

Spectrum Occupancy Measurements in the TV and CDMA Bands

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Abstract: Continuous demand, by end users, has become an issue with respect to the scarce resources of radio frequency spectrum. In this paper we conducted a 24-hour outdoor measurement of spectrum occupancy, in both rural and urban areas in Kwara State, Nigeria, spanning across the frequency range of 48.5 MHz – 880 MHz. The results obtained show that the mean average duty cycle for TV bands 1-4 and CDMA band in rural and urban locations are 2.58 % and 12.02% and 0.25% and 3.13% respectively. Findings from this measurements show that there is ample opportunity for deployment of cognitive radio for a more efficient utilization of the spectrum.

Index Terms: Duty Cycle, VHF, UHF, CDMA

I. INTRODUCTION

The anxiety about providing services to the growing number of desirous users, even, with the realization of the finite and exhaustible nature of the radio spectrum is leading scholars, practitioners and other stakeholders to venture into new things and ideas.

Reuse of already allocated frequencies, by secondary users, though relatively novel, is becoming, particularly, attractive, in this direction. This is giving way to the idea of frequency utilization, spectrum efficiency and the duty cycle. For this use to be worthy, it should not lead to interference with the primary user and its resultant degradation in quality of service.

Many techniques are being experimented on, towards the realization of the goal of meeting continuously growing demands for spectral spaces in the face of finitely-limited spectral spaces. Prominent among these are the plethora of spectrum management/licensing regimes all designed to enhance efficient spectrum usage. Joseph Mitola [1] proposed the idea of *cognitive radio*, a software defined radio with capability to monitor the radio environment for the purpose of determining

whether or not, and they are occupied. Spectrum sensing is the process of detecting the presence of primary users in a licensed frequency band. There are broad categories spectrum sensing: cooperative sensing, non cooperative and interference based sensing.

Measurement of duty cycle gives valuable information on spectrum availability by frequency band, time and location; by extension it provides enough information to enable deployment of secondary user-devices. Duty cycle is a measure of the ratio of period of occupancy and period of observation, t/T where, t and T are, respectively, the period of usage and period of observation. In this paper we conducted a 24-hour outdoor measurement of spectrum occupancy, in both rural and urban areas in Kwara State, Nigeria, spanning across the frequency range of 48.5 MHz – 880 MHz.

II. RELATED WORKS

Several spectrum occupancy measurements and survey has been conducted globally, but minute research work has been conducted in Africa as most of the existing works were conducted in the USA, Europe and Asia. In [2]-[7] they made effort to conduct a field survey to protocols and model developments in improving spectrum utilization in VHF and UHF bands in Nigeria.

In [8], measurement and Analysis of Wideband spectrum utilization in Indoor and Outdoor environments was provided. In [9] they concluded that channel occupancy varies on 24 hour duration. In [10] same energy detection (ED) threshold presented in [11] was used and measurement was conducted in Hull, United Kingdom between 180 MHz – 2700 MHz on top of a building and it measurement was taken within 24 hours. The frequency was sub-divided into six groups respectively. The average duty cycle for 180MHz – 850MHz was 10.18% and 880MHz – 960MHz was 32.19% which was the most utilized sub-band .But the mean spectrum occupancy of all the bands

was 11.02% also it was observed that frequency 1.9GHz was the least underutilized.

In [11] they measured between 25MHz – 3400MHz with 14 different frequency groups. They took the measurement outside a top building. The average duty cycle for 25MHz – 230MHz was 28.44%, 230MHz – 400MHz was 11.09%, 400MHz – 470MHz was 18.37%, 470MHz – 766MHz was 40.02% and 766MHz – 880MHz was 12.30%. The mean occupancy was 12.19% which showed that the occupancy over the bands was pretty low but the most occupied group was between 880 -960 MHz which was 46.8% indicating that there were more users using the GSM band.[11]. In [12] they conducted an extensive spectrum occupancy measurement at the frequency range of 300MHz – 4900MHz, and generated a data for a period of more than 6 month in Bristol, UK. Their main objective was to discover which channel might be suitable for CR use on a time interleaved basis, and to discover how the availability of these channels varies according to the time of day and to find out more about the short-term temporal variability. In [13] an extensive measurement campaign to compare indoor and outdoor spectrum occupancy using energy detection sensing method. The measurement was carried out at Aachen, Germany and the frequency range considered was between 20MHz – 1520MHz, 1.52GHz to 3GHz and 3GHz up to 6GHz. The ED threshold used was 3dB above the measured noise floor and results was analyzed using amplitude probability distribution (APD) to observe primary user activity. In paper [14] he conducted his outdoor experiment on top of a building in Ohio, USA from frequency range 30MHz – 300MHz. He chose 7dB above noise level as ED threshold. Approximately 80% of the total spectrum measured showed that it was free and further explained that in a rural location the spectrum occupancy percentage will decrease because of lesser traffic.

