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INVESTIGATION OF RADIO SPECTRUM USAGE PATTERN IN ILE-IFE, NIGERIA USING GNU RADIO AND UNIVERSAL SOFTWARE RADIO PERIPHERAL

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ABSTRACT

Dynamic spectrum access has been widely accepted as the panacea to the problem of unprecedented demand for radio frequency spectrum. In this study, spectrum occupancy measurements were carried out to assess the usage of the frequency spectrum and the viability of implementing dynamic spectrum access through cognitive radio in Ile-Ife, Nigeria. The measurements covered six frequency bands: 88 MHz to 108 MHz, 400 MHz to 850 MHz, 840 MHz to 980 MHz, 850 MHz to 1300 MHz, 1300 MHz to 1750 MHz and 1700 MHz to 1900 MHz bands. The outcome of the study shows that a massive amount of the radio frequency spectrum in Ile-Ife has a low level of utilization. The results indicate that cognitive radio applications can be deployed effectively in Ile-Ife and the vicinity.

1. INTRODUCTION

Recently, there has been a burgeoning demand for space on the wireless communication spectrum as more devices and services are being deployed to make use of the spectrum (Iroh, Nosiri, Dike, & Ononiwu, 2016; Popoola et al., 2016; Regula, Gilbert, & Sheikh, 2020; Riahi Manesh, Subramaniam, Reyes, & Kaabouch, 2017). Nevertheless, the available space on the electromagnetic spectrum is limited and currently, most, or all the space in some cases has been statically allocated to be used for specific purposes and by some licensed users and organizations, thereby leaving little or no room for the spectrum to accommodate its ever-increasing demand (El Barrak, Lyhyaoui, Puliafito, & Serrano, 2017; Höyhtyä et al., 2016; Popoola et al., 2016; Regula et al., 2020).

Nevertheless, research has revealed that despite the scarcity of spectrum to accommodate new services, there is underutilization in a substantial amount of the already allocated spectrums (Tony & Jacob, n.d.; Iroh et al., 2016). This discovery led to the introduction of dynamic spectrum access (DSA), which is a scheme that gives room for opportunistic or secondary users (SUs) to make use of the spectrum in the absence of the licensed user or primary user (PU) on the licensed portions of the spectrum (Popoola et al., 2016; Riahi Manesh et al., 2017). Further, the enabling technology for DSA is the cognitive radio (CR), which is an intelligent, radio frequency (RF) aware and adaptive wireless communication system with the ability to learn from the activities that are going on in its RF operating environment (Iliya, Goodyer, Gow, Gongora, & Shell, 2015; Iroh et al., 2016).

Spectrum sensing is one of the key steps involved in the implementation of a CR system. It involves determining the status of the spectrum, that is, either empty or being occupied by the PU, to ensure no harmful interference is caused to the PU by the SUs (Iliya et al., 2015; Riahi Manesh et al., 2017). In other words, determining spectrum occupancy ensures the sharing of the spectrum with tolerable interference and subsequently, more efficient utilization of the spectrum.

By means of spectrum analysers, a number of spectrum occupancy studies have been carried out globally and at different locations in Nigeria. For example, spectrum occupancy studies have been conducted in Gwarimpa, Abuja (Bara'u Gafai, Wenjiang, & Kadri, 2013); Ado-Ekiti, Akure, Ikeja, Osogbo, Abeokuta (Popoola et al., 2016; Popoola, 2018); Benin City (Omorogiuwa & Nwukor, 2019; Ufoaroh & Abu, 2019) and Owerri (Iroh et al., 2016). All the studies reported a significant amount of underutilization. The underutilized bands could be utilized for some other relevant services, as was done by Ramoroka (2014) in delivering wireless internet connection through the unoccupied bands to underprivileged schools in some rural areas in South Africa, and Almantheri (2016) who also implemented an internet delivery system. However, it has been established that spectrum occupancy is spatio-temporal in nature, varying from one location to another and at different times (Haykin, 2005; Awe, Deligiannis, & Lambotharan, 2018).

