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Duty Cycle Analysis of Radio Spectrum Profile Utilization for Cellular Bands

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Abstract

The high increase in the growth of wireless devices with the present static radio spectrum management has created an inadequacy in the available radio spectrum and presently the spectrum regulatory bodies are of the view that static spectrum management approach giving right of way to use licensed is still efficient. In this paper spectrum occupancy of GSM 900 MHz, GSM 1800 MHz and 3G are investigated. The measurement is done with Advantest U3741 spectrum analyzer with the frequency range of 9 kHz to 3 GHz using energy detection method and selecting a 10 dBm noise floor value as proposed by the International Telecommunication Union (ITU). The study reveals a duty cycle of 35.31%, 9.59% and 28.08 for GSM 900 MHz, 1800 MHz and 3G respectively. The results show that the spectrum is highly underutilized.

1. Introduction

Wireless technology offers more flexible and inexpensive ways of communication and with four key comparative advantages over the wired technology – increased efficiency, high availability, greater flexibility and mobility for users at a far better reduced cost of installation and maintenance [1]. The high increase in the growth of wireless devices with the present static radio spectrum management has created an inadequacy in the available radio spectrum [2], and presently the spectrum regulatory bodies are of the view that static spectrum management approach giving exclusive right of way to use licensed is still efficient [3]. 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 and beyond that as forecasted by Cisco visual networking index [4]. This static allocation of radio spectrum is no longer adequate to grant access to the exponential growth of the wireless device because some portions of the radio spectrum are heavily used while the others are rarely used or not used at all; thus the inadequate sharing of the radio spectrum among users can lead to the opening of unwanted denial of service event [5]. In addition, the demand for wireless coverage, capacity, connectivity and services will continually expand and a critical barrier is the scarcity of the radio spectrum because it is fixed and cannot be expanded.

In view of this spectrum constraint, an obvious question is how efficient is the current use of the radio spectrum? Quantitatively, spectral efficiency is measure in bits per second per Hertz (bps/Hz) which is the amount of data transmitted per unit bandwidth, although this efficiency has steadily increased due to technical improvement [6, 7] but the growth rate has being declined [8], so due to this congestion, improving the state of spectral efficiency by other means is necessary for the growth of wireless networks. In addition, current spectrum management also has another serious operational problem as several licensed bands are not efficiently utilized with utilization varying abysmally over frequency, space and time and it was discovered through actual spectral occupancy measurements that vast portions of the licensed radio spectrum are randomly or rarely used by the licensed users [9 – 17].

One of the approach to solve the challenges of static spectrum management is the use of cognitive radio technology, which has undergone extensive research for almost two decades [18] and based on the principle of Dynamic Spectrum Access (DSA) technique [19]; performing key functions – spectrum sensing, spectrum management and decision, spectrum sharing and spectrum mobility [19]. In the concept of Cognitive Radio (CR), licensed spectrum users are called Primary Users (PUs) and unlicensed Users are called Secondary Users (SUs). This SUs will access the spectrum when the interference on the PU receivers is low or below a prescribed level [20]. Figure 1 is showing the combination of a primary network and CR network. CR network can be divided into – interwave, underlay and overlay networks [16], [21 – 25].

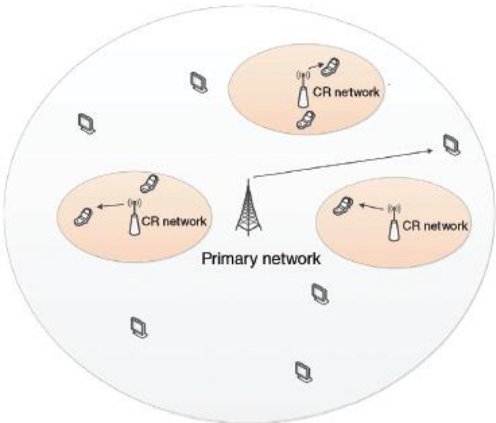

Figure 1: Cognitive Radio (CR) networks existing within a primary network

The rest of the paper is organized as follows: In Section II, relevant concept into the research is presented in few. The details on the field measurements conducted to evaluate the spectrum occupancy in the study area are presented in Section III. The results obtained in Section III were analyzed and discussed in Section IV. Section V, which is the last section, concludes the paper.

