Spectrum Occupancy Measurements and Analysis in the 2.4-2.7 GHz Band in Urban and Rural Environments

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***Abstract*—Continuing proliferation of wireless devices exposes humanity to the reality of the twin challenge posed by finite frequency spectrum and almost infinite demand for the same frequency spectrum, necessitating the need for more ingenious spectrum management techniques. The band 2.4-2.7 GHz was originally created and classified for ISM, 3G, UMTS and WiMAX systems. It has become a frequency band which is generally used by end users due to the fact that it's inexpensive, easy to deploy and enhances frequency re-use. Quite a few measurements have been carried out in countries like France, Germany, India, Romania, UK and USA. This paper presents a study of an outdoor measurement on spectrum occupancy in both rural and urban areas in Kwara State, Nigeria, spanning across the frequency range of 2.4 GHz – 2.7 GHz. The results show that the band being investigated is immensely underutilized with upper and lower occupancy values of 22.56% and 0% in urban and rural environments. These results were compared to other measurements conducted globally in this band or closely aligned bands.**

***Index Terms*—ISM band, spectrum occupancy, spectrum utilization, UMTS network.**

I. Introduction

Continuing proliferation of wireless devices is bringing to the fore the twin challenge of finite frequency spectrum and almost infinite demand for the same frequency spectrum, dictating the need for the use of more ingenious spectrum management techniques, to accommodate more desirous users. More appealing to scholars and practitioners, worldwide, is the idea of frequency reuse and cognitive radio. This brings about the questions *spectrum occupancy* versus *frequency availability*. In recent years the demands of wireless data services have been increasing exponentially, due to global increase in connected mobile devices, such as smart phones. The global monthly data traffic grew by about 69% from 1.5 exabyte in 2013 to 2.5 exabyte at the end of year 2014 and this is expected to reach up to 24.5 Exabyte in 2019 as forecasted by Cisco visual networking index [1]. In order to meet up with these demands, there is the need to improve on efficient use of the scarcely-available radio spectrum. Accurate assessments of the radio spectrum utilization and profiling are crucial for the development of next generation systems. Not only that, studies have shown that vast amount of the spectrum remain under utilized and also most countries have started implementing some next generation systems such as TV White space technologies [2] which aim to reuse vacant TV spectrum. This will however, require accurate census of available spectrum. The frequency band 2.4-2.7 GHz have been, primarily, allocated to the third generation (3G) wireless systems, Universal Mobile telecommunication Systems, Worldwide Interoperability for Microwave Access (WiMAX) and industrial, scientific and medical (ISM) use. Table I provides details of the licensing and spectrum block for each of the services. There is no global uniformity in licensed-spectrum application, for example the WiMAX Forum [3] has published three licensed spectrum profiles: 2.3 GHz, 2.5 GHz and 3.5 GHz. 2.5 GHz is been used in the USA [4], 2.5 GHz and 3.3 GHz in Asia while Pakistan uses 3.5 GHz. However, the Radio communication Sector of the International Telecommunication Union (ITU-R), in October 2007, included WiMAX technology in the IMT-2000 set of standards to use the 2.5-2.69 GHz band [5].

The ISM radio bands (i.e. 2.4-2.5 GHz) are the portions of the radio spectrum dedicated by the ITU for industrial, scientific and medical purposes, other than telecommunication. Despite the intent of the original allocations, and because there are multiple allocations, developments in recent years have seen tremendous growth in the use of these bands for short-range, low power communications systems. Other devices that share these bands include Cordless phones, Bluetooth devices, and wireless computer networks.

In recent years, ISM bands have also been shared with (non-ISM) license-free error-tolerant communication applications such as wireless sensor networks, wireless LANs and cordless phones in the 2.45 GHz band. Since unlicensed devices are, characteristically, tolerant of ISM emissions in these bands, unlicensed low power users can be harboured at no risk of interference to co-ISM users.

The Nigerian Communications Commission (NCC) in [6] opened up the ISM to enhance a wider range of services to subscribers, through the provision of last mile broadband access, for final distribution to end users; open up new possibilities for the pleasure and convenience of subscribers. It will also allow home-based users to have access to a variety of IP-based services, thereby enhancing universal service objectives.

