Spectrum Occupancy Survey in Leicester, UK, For Cognitive Radio Application

Sunday Iliya, Eric Goodyer, John Gow, Mario Gongora and Jethro Shell

Abstract— Cognitive radio (CR) technology has emerged as a promising solution to many wireless communication problems including spectrum scarcity and underutilization. Knowing the current state of spectrum utilization in frequency, time and spatial domain will enhance the implementation of CR network. In this paper, we evaluate the spectrum utilization of some selected bands in Leicester city, UK; based on long time spectrum measurements using energy detection method. This study provides evidence of gross underutilization of some licenses spectrum which can be exploited by CR for efficient spectrum utilization.

Index Terms— Cognitive Radio, Primary User, RF Power, Duty Cycle, White Space, Spectrum.

1 Introduction

DUE to the current static spectrum allocation policy, most of the licensed radio spectrum are not maximally utilized and often free (idle) while the unlicensed spectrum are overcrowded. Hence, the current spectrum scarcity is the direct consequence of static spectrum allocation policy and not the fundamental lack of spectrum. The first bands to be approved for CR communication by the US Federal Communication Commission (FCC) because of their gross underutilization in time, frequency and spatial domain are the very high frequency and ultra-high frequency (VHF/UHF) TV bands [1],[2],[3]. In this paper, we focused on the study of real world RF power distribution in some selected channels (50 - 860 MHz, 868 - 960 MHz, 1.7 - 1.88 GHz and 2.4 - 2.5 GHz) within the VHF/UHF TV bands, FM band, ISM 868 MHz band, GSM 900 band, GSM 1800 band, and ISM 2.4 GHz band. The problem of spectrum scarcity and underutilization can be minimized by adopting a new paradigm of wireless communication scheme. Advanced Cognitive Radio (CR) network or Adaptive Spectrum Sharing (ASS) is one of the ways to optimize our wireless communications technologies for high data rates in a dynamic environment while maintaining user desired quality of service (QoS) requirements. CR is a radio equipped with the capability of awareness, perception, adaptation and learning of its radio frequency (RF) environment [4]. CR is an intelligent radio where many of the digital signal processing that were traditionally done in static hardware are implemented via software. CR has the followings basic features: observation, adaptability and intelligence. CR is the key enabling tool for dynamic spectrum access and a promising solution for the present problem of spectrum scarcity and underutilization. Cognitive radio network is made up of two users i.e. the license owners called the primary users (PU) who are the incumbent legitimate owners of the spectrum and the cognitive radio commonly referred to as the secondary users (SU) who intelligently and opportunistically access the unused licensed spectrum based on some agreed conditions. CR access to licensed spectrum is subject to two constrains i.e. on no interference base, this implies that CR can use the licensed spectrum only when the licensed owners are not using the channel (the overlay). The second constrain is on the transmitted power, in this case, SU can coexist with the PU as long as the interference to the PU is below a given threshold which will not be harmful to the PU nor degrade the QoS requirements of the PU (the underlay CR network scheme) [5],[1]. There are four major steps involved in cognitive radio network, these are: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility [6],[7].

In spectrum sensing, the CR senses the PU

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spectrum using either energy detector, cyclostationary features detector, cooperative sensing, match filter detector, eigenvalue detector, etc to sense the occupancy status of the PU. Based on the sensing results, the CR will take a decision using a binary classifier to classify the PU channels (spectrum) as either busy or idle there by identifying the white spaces (spectrum holes or idle channels). Spectrum sharing deals with efficient allocation of the available white spaces to the CR (SU) within a given geographical location at a given period of time while spectrum mobility is the ability of the CR to vacate the channels when the PU reclaimed ownership of the channel and search for another spectrum hole to communicate. During the withdrawal or search period, the CR should maintain seamless communication. Many wireless broadband devices ranging from simple communication to complex systems automation are deployed daily with increasing demand for more, this calls for optimum utilization of the limited spectrum resources via CR paradigm. Future wireless communication device should be enhanced with cognitive capability for optimum spectrum utilization.

To facilitate the implementation of CR network, there is need for accurate knowledge of current spectrum utilization, hence in this study we conducted spectrum occupancy survey which aim at detecting underutilized bands that can serve as potential candidate bands to be exploited by cognitive radios (CR).