2. Related Concept

Several studies have been conducted to analyzed the licensed radio spectrum to evaluate the degree of spectrum usage allocation in many countries such as US, New Zealand, Germany, Singapore, China, Spain, Qatar, Vietnam, and India in order to evaluate and select suitable spectrum bands for the application of cognitive radio [26 - 37].

A research survey conducted by the Federal Communications Commission shows that the usage of allocated radio spectrum varied from 15% to 85% in the United State of America (USA) [38], stating that 22% allocated radio spectrum is utilized in urban area and as low as 3% in rural areas [38]. Islam *et al.* [30], performed a survey on radio spectrum occupancy measurement in Singapore, the goal was to analyzed the radio spectrum of the bands of diverse services and discover the less active bands that can be used for cognitive radio technology and some other future usage. The spectrum measurement result shows that the average utilization of the spectrum was 4.54% in Singapore.

In addition, in South Africa, the spectrum occupancy measurements conducted in the Hatfield area of Pretoria for ultra-high frequency (UHF) band, global system for mobile communications (GSM) 900 MHz and GSM 1800 MHz bands by [39] show variations in usage of the three spectrum bands. The UHF band shows an approximately occupancy of 20% and those of GSM 900 MHz and GSM 1800 MHz bands are at approximately 92% and 40% respectively [41]. Similar study carried out in Kampala, Uganda capital using GSM900, GSM1800, the universal mobile telecommunications system 2100 (UMTS2100) and long term evolution 2600 (LTE2600) radio spectrum bands showing variations in the frequency bands under consideration. The study reported average occupancy rates of 8.8% and 52.4% for both the uplink and downlink respectively in GSM900 band, 0.6% and 13.6% occupancy rates for GSM1800 band in the uplink and downlink respectively, 0.56% and 48.7% respectively for the UMTS2100 band and 0% and 0.6% respectively obtained for the LTE2600 band [40].

In [34] a spectrum survey was carried out in two different countries three locations, France with two locations and the other location Czech Republic with the set aim of correlating the measurements evaluation of the two countries in terms of their similarities and physical as relative to future radio spectrum management. The measurement campaign reveals that the spectrum utilization from 400MHz-3GHz in location 1, 2 and 3 are 6.5%, 10.7% & 7.7% respectively. Also, Jayavalan *et al.* [41], conducted measurements and analyses on the utilization of frequency spectrum in the cellular and TV bands in Malaysia. The purpose is to quantitatively explore the usage of the radio spectrum and look into the possibility of other wireless communication systems or cognitive radio to utilize and access the unused bands. The result analysis indicated that GSM 900 has an average duty cycle of 35 %, GSM 1800 10% and 3G, 26%.

In [42] 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 performed The measurement shows the spectrum usage for each location has thus: for Guangzhou Trade Center and 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. More also, Chiang *et al*. [28] studied the profile usage of radio spectrum in New Zealand revealing that the average duty cycle of 6.21% and 5.72% utilization of spectrum, in the band, in an outdoor and indoor location respectively.

Similarly, in Nigeria, Adeseko et al. [43] conducted spectrum occupancy measurement and analysis in the 2.4 2.7 GHz Band in urban and rural environments; the measurement was conducted in Kwara State and the result obtained showed that the band is underutilized with an average duty cycle of 10.79% in urban area. In [44] an insight into spectrum occupancy was conducted at Gwarinpa District in Abuja. The report showed that the variation of usage of licensed spectrum in Abuja, the Nigeria Federal Capital Territory, ranges from 17% to 26% at 700 – 2400 MHz frequency band. Also, in another study on spectrum occupancy measurements in Nigeria [45], which were carried out in Abuja and Katsina depicted variations in spectrum usage in the selected measurement locations with occupancies variations from 0.45% to 26%.