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 and a data storage. Agilent N9342C Handheld Spectrum Analyser (HSA) capable of measuring from 100 KHz to 7GHz was used. The device uses energy detection to directly measures received signal level in dBm. 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. The measurement setup at the locations is shown in Fig 1. The SA's parameters were configured according to the values shown in Table I. Analysis of the data was then post-processed offline using a PC.



Fig 1: Agilent N9342C Spectrum analyser and project vehicle.

TABLE I: 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 II shows the measurement sites and type of environment considered, with their respective coordinates. Table III shows the frequency bands that was considered

TABLE II: MEASUREMENT LOCATIONS

Location	Type	Coordinate	Identifier
Adio village, Oke Oyi	Rural	4°29'42" E; 8°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

IV. RESULTS AND DISCUSSION

TABLE III: SERVICE BANDS CONSIDERED.

Service Bands	Frequency range	Bandwidth (Hz)
TV Band 1	48.5-92 MHz	43,000,000
TV Band 2	167-233 MHz	66,000,000
TV Band 3	470-566 MHz	96,000,000
TV Band 4	606-870 MHz	264,000,000
CDMA DL	870-880 MHz	10,000,000

C. Data Collection and Processing

The measurements were taken for 24 hours at each location. 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_i 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.

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)

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

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

$$\text{Duty Cycle} = \frac{nt}{m} \times 100\% \quad (2)$$

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.

Figures 2 and 3 provide pie chart of the duty cycle for locations 2 and 3 which are all in the rural areas. In location 2, TV band 2 recorded the highest occupancy value of 2.47% while in location 3 TV band three has the highest occupancy of 14.19 %. In both locations, CDMA band was completely unoccupied with zero percent utilization. In the urban scenario, TV band 3 has the highest occupancy as shown in Figures 4 and 5. The average duty cycle for each of the bands was computed for the locations (i.e. LOC 1-9) the results are shown in Table IV. In Table IV, the average duty cycle of 0% for TV band 4 (606 – 870 MHz), was obtained for LOC 1, 3, 4 and 5 which are all rural locations. Across all the locations, the average mean duty cycle for TV band 1 (48.5 – 92 MHz), TV band 2 (167 – 233 MHz), TV band 3 (470 - 566 MHz), TV band 4 (606 – 870 MHz) and CDMA band (870-880MHz) are 2.77 %, 4.64%, 16.56%, 3.12% and 1.53% respectively. In terms of mean occupancy across all the bands, LOC 9 has the overall occupancy value of 13.39% followed by LOC 8 with 12.38 % and LOC 6 with 11.38% with all of these in urban areas. LOC 5 and LOC 3 in the rural areas have considerable occupancies.

TABLE IV. DUTY CYCLE (%) FOR LOCATIONS

	TV Band 1	TV Band 2	TV Band 3	TV band 4	CDMA	Mean (%)
Loc1	0	0	0	0	0.65	0.13
Loc 2	2.11	4.72	0.48	0.03	0	1.46
Loc 3	0.24	5.49	14.91	0	0	4.12
Loc 4	0	0	0	0	0.2	0.04
Loc 5	0.92	2.45	20.26	0	0.41	4.81
Loc 6	5.37	6.01	29.36	15.14	1.01	11.38
Loc 7	2.61	0.82	13.59	0.134	0.44	3.52
Loc 8	6.42	11.49	37.27	6.42	0.3	12.38
Loc 9	7.23	10.84	33.21	6.38	10.8	13.69
Average	2.77	4.64	16.56	3.12	1.53	