This paper investigates and reports the usage pattern of radio spectrum in Ile-Ife, southwestern Nigeria for cognitive radio application. In the study, six, 24-hour spectrum occupancy measurements data were collected in February and March 2018 and analysed. The bands considered are 88 MHz to 108 MHz, 400 MHz to 850 MHz, 840 MHz to 980 MHz, 850 MHz to 1300 MHz, 1300 MHz to 1750 MHz and 1700 MHz to 1900 MHz. The assessment of the RF activities in bands was carried out with the aid of a National Instrument universal software radio peripheral hardware (NI USRP 2920) device. To the best of our knowledge, this study is the first reported spectrum occupancy measurement and utilization study in Ile-Ife and that makes use of the universal software radio peripheral (USRP) and GNU radio approach for spectrum occupancy assessment in Nigeria.

1.1. Motivations and Related Works

Hitherto, frequency allocation to various wireless services in Nigeria adopts a static approach similar to what obtains elsewhere around the globe, where assignment of bands is done in a command-and-control manner. However, in conformity with the widely acceptable shift from static frequency allocation to dynamic spectrum access, several spectrum occupancy measurements and utilization studies have been conducted at several locations around the world (Khamlichi et al. 2016; Xue et al., 2013; Engiz and Rajab, 2019).

In Nigeria, an indoor spectrum occupancy measurement was conducted by Bara'u Gafai et al. (2013) with the aid of a spectrum analyser. The measurement, which was carried out at Gwarimpa, Abuja covered the frequency range of 700 MHz to 2.5 GHz and spanned over a period of 12 hours. The study indicated an underutilization level between 74% and 99.55%. Another measurement campaign that revealed an underutilization level of between 35.2% and 99.92% was reported by Popoola et al. (2016). The experiment was also carried out at with a spectrum analyser at Ado-Ekiti, Akure and Ikeja, and covered the frequency range of 80 MHz to 2.2 GHz.

Ayeni et al. (2016) also carried out spectrum occupancy measurement in both rural and urban areas of Kwara State studying frequency from 2.4 GHz – 2.7 GHz. The report indicated an underutilization with upper and lower occupancy values of 22.56% and 0% in urban and rural environments, respectively. In a related study, Babalola et al. (2015) carried out a 24-hour outdoor measurement of spectrum occupancy, in both rural and urban areas in Kwara State, spanning across the frequency range of 48.5 MHz – 880 MHz. The results obtained revealed that the average duty cycle for TV bands 1-4 are 2.58 % and 12.02% and for CDMA band are 0.25% and 3.13%, in rural and urban locations, respectively. Similar study was reported by Popoola (2012) at Abeokuta, Ikeja and Osogbo, with a spectrum analyser. The result of the study indicated a 70% underutilization of the licensed spectrum in space, time and frequency. The study spanned a period of three weeks and covered the frequency range from 80 MHz to 2.2 GHz. Furthermore, an outdoor 24-hour spectrum occupancy measurement was carried out on the 240 MHz – 960 MHz band by Iroh et al. (2016) in Owerri, with the aid of a spectrum analyser. The result also showed an underutilization level of 60.7%.

Moreover, two separate studies were carried out by Omorogiuwa and Nwukor (2019) and Ufoaroh and Abu (2019) in Benin City. A NooElec RTL-SDR was used by Omorogiuwa and Nwukor (2019) to investigate the radio frequency range between 87.5 MHz and 108 MHz at four locations in Benin. The result of the study indicated a 90% underutilization of the radio spectrum. Also, an assessment of the 470 MHz – 870 MHz band was done in Ugbowo, Benin by Ufoaroh and Abu (2019) using a spectrum analyser. The result of the study indicated an underutilization level of over 58% for the 50 channels investigated.

As it can be noted from the reported experiments, a significant amount of underutilization is recorded at the various locations considered. This highlights the shortcoming of the current, static spectrum allocation policy in Nigeria.

In this paper, we considered frequency occupancy measurement campaign for Ile-Ife, an ancient city with five post-secondary / higher educational institutions, one government-owned teaching hospital, a major, privately owned hospital and five research centres. There are also four radio stations and a television service broadcasting station. Evidently, a lot of RF activities are going on in Ile-Ife owing to the proliferation of wireless radio devices and RF related research being carried out. Yet, availability of unused licensed bands and the possibility of harnessing the radio spectrum white space has not been established. It is noteworthy that frequency occupancy measurement campaigns have not been reported for Ile-Ife.