This research discusses spectrum occupancy in the 2.4-2.7 GHz band, with measurements taken in Kwara state, Nigeria, in nine locations that span across rural, suburban and urban

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areas. The work also provides comparison with global occupancy measurement results conducted in this band.

II. Related Works

There has not been active research works conducted in Nigeria, in the area of spectrum occupancy, aside the one presented by Najashi *et al.* [7]. However, research efforts have been made in [8]-[13] ranging from field survey to protocol and model developments, to improve on spectrum utilization so that secondary use of radio spectrum is possible. Attard *et al.* [14] provides occupancy rate of the spectrum band of 2.4 GHz using a cooperative sensing technique, with a combination of metrics such as AND, and OR on the measurement data to define the utilization of the spectrum. The low transmission power level results in the utilization of the spectrum being deeply dependent on the location of the measurement. Hoyhtya *et al* [15] carried out a spectrum occupancy measurement in the 2.3-2.4 GHz band at Turku, Finland and compared this to the situation in Chicago, USA. The Finland measurement was conducted at a single point location located at Turku University of Applied Sciences Sepänkatu campus, on the roof of a four storey building. The Chicago data was collected at Harbor Point, in the eastern part of downtown Chicago. The researchers observed that, there is a need for location specific measurements in the 2.3-2.4 GHz band due to factors such as the limited transmission power of incumbent users in a location. In [16], measurements were carried out on spectrum occupancy in India (Mumbai and Pune) for 700 MHz-2.7 GHz. The main purpose of the survey was to perform a research that would reveal the level of utilization of spectrum of the specified frequency bands in an outdoor area in the suburban of Mumbai, suitable for deploying cognitive radio technology. The results of this research indicated that the average utilization of the spectrum was found to be 6.62%. Adediran *et al.* [17] provides TV White Space in Nigeria in UHF band: Geo-spatial approach. They provided a map showing the concentration of available radio spectrum within the country. Similarly, in [18] and [19] algorithm for predicting DTV coverage, and protection contour estimation for spatial white space and DTV protection regions for spectrum sharing, respectively, are provided.

Jayavalan *et al.* [20], carried out measurements and analyses on the utilization of frequency spectrum in the cellular and TV bands in Malaysia. The goal is to quantify the usage of the spectrum and also exploring the possibility of other wireless communication systems or cognitive radio to utilize the unused bands. The result analysis indicated that GSM 900 has an average duty cycle of 35 %, GSM 1800 10% and 3G, 26%. In addition, the VHF of the TV broadcasting bands acquire the average duty cycle of 11% while the UHF possesses an average duty cycle of 13%. Spectrum utilization on a simultaneous large scale measurement in south china to assess the realistic usage of the spectrum from 20 MHz to 3 GHz was conducted in [21]. The results reveal that each location has different spectrum usage as follows: for Guangzhou Trade Center & Guangzhou Canada Garden (urban areas) the average duty cycle are 41 % and 29.8 % respectively while Zhongshan in Suburban, and Jiangmen in rural are 35.9 % and 21.6% respectively. Chiang *et al*. [22] studied the usage of spectrum in New Zealand results reveal that the utilization of spectrum, in the band, give the average duty cycle of 6.21% and 5.72% in an outdoor and indoor location respectively.

Islam *et al.* [23], conducted a survey on occupancy measurement in Singapore, The goal was to evaluate the occupancy of the bands of diverse services and discover the possible candidate bands that can be for futuristic usage. The spectrum measurement result shows that the average utilization of the spectrum was established to be just 4.54% in Singapore.