3. Methodology

Measurements were conducted in the Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria. The spectrum occupancy measurement set up as shown in Figure 2 is made up of Advantest U3741 spectrum analyzer with the frequency range of 9 kHz to 3

GHz, a personal computer (PC) connected to the spectrum analyzer with a general purpose interface bus (GPIB), LabView software installed on the PC to control the spectrum analyzer for data capturing purpose; the set up were kept indoor to prevent damage from rain. A coaxial cable is laid out through a window to connect the antenna and the spectrum analyzer.

Figure 2: Measurement set up

Energy detection method is employed in this study. It compares the received signal energy in a certain frequency band to a predefined threshold. The decision threshold as recommendation in ITU spectrum monitoring handbook is 10 dB above the average noise floor [46]. However, the noise floor varies for different frequency range. The measurement was conducted for 24 hours and the received signal power collected by the spectrum analyzer in dBm is of the form

$$Y_{i,j} = \begin{bmatrix} P(t_i f_j) & \cdots & P(t_i f_m) \\ \vdots & \ddots & \vdots \\ P(t_n f_j) & \cdots & P(t_n f_m) \end{bmatrix} \quad (1)$$

Where $t_i = t_i, t_2, \ldots\ t_n$that denotes time slot and $f_j = f_1, f_2, \ldots\ f_m$ that also demotes the frequency being measured.

The duty cycle is the percentage ratio of the time a frequency band is occupied to the total time period at which the band is being occupied

$$Duty\ Cycle = \frac{Frequency\ band\ occupancy\ time}{Total\ time\ taken}\ x\ 100 \quad (2)$$

Table 1 shows the summary of the frequency range under consideration for the research work.

Table 1: Frequency Band

Services Allocation	Frequency Range MHz	Bandwidth MHz
GSM 900	880 – 960	35
GSM 1800	1710 – 1880	75
3G IMT-2000	1885 – 2200	315

4. Results and Discussion

Figure 3 shows the measurement result for spectrum occupancy in GSM 900 MHz band, the figure is divided into three section; the top most part is the Power Spectral Density (PSD) follows by the spectrum occupacy period and the last is the duty cycle. The average noise level was calculated was found to be -92.8 dBm and adding the decision threshold of 10 dBm to give -82.8 dBm corresponding to a average duty cycle of 35.31%. when compare with the study conducted by the author of [40] in Uganda with average duty cycle of 52.4% shows that this band has the highest unlization level.