1.2. Contributions

The main contributions of the paper are as follows:

i. We have studied the spectrum utilization in six different RF sub-bands covering the frequency range of 88 MHz to 108 MHz, 400 MHz to 850 MHz, 840 MHz to 980 MHz, 850 MHz to 1300 MHz, 1300 MHz to 1750 MHz and 1700 MHz to 1900 MHz in Ile-Ife using GNU Radio and USRP method.
ii. We analysed the spectral activities in the frequency range considered and quantified the availability of unutilized radio resources in terms of average percent utilization and duty cycle.
iii. The findings provide the scientific community specific information about the availability of unutilized radio resources in the licensed bands considered, for contemporary cognitive radio and machine-2-machine applications and wireless communications related studies.
iv. The results also provide regulatory agencies insight into the level of compliance by licensed broadcast service stations in Ile-Ife and environs, to prescribed transmit power policies.

The rest of the paper is organized as follows. Section 2 describes the methodology used for the experiment set-up and measurements analysis. The results and discussion are presented in section 3 while section 4 concludes the paper.

2. METHODOLOGY

2.1. Experimental Set-up

The spectrum measurements were carried out at two locations within Obafemi Awolowo University (OAU) campus area. The first location is at road 7B quadrangle of the senior staff quarters (latitude 7.5191, longitude 4. 5346) while the other set-up was located at the Faculty of Science building, popularly called White House (latitude 7.5195, longitude 4.5206). These locations are strategic to the higher educational institutions and research centres in Ile-Ife, offer guaranteed access to continuous power supply and facilitate the monitoring of the experiment. Further, in the acquisition of the spectrum data, two major components were utilized. The first component is the hybrid C++ and python-based GNU radio, an open-source software development toolkit that allows the implementation of software defined radios and signal processing systems in a real-time environment using low cost and reconfigurable radios.

The other component is the NI USRP 2920. It was developed by Ettus Research LLC that provides the low-cost radio systems for commercial and research applications. Within the hardware, the USRP provides digital baseband and intermediate frequency section, which enables us to utilize general purpose computers to function as high bandwidth software radios. Moreover, the board allow us to interface it with various daughterboards for a wide range of applications. An especially appealing feature of the USRP is that it provides all waveform specific features like modulation and demodulation in CPU, while high-speed operations like interpolation, decimation, digital up and down conversion are provided within FPGA (Open-Source GNU-Radio). The interfacing of the hardware and software components was done on a computer that runs on the Linux operating system. We adopted a Linux operating system due to its ease of integration to GNU radio and its dependencies. However, for the data analysis, we used the MATLAB program on a Windows operating system.

A modified version of the python script, usrp_spectrum_sense.py, served as the script for the data acquisition. The NI USRP 2920 can only scan through a maximum of 8 MHz of RF spectrum due to USB bus limitations ("Some Usrp_spectrum_sense.Py Code Explanation," 2008), hence, the USRP RF frontend had to be tuned in suitable steps to examine a large RF spectrum of more than 8 MHz. The usrp_spectrum_sense.py script takes RF measurements by scanning across the spectrum in the specified steps thereby enabling the script to sense a large bandwidth in near real-time ("Some Usrp_spectrum_sense.Py Code Explanation," 2008).

2.2. Data Acquisition and Processing

The components of the data acquisition setup were GNU Radio Software, Ubuntu Linux operating system version 17.04, a laptop personal computer (PC) and the NI USRP 2920 device. The GNU radio was installed on the Ubuntu Linux that is running on a PC with 4 GB of RAM, 500GB hard drive, 2 USB 3.0 port and 2.40 GHz Dual Core processor. The USRP device was connected to the PC via a USB 3.0 Gigabit Ethernet adapter. It is necessary that the PC be equipped with Gigabit ethernet port or a USB converter/adapter can be used. The setup is shown in Figure 1 and the system representative block diagram is shown in Figure 2.

Figure 1. Indoor Experiment Setup

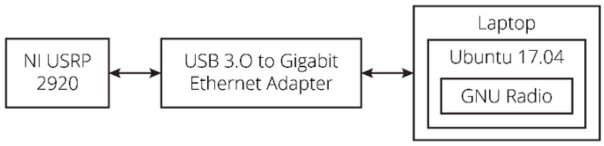


Figure 2. System block diagram

2.3. GNU Radio Broadcast FM Receiver

Prior to sensing the frequency bands of interest, we verified the integrity of the USRP by configuring the device and tuning it to known, operating broadcast frequencies of some local, commercial FM stations. The GNU Radio Companion (GRC) was used as a software-based spectrum analyser and to derive a real-time Fast Fourier Transform (FFT) of the signals captured by the USRP device, operated in the receiver mode. Figure 3 shows the flowgraph of the working software radio configured in the GRC as a broadcast FM receiver (Pandeya, 2016). The frequency was tuned to known local broadcast FM stations, demodulated and the audio signal was relayed to the PC speakers. The audio at the output was used to identify the broadcast FM stations in the vicinity of the data acquisition location. The verification step also provided an insight into the noise threshold of the study area.