TABLE I: Some Licensed and Unlicensed Bands within 2.3-2.7 GHz

Service/system	*Frequency*	*Example*
3G wireless	2.5-2.69 GHz	3G, UMTS, Wimax
Wireless communications service	2.305-2.32 GHz, 2.345-2.36 GHz	WLAN, Wimax
ISM band II	2.4-4.835GHz	Bluetooth,802.11b WLANs
U-NIII band I	5.1-5.25GHz	Indoor systems, 802.11a WLANs
U-NII band II	5.2-5.35GHz	Short range outdoor systems,802.11aWLANs

In [24], bands of frequencies with range from 450 MHz to 5 GHz were studied, except for 566-606 MHz due to the prohibitions to announce the measurement result by the related civil provisions. The results in china in the band 470-566 MHz and 3400-3700 MHz reveal the frequency occupancy was slightly below 0.4, which can be 39.5%, also 606-790MHz above 0.2 which can be 27%, also 1427-1527MHz above 0.1, which is 17% also from 3700-4200MHz shows above 0.6 which is 66% occupancy of the spectrum and others are far below 0.1. Ayeni *et al.* [25] provide spatial Spectrum Utilization Efficiency Metric for Spectrum Sharing System. The work developed an analytical metric that takes into account system parameters to evaluate the efficiency of reusing a spectrum. Spectrum occupancy measurements were cconducted in Barcelona, Spain by Benítez *et al.* [26] from 75 MHz to 7075 MHz. The results revealed that the utilization of the spectrum from 75 MHz – 1000 MHz, 1000 MHz – 2000 MHz, 2000 MHz – 3000 MHz, 3000 MHz - 4000 MHz, 4000 MHz – 5000 MHz, 5000 MHz – 6000 MHz and 6000 MHz-7075 MHz had an average duty cycle of 42.00%, 13.30%, 3.73%, 4.01%, 1.63%, 1.98% and 1.78% respectively. It was concluded that the study revealed the overall duty circle observed in frequency and time for the stipulated spectrum from 75MHz-7075MHz to give the value of 17.78% which shows a considerable fact that the entire spectrum experiences low utilization and shows potential for CR usage. In [27] a spectrum survey was conducted which covers two different countries three locations, two locations in France and Czech Republic with the goal of correlating the measurements analysis of the two regions and summarize its similarities and physical aspect that will have to be measured in the future radio spectrum management. The result reveals the overall utilization from 400MHz-3GHz in location 1, 2 & 3 are 6.5%, 10.7% & 7.7% respectively.

III. METHODOLOGY

A. Measurement Set up

The measurement setup and settings used are identical for the rural, urban and sub urban locations. The spectrum occupancy measurement setup consists of a spectrum analyzer, a data storage device, and data manipulation equipment (laptop). Agilent N9342C Handheld Spectrum Analyser (HSA) capable of measuring from 100 KHz to 7GHz (tuneable to 9 kHz) was used. The device uses energy detection to directly measures received signal level in dBm. It also capable of displaying the spectrograph of signals. It also has GPS (global positioning system) location features. A 32 Gigabyte Storage device was used to save the log files generated by spectrum analyzer in real-time to be worked on with a laptop. The measurement setup at the locations is shown in Fig. 1.

Fig. 1. Agilent N9342C Spectrum analyser and project vehicle.

The SA's parameters were configured according to the values shown in Table II. Analysis of the data was then post-processed offline in a powerful PC.

TABLE II: SPECTRUM ANALYZER CONFIGURATION

Parameter	*Value*
Resolution/ Video Bandwidth (RBW/VBW)	100 kHz/ 100 kHz (Automatically selected by SA)
Sweep time	34.10 ms (Automatically selected by SA)
Sweep Type	Continuous
Reference Level	-50 dBm
Number of points	461

B. Measurement Locations

The measurement was conducted outdoors at specific urban and rural locations in Kwara state, Nigeria to ascribe a wide view to our spectrum occupancy. Table III shows the measurement sites and type of environment considered, with their respective coordinates.

C. Data Collection and Processing

The measurements were taken for 24 hours in the locations. All raw data was collected by the analyzer in a matrix form with elements of the received signal powers $P(f_i, t_i)$ (in dBm). Where f_i denotes the frequency or channel and t_j records the time slot with 461 as the number of time slots (N) measured per received frame. A total of 1500 frames were received into the Analyzer per band per location. Fifty frames 50 samples were randomly chosen from the raw data leaving a matrix *Y* of signal power (50, 461) to be processed in order to evaluate the occupancy statistics and to produce frequency-time occupancy plots.

