Short-Term Variation of Duty Cycle in the VHF and UHF Bands

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Abstract: **The continuing high demand, by end users, has become worrisome with respect to scarce resources of the radio spectrum. TV bands, spanning across has being in existence for quite a while now and much of the frequency bands, within these range, have been allocated to FM stations, TV stations and DTV stations in Nigeria. In this paper we conducted a 24-hours outdoor measurement of spectrum occupancy in both rural and urban locations in Kwara State, Nigeria, spanning across the frequency range of 48.5 MHz – 870 MHz. The results obtained show that TV band 3 was the most occupied TV band in both rural and urban areas, with occupancy of up 20.26% and 37.27% respectively. Also the mean average of the duty cycle in the urban location is 12.02% compared to 2.58% in the rural locations. Findings from this measurements show that there is ample opportunity for deployment of software defined radio for a more efficient utilization of the spectrum.**

Keywords: Short-Term; Duty Cycle; VHF; UHF

I. INTRODUCTION

Frequency utilization is fast becoming an issue in today's research activities, primarily, due to the realization that *demand* for frequency seems to be outgrowing *supply.* The reality, today, is that demand for space, in the wireless medium is increasing at a rate, sufficient to arouse questions about *availability* and, by extension, *frequency utilization*. This is due to the continuing emergence of wireless devices, on account of preferences for them as a means of information transmission. This has, over time, given rise to the ideas of *frequency reuse* and *cognitive radio.* Cognitive radio is an intelligent radio which can be programmed and, dynamically, configured, to enable it use the best wireless channels in its vicinity. Such a radio, automatically, detects available channels in the wireless spectrum and changes its transmission or reception parameters, to allow more concurrent wireless communications in a given spectrum band, at a particular location. This process is a form of dynamic spectrum management. Frequency occupancy measurement enhances an estimation of *frequency utilization* and its related parameter, *duty cycle*, both of which, obviously, vary over time.

With the emergence of Wireless Local Area Networks (WLANs), in various environments, as well as proliferation of other wireless devices, the issue of frequency utilization is brought, further, to the fore. Considering that data is not transmitted on a continuous basis, the assumption of a continuous transmission, often made, is misleading as it overestimates frequency utilization, leading to underutilization of spectrum. Actual duty cycles of WLAN, as well as those of other wireless channels, are, thus, of importance, for purpose of frequency utilization determination and by extension cognitive radio deployment.

II. RELATED WORKS

Recently, there is growing spectrum occupancy measurements and survey due to global demand of more spectral spaces to accommodate increase in wireless data services. No significant work, in this area, has been carried out in Africa as most of the existing works were conducted in the USA, Europe and Asia. However, research efforts have been made in [1]-[6] ranging from field survey to protocol and model developments, to improve on spectrum utilization, so that secondary use of radio spectrum in the VHF and UHF bands in Nigeria can be made feasible.

In [7] a bid to study the utilization of RF spectrum in indoor and outdoor environments simultaneously performed measurements in the 700MHz - 3000MHz frequency band, over three consecutive days, at an indoor and outdoor location simultaneously. Their findings show that there are striking and quantifiable differences in the spectrum utilization profiles between indoor and outdoor

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environments and bandwidth utilization differs for the different environments. With mean values of 1% and 15%, standard deviation of 0.2 and 0.5, for indoor and outdoor, respectively, the need for specifying the environment type is obvious whenever spectrum utilization is being measured. In [8] a measurement campaign covering a total of 4500 km along a route from Denver, Colorado to Washington DC in the band 698MHz - 806MHz, covering a variety of busy urban centers and quiet rural areas along the route. The aim was to evaluate the actual spectrum usage, in the 700MHz band, which was the subject of FCC auction 73.

In [9] same energy detection (ED) threshold presented in [10] 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. It showed that the most utilized sub-band was 880MHz - 960MHz and the occupancy measured was 32.19%. But the mean spectrum occupancy of all the bands was 11.02% also it was observed that frequency 1.9GHz was underutilized. In [9] they recommended that frequency above 1GHz is the best and most under-utilized band which provides allowance for secondary user.