3. RESULTS AND DISCUSSION

The results of the spectrum occupancy measurements for the six bands are presented in this section. Occupancy measurement from each band is described by 3-dimensional plots and the measurement from FM radio band is described by four, additional 2-dimensional plots. Also, the duty cycle can be computed using the expression

$$duty\ cycle = \frac{T_{cu}}{T_{cu}+T_{ci}} \quad (1)$$

where T_{cu} is the total time that channel is in use or occupied by the licensee and T_{ci} is the total time channel is idle or not in use by licensee, in hours over a 24-hour period and expressed in percentage.

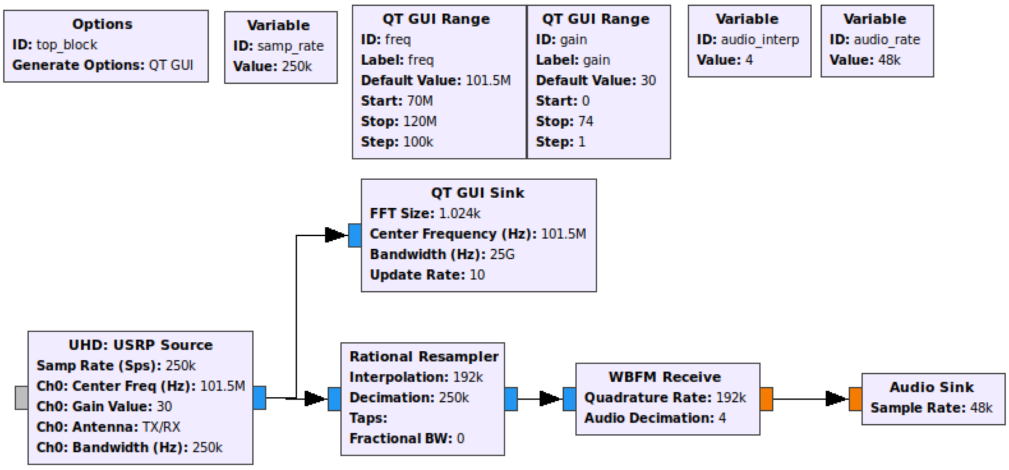


Figure 3. Flowgraph of software radio configured as a broadcast FM receiver

Figure 4 shows the result for the 88 MHz to 108 MHz band (FM radio band). It is seen from the plot that some FM radio stations, like Orisun FM (89.5 MHz) located at latitude 7.4852, longitude 4.5589 and Crown FM (101.5 MHz) situated at latitude 7.4941, longitude 4.5409 are clearly identifiable. However, it can be seen also that the stations stop transmission at about midnight and resume around 5 am. This leaves the licensed band they hold licence to utilize idle for the identified period.

In Figure 5, Figure 6 and Figure 7, we show details on the spectrum occupancy of 3 FM radio channels. These are 89.5 MHz (Orisun FM), 101.5 MHz (Crown FM) and 103.1 MHz (Unique FM, latitude 7.6262, longitude 4.7532). The duty cycle of the three channels on the average are 80.20%, 79.17% and 77.57% respectively.