TABLE III: MEASUREMENT LOCATIONS

Location	*Type*	*Coordinate*	*Identifier*
Adio village, Oke Oyi	Rural	4°29'42" E; °46'40"N	LOC 1
Malete	Rural	4°29'42"E 8°22'34"N	LOC 2
Alamote	Rural	4°29'42"E 8°22'34"N	LOC 3
Odo Oke	Rural	4°31'55"E 8°17'09"N	LOC 4
Lagiki,	Rural	4°33'02"E 8°16'46"N	LOC 5
University Quarters, Ilorin	Urban	4°38'47"E 8°27'49"N	LOC 6
University of Ilorin, Ilorin	Urban	4°67'60" E 8.48'74"N	LOC 7
Pipe Line	Urban	4°35'07" E 8°27'57"N	LOC 8
Kwara Stadium, Ilorin	Urban	4°32'29"E 8°28'36" N	LOC 9

The process of evaluating the occupancy statistics comprises of three steps- raw data input, setting of an adaptive threshold, and computing the average duty cycle of each channel. Raw data inputs are received power levels at the antenna output that have not been processed. Adaptive threshold setting is done as each channel has different noise power. In order to minimize false alarm, a threshold of 10 dB above the noise floor was used for this experiment. The average measured occupancy or Duty cycle indicates how often the signal is perceived during a sampled period of scanning a band. The duty cycle is delimited as the percentage of time a frequency band or channel is occupied over a given period as shown in the equation (1)

$$\textit{Duty}\ \text{Cycle} = \frac{\text{Signal Occupation period (n)}}{\text{Total Observation period (m)}} \times 100\% \tag{1}$$

When given a time series of channel power measurements the duty cycle can be calculated as:

$$\textit{Duty}\ \text{Cycle} = \frac{nt}{m} \times 100\% \tag{2}$$

where *n* denotes number of time slots t, where the received signal level is above the decision threshold λ_j and *m* is the total number of time slots.

IV. RESULTS AND DISCUSSION

Table IV shows the results of the occupancy measurement in between 2.4-2.7 GHz band in nine (9) different locations in Kwara state, Nigeria. The locations cut across rural, suburban and urban areas. In Table IV, a duty cycle of 0% was obtained in locations 1-5 which are all rural areas. This result signifies that the band is completely unoccupied. This is an indication of the low penetration of devices that operate in this band in a typical rural Nigeria settlement that has little or no wireless network infrastructures. However, in the two urban locations

(LOC 6 & 7) the results show high occupancy level. Surprisingly the duty cycle of the locations i.e. LOC 6 and LOC 7 are quite higher than for LOC 8 and LOC 9. The occupancy values of 18.56% and 22.56% respectively were measured in these locations, which are about a ratio of 20:1 and 17:1 when compared to the occupancy of 1.08% and 0.95% obtained in LOC 8 and LOC 9. The result is not far-fetched because the locations described as LOC 6 and LOC 7 are campus areas where a lot of wireless LAN devices connect to the institution's internet connection, while LOC 8 and LOC 9 are residential and commercial areas of Ilorin. From an economical point of view the obtained results are very encouraging for cognitive radio technology deployment since lower duty cycle is a desired phenomenon for secondary/opportunistic use of the 300 MHz of available bandwidth within the band. The overall average duty cycle of both the rural (0%) and urban settlements (10.8%) indicates very low utilization and hence large opportunity for reuse of this band in Kwara state, Nigeria. According to [28], the low occupancy measurements obtained here might be attributed to the fact that this frequency band is usually occupied in indoor environments, hence there is a higher probability that the utilization in indoor might be higher.

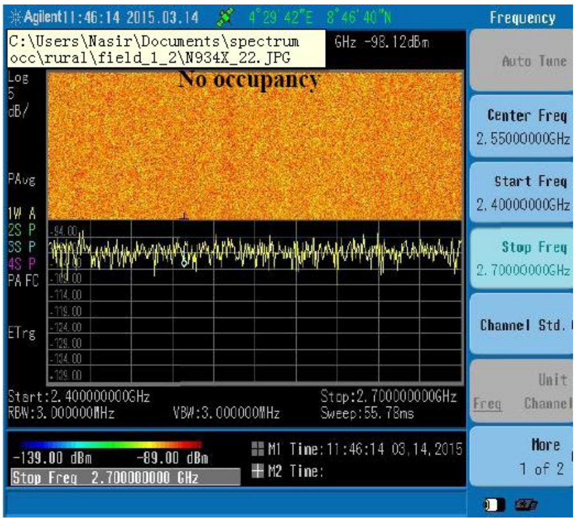

Fig. 2. Spectrogram for location 1 (Adio village, Oke Oyi).