In [11] 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 [8] they concluded that channel occupancy clearly varies on a 24 hour cycle. Mean time and frequency occupancy figures have shown that occupancy varies periodically, with a strong 24 hour cycle being visible.

In [12] 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 [13] he conducted his outdoor experiment on top of a building in Ohio, USA from frequency range 30 MHz – 300 MHz . 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, 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 I. Analysis of the data was then post-processed offline in a powerful PC.

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 Village	Rural	4°29'42"E 8°22'34"N	LOC 2
Alamote Village	Rural	4°29'42"E 8°22'34"N	LOC 3
Odo Oke Village	Rural	4°31'55"E 8°17'09"N	LOC 4
Lagiki, Village	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

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

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.

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)

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

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

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

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

TV broadcasting frequencies is categorized into four bands i.e. TV band 1, TV band 2, 3 and TV band 4. Table III provides details of the frequency range for each band. The average duty cycle for each of the bands was computed for locations (LOC) 1-9. In table IV, the average duty cycle of 0% was obtained for locations 1 and 4 across all the bands. For TV band 1 (48.5 MHz – 92 MHz), LOC 9 has the highest occupancy of 7.23 %. For TV band 2 (167 MHz – 233 MHz) and TV band 3 (470 MHz - 566 MHz) LOC 8 has the highest occupancy of 11.49%. and 37.37% respectively. However for TV band 4 (606 MHz – 870 MHz), LOC 6 has the highest occupancy value of 15.14%.

In terms of mean occupancy, LOC 8 has the overall occupancy value of 15.4% followed by LOC 9 14.41% and LOC 6 with 13.97% with all of these in urban areas. TV band 1 recorded the least occupancy across all the locations when compared with other bands this is because only one active transmitter (i.e. Unilorin FM radio, operating on 89.3 MHz frequency) in the VHF channels is allotted for FM radio broadcasting. Therefore, no significant activity was captured, although the experiment did not cover other bands, in which other radio transmitters such as Royal FM transmitting on 95.1 MHz, Harmony FM operating 103.5 MHz and Midland FM 105.3MHz are operating. TV band 3 recorded the highest occupancy value as up to 40% of the band is occupied during the period of the measurements. This value is expected to vary depending on time and usage. There was no much activity in the TV band 4 as only about 15% of the band is occupied and considering the frequency band of 606 – 870 MHz which is UHF band; this would be suitable for secondary network deployment with high capacity. However, the duty cycle for LOC 7 was 2.61% in TV band 1 which is very low compared to other urban locations in spite of its closeness to the Radio transmitter of about 100 m. The observed low duty cycle is accounted for, by the phenomenon of near far effects.