1.1 Contribution of this paper

We investigate the spectrum occupancy or utilization of some communication bands in Leicester UK, ranging from 50MHz to 860MHz consisting of radio and TV broadcasting channels; and 868MHz to 2.5GHz with emphases on ISM 868 band, GSM900 and GSM1800 bands and ISM 2.4GHz band, some bands within these ranges where also considered. The success of CR network is largely dependent on the overall world knowledge of spectrum utilization in time, frequency and spatial domain, thus this study will add to the existing spectrum survey campaigns conducted in other part of the world in order to facilitate the implementation of CR network. To the best of our knowledge this is the first spectrum survey conducted in Leicester city, UK using real world RF data.This paper built on the experiment conducted in our work presented in [8],[9].

The rest of this paper is consist of the following sections. Experimental details are discussed in Section 2 while the spectrum occupancy and utilization estimate are presented in Section 3. The paper is concluded with Section 4, which discusses the results of the experiments and Section 5 gives the summary of the findings and future work.

2. Experimental Setting for RF Power Measurement

The datasets used in this study were obtained by capturing real world RF signals using universal software radio peripheral 1 (USRP 1) for a period of two months. The USRP are computer hosted software-defined radios with one motherboard and interchangeable daughter board modules for various ranges of frequencies. The daughter board modules serve as the RF front end. Two daughter boards, SBX and Tuner 4937 DI5 3X7901, having continuous frequency ranges of 400MHz to 4.4GHz and 50 MHz to 860 MHz respectively, were used in this research. The daughterboard perform analog operations such as up/down-conversion, filtering, and other signal conditioning while the motherboard perform the functions of clock generation and synchronization, analog to digital conversion (ADC), digital to analog conversion (DAC), host processor interface, and power control. It also decimates the signal to a lower sampling rate that can easily be transmitted to the host computer through a high-speed USB cable where the signal is processed by software. This study is focused on the following frequencies: 50 - 860 MHz, 868 - 960 MHz, 1.7 - 1.88 GHz and 2.4 - 2.5 GHz bands. The TV channels bandwidth is 8 MHz while GSM 900, GSM 1800, and FM bands has a channel bandwidth of 200 KHz and ISM 868 have the least channels bandwidth of 25 KHz. We divided the spectrum into subchannels called resource block, each consisting of 300 KHz bandwidth. To ensure that no spectral information is lost, we used a sample frequency of 1MHz and obtained 512 samples for each sample time. This gives a very high frequency resolution of 1.172 KHz since for every 300 KHz resource block, there are 256 frequency bins. Frequency resolution of 1.172 KHz is very adequate to capture all the carriers spectral information within the band with the least channels bandwidth (25 KHz) considered in this study.

Without loss of generality, to capture the RF signal in a given band, the capturing was constrained within one resource block at a time using a channel filter; this gives a high frequency resolution at lower sampling rate that can easily be processed by the host computer. But the higher the frequency resolution, the lower the temporal (time) resolution. The power was obtained using both the time and frequency domain data. For the frequency domain, after passing the signal through the channel filter, the signal was windowed using hamming window in order to reduce spectral leakage. The stream of the data was converted to a vector and decimated to a lower sampling rate that can easily be processed by the host computer at run time. This is then converted to the frequency domain and the magnitudes of the bins were passed to a probe sink. The choice of probe sink is essential because it can only hold the current data and does not increase thereby preventing stack overflow or a segmentation fault. This allows Python to grab the data at run time for further analysis. The interval of time between consecutive sample data was selected at a random value between 5 seconds and 30 seconds. The choice of this range is based on the assumption that for any TV programme, FM broadcast or GSM calls, will last for not less than 5 to 30 seconds. In order to capture all possible trends, the time between consecutive sample data is selected at random within the given range instead of using regular intervals. The experimental setting is as shown in Fig. 1. The RF powers of some of the bands captured during this survey are presented in Fig. 2, 3 and 4. The experiment was conducted indoor in Centre for Computational Intelligence, De Montfort University, Gateway House, Leicester, United Kingdom (GPS location: latitude 52.629472^{0}N, longitude 1.138028^{0}W). The capturing of the data and the signal processing were implemented using gnu-radio which is a combination of Python and C++.