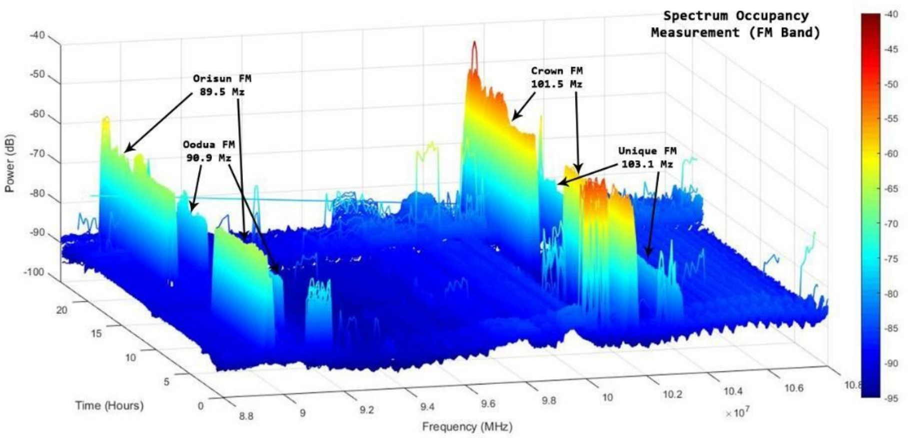


Figure 4. Plot of Spectrum Occupancy Measurement in the FM band

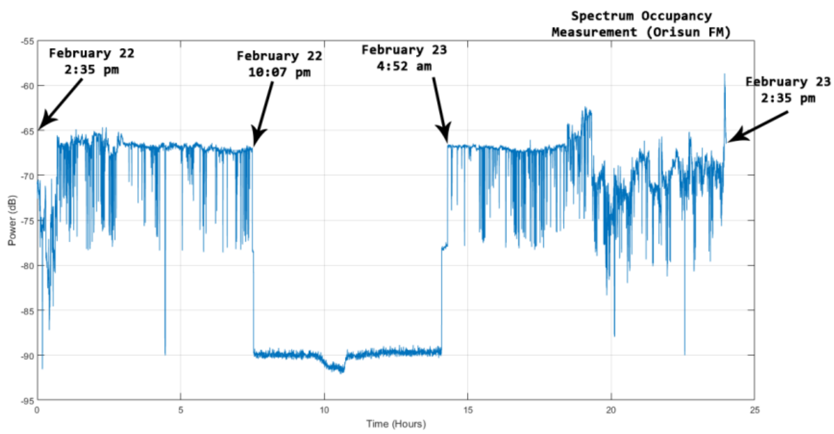


Figure 5. Close-up Plot for Orisun FM (89.5 MHz)

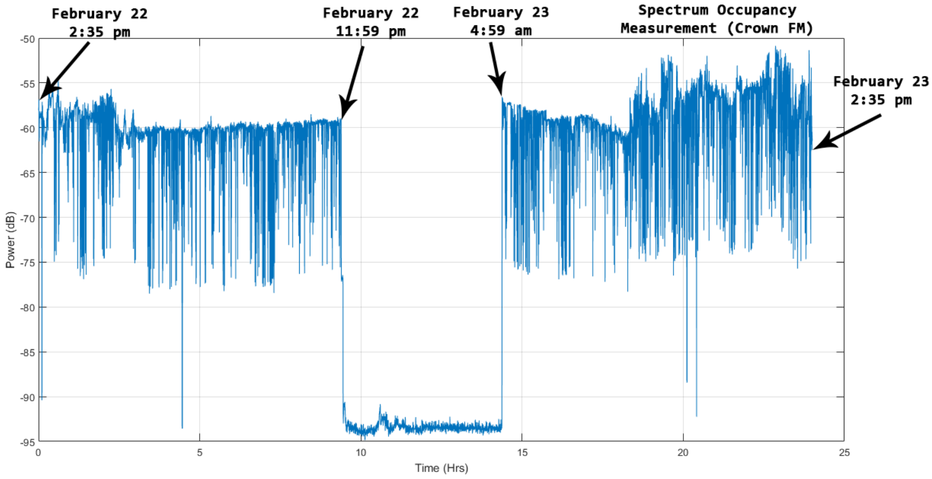


Figure 6. Close-up Plot for Crown FM (101.5 MHz)