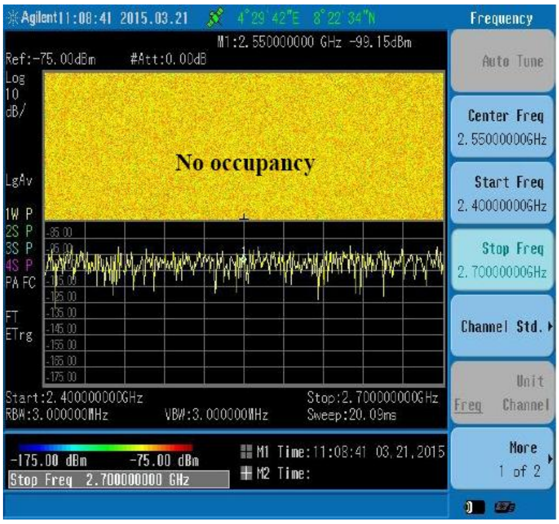

Fig. 3. Spectrogram for location 2 (Malete).

Table V provides a comparison between measured duty cycle for Kwara State, Nigeria and for some other locations. Comparing our experiment with [16], it can be shown that in Table V, the occupancy level for Ilorin is higher than Mubai. However these results are location dependents. Results within this band from Mumbai [16], Hull City, UK in [29] and Romania [30] are bit lower than the values obtained. This is expected as the duty cycle in these bands are location dependent. However the results presented in [27] and [9] may not be taken into consideration as the frequency spans of 200 MHz and 100 MHz which are below 300 MHz used in this experiment.

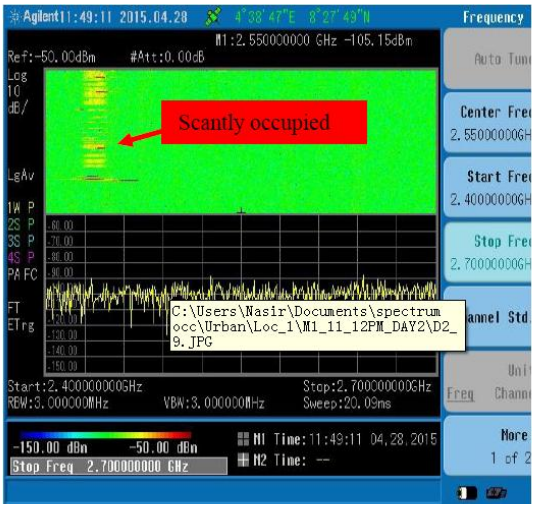

Fig. 4. Spectrogram for location 6 (University of Ilorin Quarters).

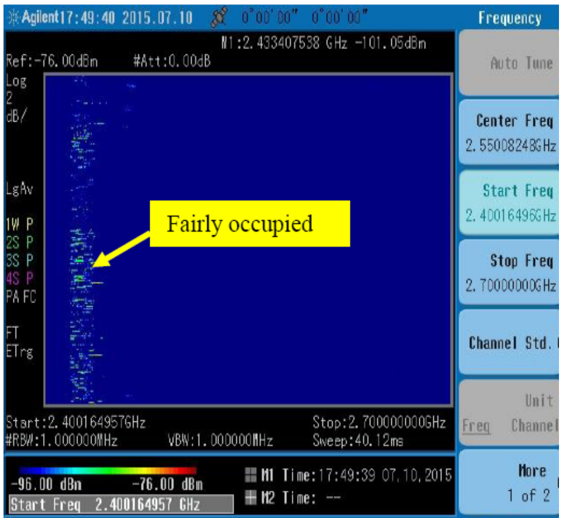

Fig. 5. Spectrogram for location 7 (University of Ilorin, main campus).