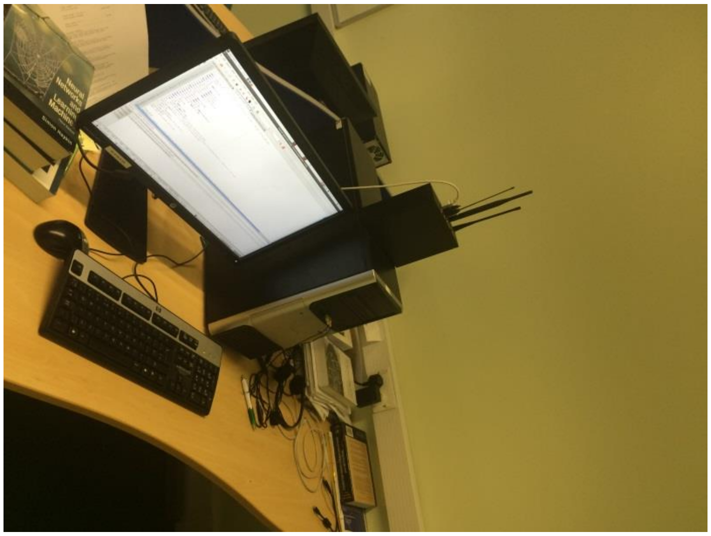

Fig. 1: Experimental setting

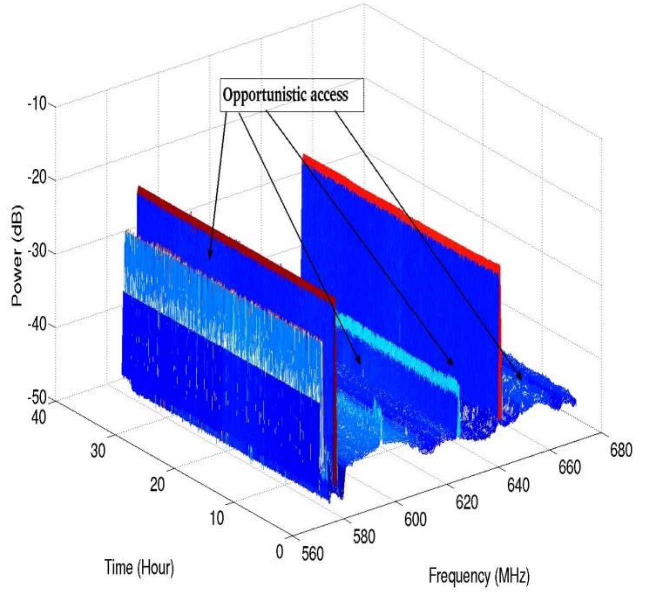

Fig. 2: TV band 570-670MHz spectrum

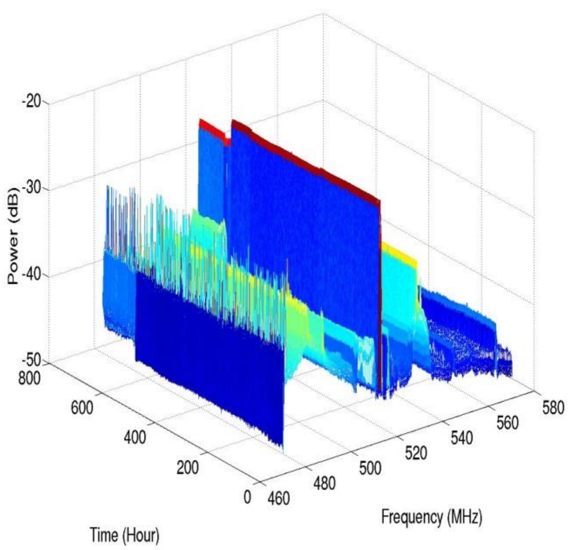

Fig. 3: TV band 470-570MHz spectrum

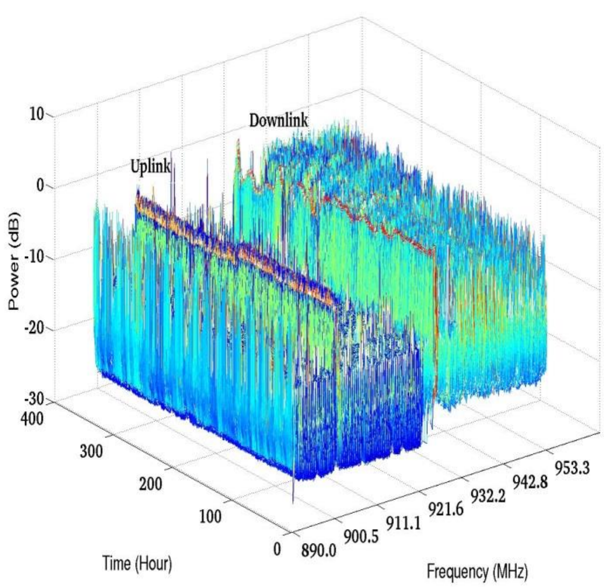

Fig. 4: GSM 900 band

3. Spectrum Occupancy and Utilization Estimate

One of the core operations of CR is spectrum sensing, in which the CR senses the PU occupancy status (RF activity). Based on the sensing results the channel is classified using a binary classifier as busy or idle. There are many detection methods that have been proposed, among these are: the energy detector, cyclostationary features detector, cooperative sensing, match filter detector, eigenvalue detector, wavelet transform based estimation and Multitaper spectrum estimation [10]. Of all the proposed methods, the energy detector is the only one that does not require any a priory knowledge of the PU signal, hence it is the method used in this study. The major challenge of energy detection is the correct choice of threshold such that if the energy is above the threshold the channel is considered busy otherwise it is idle (vacant). If the threshold is too low, there will be high probability of false alarm (false positive) i.e. declaring a channel to be busy while it is idle (free). This is safe to the PU but is a waste of communication opportunity to the SU (CR) leading to low spectrum utilization. On the other hand, if the threshold is too high, weak PU signal will not be detected resulting to high probability of miss detection (false negative) i.e. declaring a channel to be idle while it is busy. This implies high interference to the PU and lost of communication or (data) to the CR. Although the optimum choice of threshold is a current active research area, there exists an empirical method recommended by International Telecommunication Union (ITU), [11]. The ITU recommended that the threshold should be 10dB above the ambient noise. It has been proved experimental that a threshold of 10dB above the ambient noise will yield a very low probability of false alarm