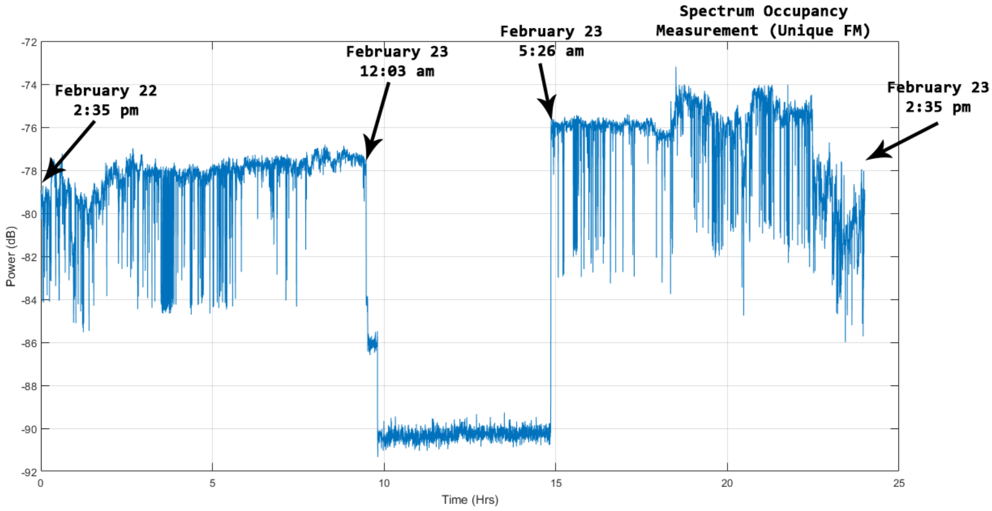


Figure 7. Close-up Plot for Unique FM (103.1 MHz)

Figure 8 shows the cumulative average of the spectrum occupancy measurement over the study period. As previously noted in Figure 4, the results show that there is a significant portion of the 88 MHz to 108 MHz band not being utilized. Therefore, the approximate utilization of the FM radio band is 78.98%.

In Figure 9, we show the plot of the spectrum occupancy measurement for the 400 MHz to 850 MHz band. In Nigeria, the band is allocated to the following services: weather forecasting, two- way radio, private CDMA networks, analogue TV, Digital Terrestrial Television (DTT), TDD-CDMA, FDD-CDMA reverse link and TV broadcasting (National Frequency Management Council of the Federal Republic of Nigeria, 2019). Overall, the utilization level is low with only few channels being completely utilized over the whole period: 480 MHz to 492.5 MHz, 495.4 MHz to 502 MHz, 707.5 MHz to 708.8 MHz and 778 MHz to 787.5 MHz. Therefore, the approximate utilization of the 400 MHz to 850 MHz band is 6.64%.

The spectrum occupancy measurement for the 840 MHz to 980 MHz band is shown in Figure 10. The band is allocated to the following services: TDD-CDMA, FDD-CDMA reverse link, TV broadcasting, FDD-CDMA forward link, GSM reverse link, GSM forward link, DME and SSR/ACAS. Overall, the utilization level is also low with only few channels, allocated for the GSM forward link, being completely utilized over the whole period — 945 MHz to 946 MHz, 947.5 MHz to 950 MHz, 955 MHz to 955.5 MHz, and 958.5 MHz to 960.5 MHz — and about 33% utilization for some channels between 900 MHz and 914 MHz. Therefore, the approximate utilization of the 840 MHz to 980 MHz band is 7.62%.

The plot of the spectrum occupancy measurement for the 850 MHz to 1300 MHz band is shown in Figure 11. The band is allocated to the following services: TDD-CDMA, FDD-CDMA reverse link, TV broadcasting, FDD-CDMA forward link, GSM reverse link, GSM forward link, DME and SSR/ACAS, Aeronautical Radionavigation Service (ARNS), and Radionavigation Satellite Service (RNSS). Overall, the utilization level is also low with only few channels, allocated for the GSM forward link, being completely utilized over the whole period — 936 MHz to 939 MHz, 946 MHz to 950.5 MHz and 954.5 MHz to 960 MHz — and about 60% utilization for the channels between 900 and 913.5 MHz. Therefore, the approximate utilization of the 850 MHz to 1300 MHz band is 4.69%.

In Figure 12, we show the plot of the spectrum occupancy measurement for the 1300 MHz to 1750 MHz band. The band is allocated to the following services: ARNS, RNSS, Fixed Mobile Radiolocation, Earth Exploration Satellite, Space Operation, Fixed Mobile, broadcast satellite, mobile satellite, weather forecasting and FDD-GSM reverse link. Overall, the utilization level is also low with only few channels, allocated for the GSM forward link, being completely utilized over the whole period — 1372 MHz to 1375 MHz, 1440 MHz to 1445 MHz and 1495 MHz to 1500 MHz — and about 66% utilization for the channels between 1745 MHz and 1750 MHz. Therefore, the approximate utilization of the 1300 MHz to 1750 MHz band is 3.62%.