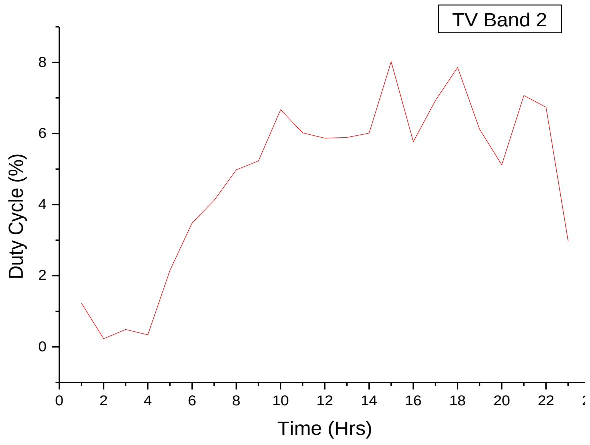

Fig. 2. Variation f Duty Cycle for TV Band 2

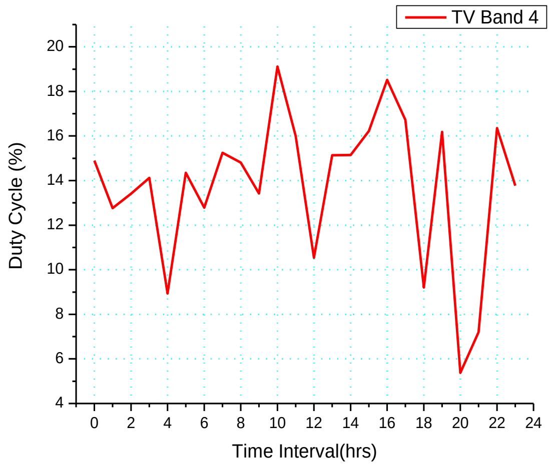

Fig. 4. Variation f Duty Cycle for TV Band 4

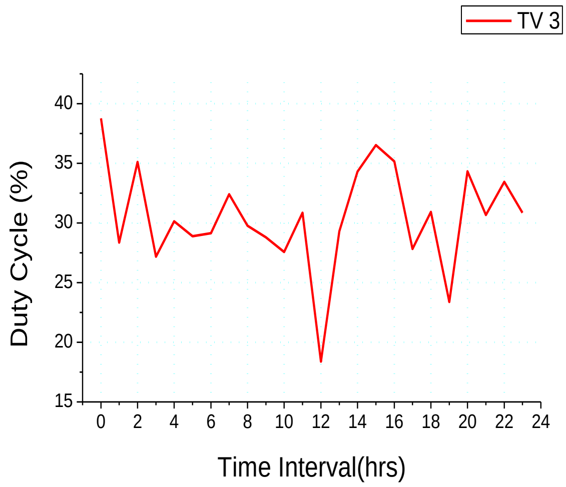

Fig. 3. Variation of Duty Cycle for TV Band 3

TABLE IV
DUTY CYCLE FOR LOCATIONS 1-9

Locations	**Location Type**	**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)**	**Mean (%)**	**Mean Average (%)**
Loc 1	Rural	0	0	0	0	0	2.58
Loc 2	Rural	2.11	4.72	0.48	0.03	1.83	
Loc 3	Rural	0.24	5.49	14.91	0	5.16	
Loc 4	Rural	0	0	0	0	0	
Loc 5	Rural	0.92	2.45	20.26	0	5.91	
Loc 6	Urban	5.37	6.01	29.36	15.14	13.97	12.02
Loc 7	Urban	2.61	0.82	13.59	0.134	4.29	
Loc 8	Urban	6.42	11.49	37.27	6.42	15.4	
Loc 9	Urban	7.23	10.84	33.21	6.38	14.41	

Figures 2-4 show the temporal variation of duty cycle for TV bands 2, 3 and 4 for location 6. Short term temporal variation of duty cycle is the hourly variation of the occupancy. The occupancy of the channels for every hour of the day was measured for the period of 24 hours in LOC 6. The mean of the hourly occupancy is calculated in order to establish which channels' occupancy stays constant or steady and which of the channel have a more unpredictable occupancy (regarded by higher deviation from the mean occupancy from a statistical viewpoint). The average duty cycle for each measured frequency point was computed at 1 hour periods through 24 hours, thus obtaining the time variation of the duty cycle for different frequencies. In Fig 3, at around 0-4 (hrs), the duty cycle was very low, close to zero. The duty cycle however increase with time and drops at around 24 hrs. These sudden drops were as the result of OFF periods for NTA transmitter which operates on channel 5, 203.25 MHz. NTA's transmission schedules are from 06:00 hrs to 23:59 hrs.

V. CONCLUSION

In this paper, a 24-hr outdoor measurement, on spectrum occupancy, in both rural and urban areas, of Kwara State, Nigeria, spanning across the frequency range of 48.5 MHz – 870 MHz was undertaken. Measurements obtained show that the TV bands are underutilized and, in future, it might be a very good band for the deployment of *software defined radio* SDR. Similarly further experiment will be conducted in various geopolitical zones in Nigeria to ascertain the level of spectrum occupancy at this frequency range.

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