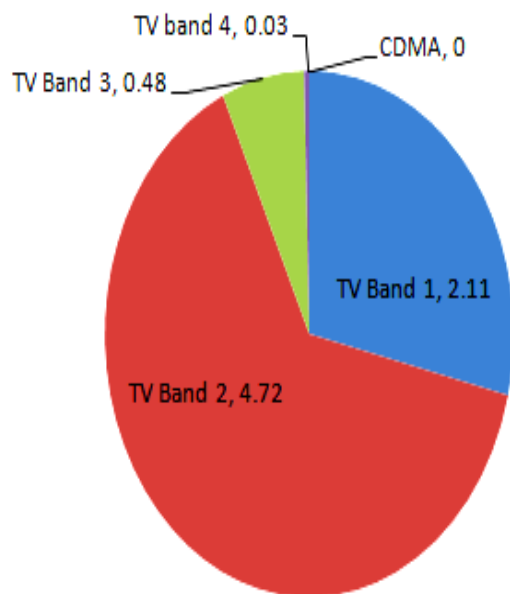


Figure 2 Duty Cycle for TV and CDMA for LOC 2

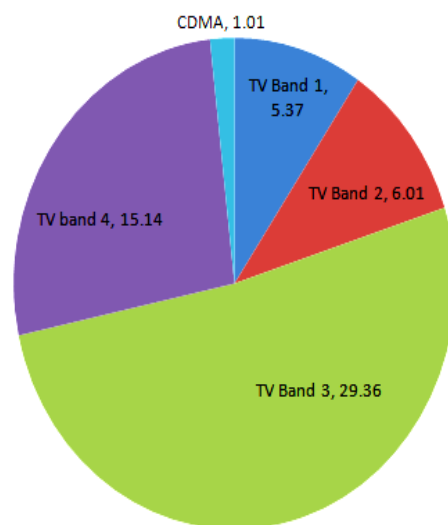


Figure 4 Duty Cycle for TV and CDMA Bands for LOC 6

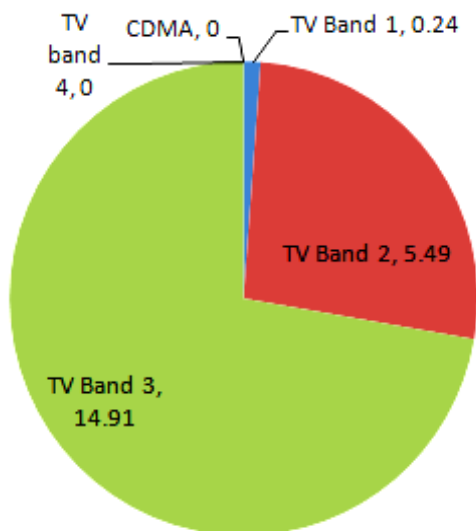


Figure 3 Duty Cycle for TV and CDMA Bands for LOC 3

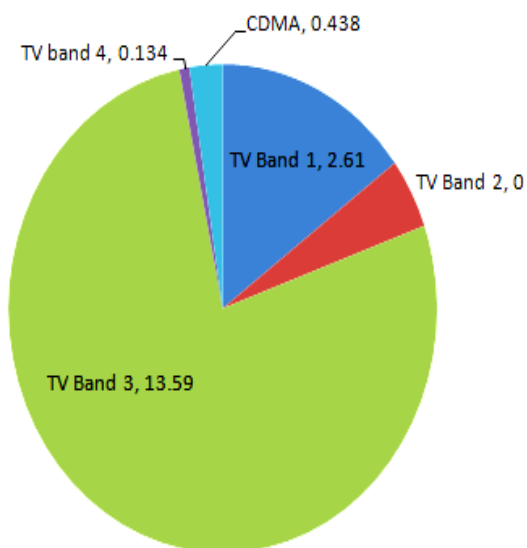


Figure. 5 Duty Cycle for TV and CDMA Bands for LOC 7

V. CONCLUSION

Evidence, from the results of our 24-hr outdoor measurement, on spectrum occupancy, show that in both rural and urban areas, CDMA bands are less utilized when compared with TV bands. However, the average occupancy of TV bands in the urban locations is still very low at 12.02%. Either of the bands is a good candidate for the deployment of *cognitive radio*.