The spectrum occupancy measurement for the 1700 MHz to 1900 MHz band is shown in Figure 13. The band is allocated to the following services: FDD-GSM reverse link, FDD- GSM forward link, TDD-WLL and FDD- CDMA reverse link. Overall, the utilization level is also low with only few channels, allocated for the GSM forward link, being completely utilized over the whole period, namely; 1820 MHz to 1835 MHz, 1854 MHz to 1857 MHz and 1870

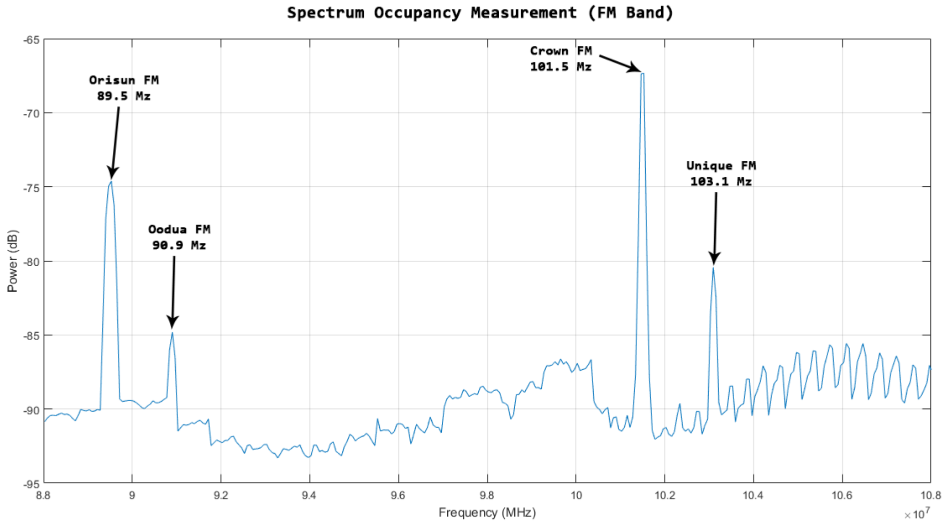


Figure 8. Average Plot of Spectrum Occupancy Measurement in the FM band

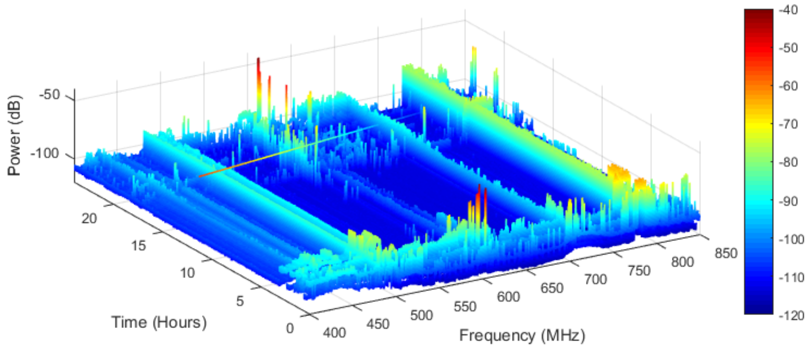


Figure 9. Plot of Spectrum Occupancy Measurement in the 400 MHz to 850 MHz band

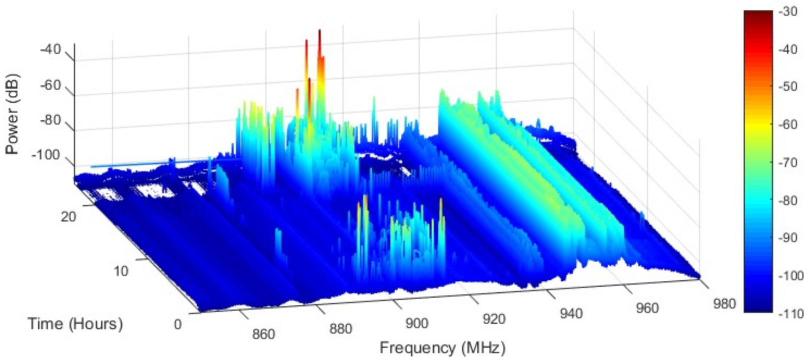


Figure 10. Plot of Spectrum Occupancy Measurement in the 840 MHz to 980 MHz band

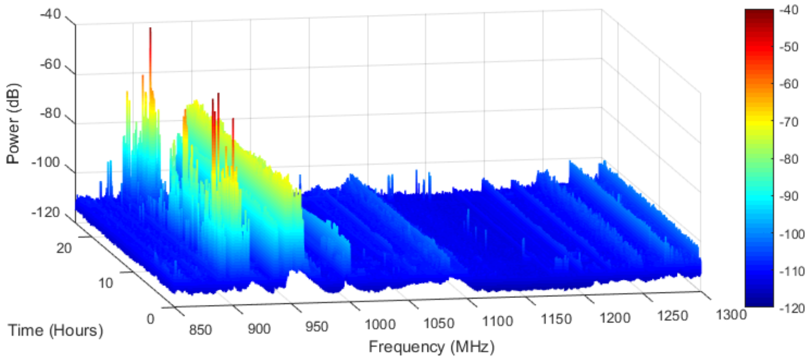


Figure 11. Plot of Spectrum Occupancy Measurement in the 850 MHz to 1300 MHz band

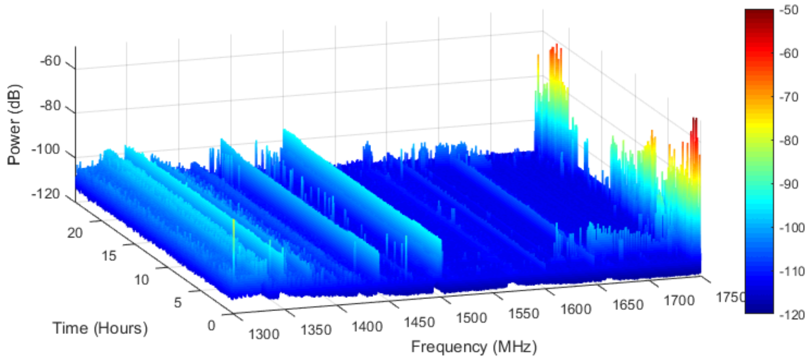
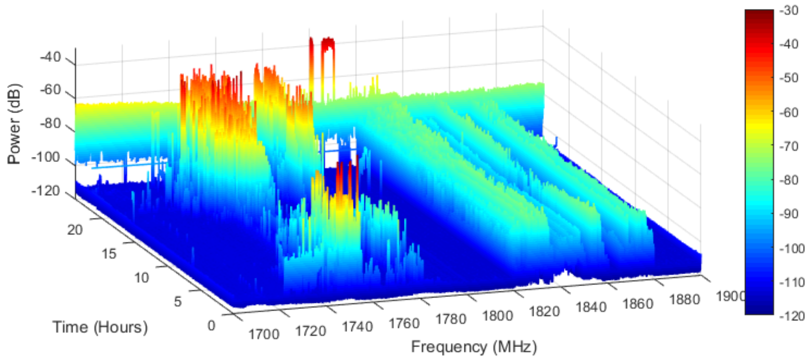


Figure 12. Plot of Spectrum Occupancy Measurement in the 1300 MHz to 1750 MHz band



MHz to 1880 MHz, about 31% utilization for the 1740 MHz to 1755 MHz channel and about 28% utilization for the 1775 MHz to 1780 MHz channel. Therefore, the approximate utilization of the 1700 MHz to 1900 MHz band is 17%.