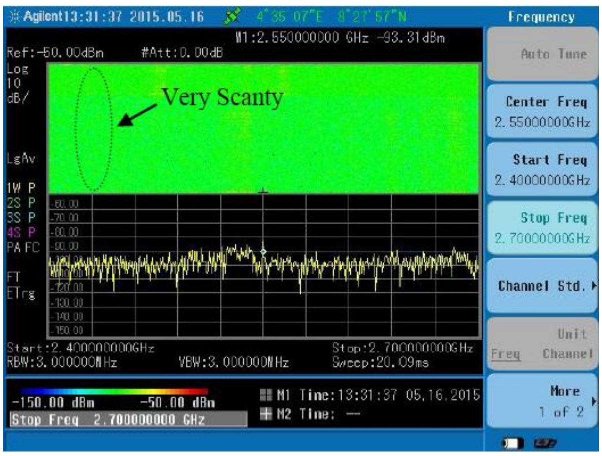

Fig. 6. Spectrogram for location 8 (Pipeline, urban).

TABLE IV: DUTY CYCLE RESULTS

LOCATION IDENTIFIER	LOCATION TYPE	DUTY CYCLE (%)	AVERAGE DUTY CYCLE PER LOCATION TYPE	AVERAGE DUTY CYCLE
LOC 1	RURAL	0	0.00 %	4.79 %
LOC 2	RURAL	0		
LOC 3	RURAL	0		
LOC 4	RURAL	0		
LOC 5	RURAL	0		
LOC 6	URBAN	18.56	10.79 %	
LOC 7	URBAN	22.56		
LOC 8	URBAN	1.08		
LOC 9	URBAN	0.95		

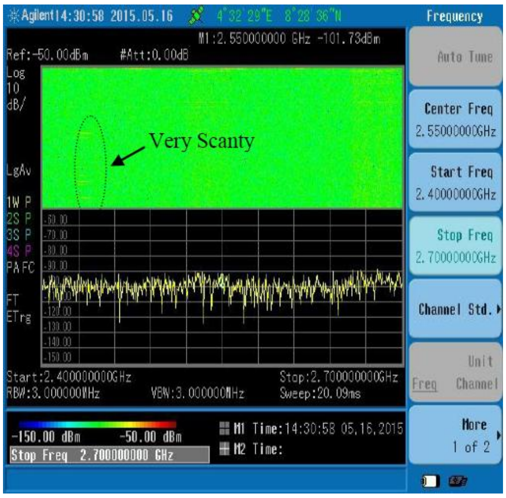

Fig. 7. Spectrogram for location 9 (Kwara State Stadium, urban area).

Fig. 2 to Fig. 7 show the spectrogram for the bands 2.4-2.7 GHz for six locations. Fig. 2 and Fig. 3 show the spectrogram for rural locations 1 and 2. The figures show no activities going on because there is no active wireless access point within the locations. Fig. 4-7 show the spectrogram for the urban locations. It is worthy of note that within these locations, only locations 6 and 7 show significant activities in the spectrogram. Due to the low occupancies in locations 8 and 9, the activities on this band were not captured on the spectrogram.

TABLE V: COMPARISON BETWEEN MEASURED DUTY CYCLE AND FOR OTHER LOCATIONS

Location	Average duty cycle %	Frequency Band (GHz)
Ilorin, Nigeria	10.79	2.4 – 2.7
Romania[30]	5.81	2.4 -2.7
Hull,UK[29]	9.40	1.9 – 2.7
Abuja, Nigeria[9]	17.42	2.2 – 2.4
Mumbai, India [16]	0.41	2.4-2.7
Czech[27]	0.20	2.4-2.5
Paris, France[27]	6.10	2.4-2.5

V. CONCLUSIONS

In this paper, we presented an outdoor measurement on spectrum occupancy in both rural and urban areas in Kwara State, Nigeria, spanning across the frequency range of 2.4 GHz – 2.7 GHz. The results obtained show that the band is immensely underutilized. There is, therefore, ample opportunity for the deployment of cognitive radio devices in the investigated band on account of low usage manifested by low occupancy.

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