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REFERENCES

- [1] J. Mitola, "Cognitive Radio an Integrated Agent Architecture for Software Defined Radio", PhD Thesis, Royal Institute of Technology (KTH), pp 45-47, 2000.
- [2] Y.A. Adediran, N. Faruk, A. A. Ayeni, O. Kolade, N.T. Surajudeen-Bakinde and O.W. Bello, "Geo-spatial Approach to Quantifying TV White Space in Nigeria in the UHF Band" Submitted for review, Journal of Engineering Letters, November, 2014.
- [3] N. Faruk, N.T. Surajdeen, O. Kolade and A.A. Ayeni, and Y.A. Adediran, "DTV protection regions for spectrum sharing" IET Journal of Engineering, Institute of Engineering and Technology, 5th Sept, 2014.
- [4] N. Faruk, A.A. Ayeni, Y.A. Adediran and N.T. Surajdeen, "Improved Path Loss Model for Predicting DTV Coverage for Secondary Access" Int. J. Wireless and Mobile Computing, vol. 7, No. 6, pp 565-576, 2014.
- [5] N. Faruk, A.A. Ayeni and Y.A. Adediran, "Impact of Path loss models on Spatial TV white space" European Scientific Journal, University of Azores, Portugal, vol. 4, pp 543-547, 2013.
- [6] N. Faruk, Y.A. Adediran and A.A. Ayeni, "On the study of empirical path loss models for accurate prediction of TV signal for secondary users" Progress in Electromagnetic Research (PIER) B, USA, vol. 49, pp 155- 176, 2013.
- [7] N. Faruk, M. Gumel, A. Oloyode and A. Ayeni, "Performance Analysis of Hybrid MAC Protocol for Cognitive Radio Networks," Int'l J. of Communications, Network and System Sciences, vol. 6 No. 1, 2013, pp. 18-28. doi: 10.4236/ijcns.2013.61003.
- [8] K. A. Qaraqe, M. S. Alouini, A. El-Saigh, L. Abuhantashi, M. Al-Mulla, A. Jolo, A. Ahmed, "Measurement And Analysis of Wideband Spectrum Utilization in Indoor and Outdoor Environments," International conference on Communication Technologies (ICCT , 2010) Riyadh, Saudi Arabia, Jan 2010.
- [9] K. E. Nolan, "700MHz Band Spectrum-Usage Measurements from Denver to Washington Dc During November 2007 And Their Value In Helping Software-Defined Radio Enter The Mainstream"
- [10] M. Mehdawi, N. Riley, K. Paulson, A. Fanan, M. Ammar, "Spectrum occupancy survey in HULL-UK for cognitive radio applications: measurement & analysis." International Journal of Scientific & Technology Research vol. 2, no. 4, pp 231-236, 2013.
- [11] A. Marțian, C. Vlădeanu, I. Marcu, I. Marghescu, "Evaluation of Spectrum Occupancy in an Urban Environment in a Cognitive Radio Context." International Journal on Advances in Telecommunications vol. 3, no. 3, pp 172 -181, 2010.
- [12] T. J. Harold, R. A. Cepeda, M. A. Beach, " Long-Term Measurements of Spectrum Occupancy Characteristics", New Frontiers in Dynamic Spectrum Access Networks (DySPAN), 2011 IEEE Symposium on. IEEE, 2011.
- [13] M. Wellens, J. Wu, P. Mahonen, " Evaluation of Spectrum Occupancy in Indoor and Outdoor scenario in the Context of Cognitive Radio", Proc. 2nd International Conference Cognitive Radio Oriented in Wireless Network Communication. CrownCom 2007, Orlando, FL, USA 2007, pp 420 - 427.
- [14] S. W. Ellingson, "Spectral occupancy at VHF: implications for frequency-agile cognitive radios," In IEEE Vehicular Technology Conference, vol. 62, no. 2, p. 1379. IEEE; 1999, 2005.