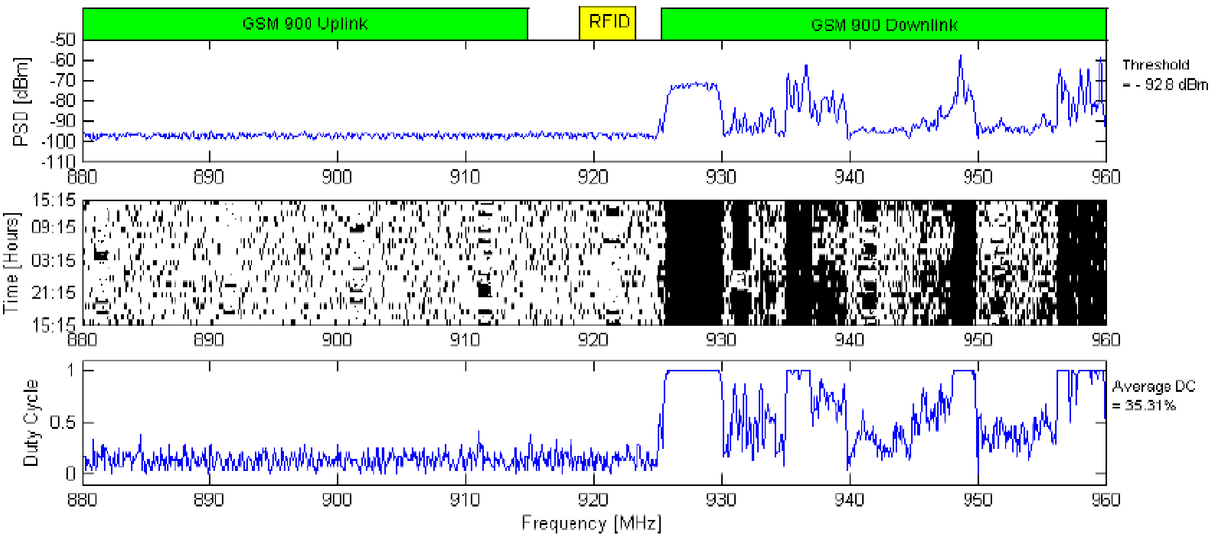

Figure 3: Spectrum Analysis for GSM 900 MHz Based on 24 Hours Measurement

Figure 4 shows the 3D plot measurement for GSM 900 MHz, it is observed that the occupancy between the uplink and downlink is not utilized in the same manner. The downlink seems to be fully occupied compared to uplink in the frequency of 880 to 915 MHz which is sparsely or rarely occupied partly due to broadcasting of control channels by the base stations on the downlink with relatively high transmitting power.

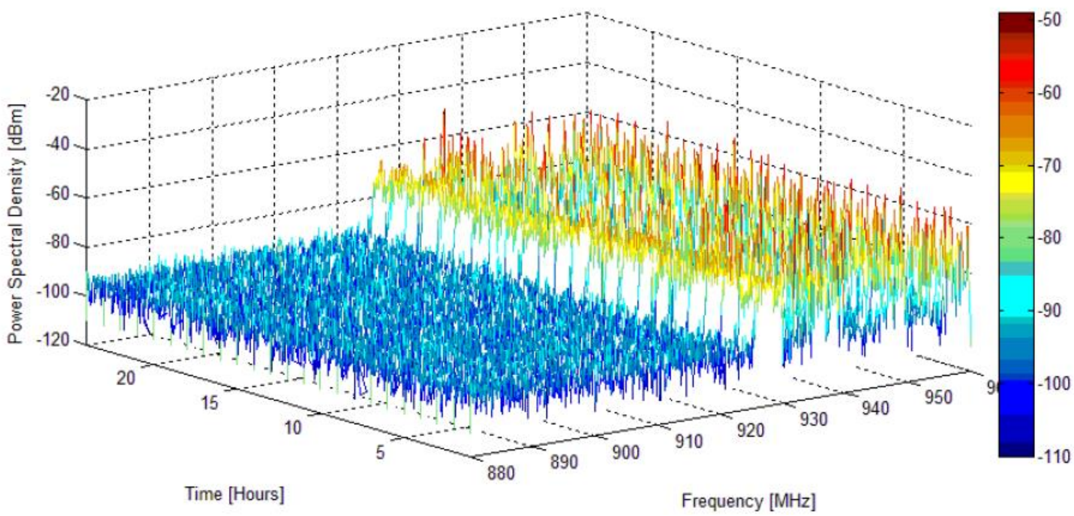

Figure 4: 3D plot of Spectrum Analysis for GSM 900 MHz

Figure 5 shows the spectrum of occupancy of GSM 1800 with average duty cycle of 9.59% and a threshold of -90.7 dBm in terms of power spectral density which is also in the region of research conducted in [3] producing value such as -80.27 dBm, -84.63 dBm and -86.99 dBm although there is a devaition because the research were conducted in cities (Ado-Ekiti, Akure and Ikeja). Figure 6 represent the spectrum occupancy of 3G band with a duty cycle of 28.08%. The reason for very low utilization in the UMTS TDD and the FDD UL band is due to the measurement method employed. The energy detection method cannot efficiently detect the presence of wideband signals such as UMTS; to detect noise-like wideband signals, more advanced methods have to be employed (e.g. feature detection) [34] but the FDD (Frequency Division Duplex) uplink and downlink shows similiar characteristic to that of the GSM 900 downlink and uplink in which the downlink is occupied and the uplink is rarely occupied; although different modulation scheme is empoyed. Table 2 shows the summary of the average duty cycle of each frequency band at the measurement location.