The summary of Ile-Ife's average spectrum occupancy is presented in Table 1. The findings show the high underutilization level in both time and frequency domains. Also, the 1300 MHz to 1750 MHz band had the highest underutilization level, 96.38%, while the FM band had the highest utilization level, 78.98%. In addition, the average spectrum occupancy rate for the 88 MHz to 1900 MHz frequency bandwidth in Ile-Ife was 19.76%, which implies that about 80.24% of the allocated spectrum was unutilized at that time.

Table 1: Summary of results

Block	Frequency Range (MHz)	Duty Cycle (%)
1	88 – 108	78.98
2	400 – 850	6.64
3	840 – 980	7.62
4	850 – 1300	4.69
5	1300 – 1750	3.62
6	1700 – 1900	17.00

4. CONCLUSION

This paper presented an indoor radio frequency spectrum occupancy measurement in Ile-Ife, Nigeria covering the frequency ranges from 88 MHz to 108 MHz, 400 MHz to 850 MHz, 840 MHz to 980 MHz, 850 MHz to 1300 MHz, 1300 MHz to 1750 MHz and 1700 MHz and 1900 MHz bands. Experimental results showed that most of the statically allocated spectrum are inefficiently utilized and therefore, there is abundant opportunity to implement cognitive radio and machine-2-machine / IoT applications. In future works, we intend to carry out further studies to investigate the effects of propagation environment on the various wireless services considered.

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