used for identifying potential frequency bands suitable for cognitive radio deployment is the Microsoft Excel 2016. By combining excel efficient functions, amplitude returned values were compared with threshold value to estimate the percentage of occupancy for each frequency range. To identify bands that could be accessed using cognitive radio, a threshold of 45% was used. Percentage values less than or equal to 45% would be ideal bands for dynamic spectrum access.

## 4. RESULTS AND DISCUSSION

Results of various analysis carried out in this work include the results of spectrum occupancy for 24 frequency bands for the range of 240-960MHz. For each band, with a band size of 30MHz, the results of the mean amplitudes with corresponding Spectrum Resource Occupancy were tabulated. Plots of Spectrum Resource Occupancy versus frequency range were presented. Results of spectrum utilization level as well as identified bands suitable for cognitive radio were shown.

The 24 possible bands of 240-960MHz were analyzed and occupancy level presented. From analysis, 240-270MHz has the highest spectrum occupancy of 100%. For a threshold of -95dBm, average signal strength of -88.18dBm shows maximum spectral activity within the region 240-270MHz. The band has decibel maximum value of -85.89dBm and a minimum decibel value of -91.42dBm.270-300MHz band is second most occupied with 51% occupancy. This band has average strength of -95.93dBm, with maximum and minimum values of -93.24dBm and -99.61dBm respectively.480-510MHz band with 47.63% occupancy is another measured band whose spectrum resource occupancy is close to half of the total spectrum occupancy. The average signal strength for this band is -101.21dBm with upper limit of -91.08dBm and lower limit of -113.82dBm.

Aside aforementioned bands, as well as 450-480MHz and 510-540MHz with Average Spectrum Occupancy (ASO) of 27.50% and 23.25% respectively, every other bands have average spectrum occupancy of less than 7%. Bands 300-330MHz, 330-360MHz, 360-390MHz, 630-660MHz, 660-690MHz, 690-720MHz, 720-750MHz, 810-840MHz, 840-870MHz, 870-900MHz and 900-930MHz have the least spectrum occupancy with ASO of 0% each. The comparative analysis of the various spectrum occupancies is as shown in Fig. 2. The degree of spectrum usage for the measurement location is shown in table 1.