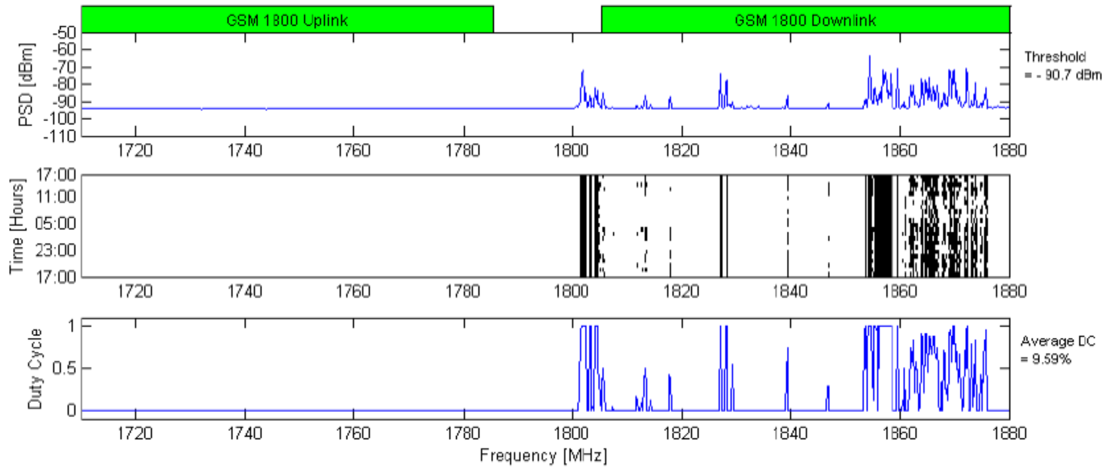

Figure 5: Spectrum Analysis for GSM 1800 MHz Based on 24 Hours Measurement

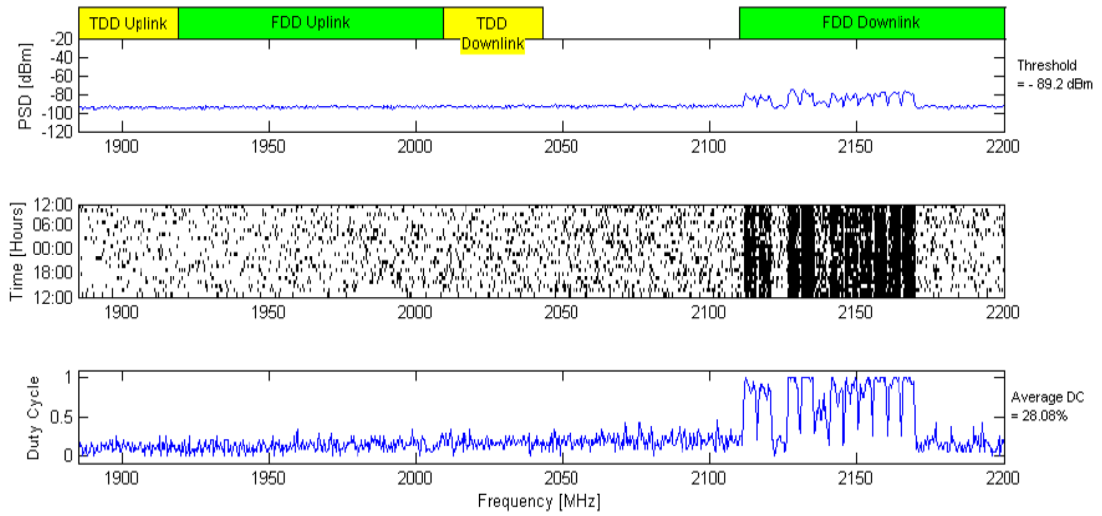

Figure 6: Spectrum Analysis for 3G GSM Band Based on 24 Hours Measurement

Table 2: Duty cycle of the selected bands

Services Allocation	Frequency Range MHz	Bandwidth MHz	Duty cycle (%)
GSM 900	880 – 960	35	35.31
GSM 1800	1710 – 1880	75	9.59
3G IMT-2000	1885 – 2200	315	28.08

5. Conclusion

Duty cycle is showing the usage of the radio spectrum in each lisenced band of the radio spectrum, thus this research work investigate the available hole on the mobile radio spectrum for the incorporation of cognitive radio into the existing network to be able to effectively and efficiently use the allocated spectrum. Although it has already been established that static allocation of spectrum is not efficient and several studies has shown this; so this measurement is also done to further established this concept and therefore the need for the usage of cognitive radio technology.

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