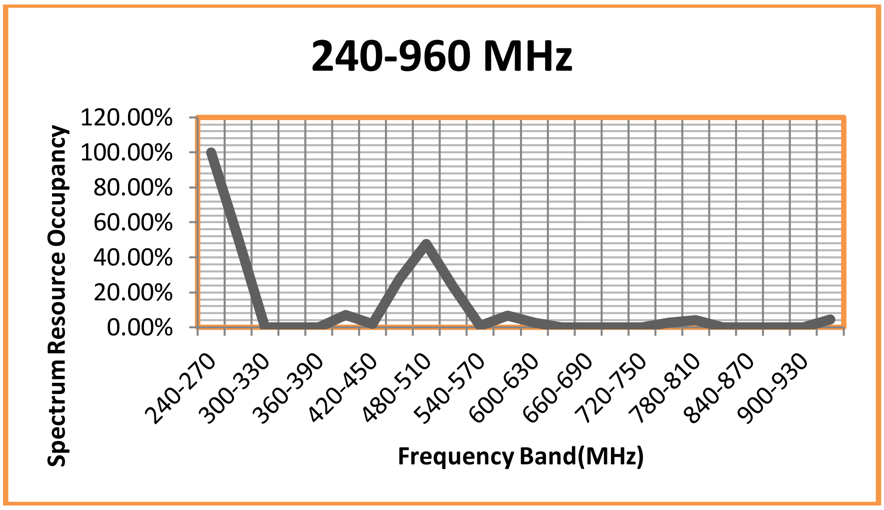


Figure 2. Comparative Analysis on Spectrum Resource Occupancy for Various Bands

Table 1. Spectrum Utilization Table for 240-960 MHz

| **S/N** | **Bands (MHz)** | **Mean Amplitude(dBm)** | **Level of Utilization** |
|---|---|---|---|
| 1 | 240-270 | 100.00% | Completely utilized |
| 2 | 270-300 | 51.00% | Partially utilized |
| 3 | 300-330 | 0.00% | Unutilized |
| 4 | 330-360 | 0.00% | Unutilized |
| 5 | 360-390 | 0.00% | Unutilized |
| 6 | 390-420 | 7.00% | Partially utilized |
| 7 | 420-450 | 1.75% | Partially utilized |
| 8 | 450-480 | 27.50% | Partially utilized |
| 9 | 480-510 | 47.63% | Partially utilized |
| 10 | 510-540 | 23.25% | Partially utilized |
| 11 | 540-570 | 0.88% | Partially utilized |
| 12 | 570-600 | 6.63% | Partially utilized |
| 13 | 600-630 | 2.50% | Partially utilized |
| 14 | 630-660 | 0.00% | Unutilized |
| 15 | 660-690 | 0.00% | Unutilized |
| 16 | 690-720 | 0.00% | Unutilized |
| 17 | 720-750 | 0.00% | Unutilized |
| 18 | 750-780 | 2.50% | Partially utilized |
| 19 | 780-810 | 4.25% | Partially utilized |
| 20 | 810-840 | 0.00% | Unutilized |
| 21 | 840-870 | 0.00% | Unutilized |
| 22 | 870-900 | 0.00% | Unutilized |
| 23 | 900-930 | 0.00% | Unutilized |
| 24 | 930-960 | 4.38% | Partially utilized |

From table 1, it is clear that unutilized bands are by far greater than completely utilized band. A band is completely utilized, twelve bands are partially utilized while eleven bands are devoid of spectral activities. The detailed analysis shows that 4.17% spectrum is completely utilized, 50% is partially occupied while 45.83% is free. Table 2 and figure 3 show the level of utilization.

Table 2. Percentage Utilization

| Utilization Level | Percentage Utilization |
|---|---|
| Complete utilization | 4.17% |
| Partial utilization | 50% |
| Un utilization | 45.83% |

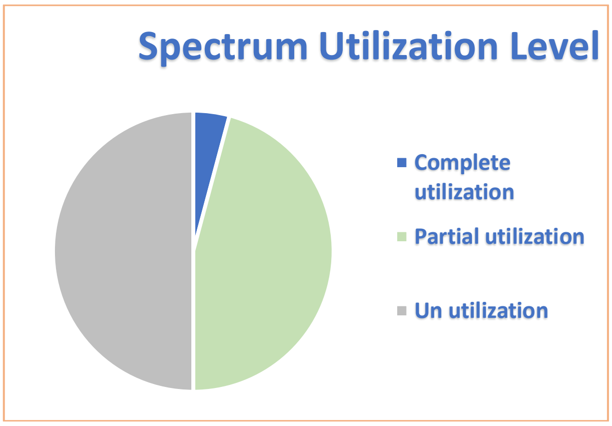


Figure 3. Percentage Utilization for 240-960 MHz

From table 1, one completely active band and two other fairly occupied bands are out of context for cognitive radio technology, hence those bands should not be accessed dynamically. Twenty-one bands have been identified for exploitation via cognitive radio technology. These are 300-330 MHz, 330-360 MHz, 360-390 MHz, 390-420 MHz, 420-450 MHz, 450-480 MHz, 510-540 MHz, 540-570 MHz, 570-600 MHz, 600-630 MHz, 630-660 MHz, 660-690 MHz, 690-720 MHz, 720-750 MHz, 750-780 MHz, 780-810 MHz, 810-840 MHz, 840-870 MHz, 870-900 MHz and 900-930 MHz.

## 5. Conclusion

Radio frequency spectrum is a useful and finite resource and therefore need efficient management system for complete utilization. As part of spectrum occupancy measurement campaign, investigation of spectrum utilization in the frequency band of 240-290 MHz was carried out in Rumuokwuta axis of Port Harcourt. The spectrum bands utilization was investigated for 24hours using RF Explorer and efficient python script. Measurements and data analysis show that the location is a good environment for dynamic spectrum access and cognitive radio deployment. Spectrum occupancy measurements should indeed be carried out in every parts of the whole world with sensitive and efficient spectrum detectors.

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