of about 0.0005% in must cases, [12]. The ambient noise is not flat even for the same band; it changes with frequency, time and geographical location. Based on this empirical recommendation, the optimum choice of the threshold hold depends on the relative cost of false alarm and misses detection. In order to increase the accuracy of the spectrum occupancy estimate; instead of setting a constant threshold over an entire band as adopted in [13], [14], [15], each frequency resource block (300 KHz) has its own threshold. The ambient noise floors are obtained by replacing the antenna with 50Ω smart antenna terminator as recommended by ITU and the average ambient noise for each resource block captured within a period of 12 hours were used as the noise floors. In this way the threshold T(f) varies with frequency as the noise floor ϱ(f) is frequency dependent. To ensure that the threshold meet up with the standard criteria set by ITU, we set the margin M(f) at constant value of 10dB taken into cognition the gain introduced in the codes that run the USRP. The threshold is giving by (1)

$$\mathrm{T(f)} = \varrho(\mathrm{f}) + \mathrm{M(f)} \tag{1}$$

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Where T(f) is the threshold of a frequency resource block f, ϱ(f) is the average ambient noise power of the given resource block f while M(f) is a constant margin whose values depend on the desired probability of false alarm.

To quantify the channel or spectrum occupancy (utilization), we compute the duty cycle of each channel or resource block. The duty cycle is defined as the percentage of time the channel is busy. If the i-th power measurement at frequency f is $P_i(f)$ and the threshold is T(f) the instantaneous spectrum occupancy rate $B_i(f)$ for frequency f at the i-th measurement is given by (2).

$$B_i(f) = \begin{cases} 1 & if\ P_i(f) > \mathrm{T(f)} \\ 0 & Otherwise \end{cases} \quad (2)$$

Where i is time index, 1 and 0 are binary status for busy and idle (vacant) respectively. For this spectrum occupancy campaign, the threshold T(f) is the threshold of resource block f. The channel or resource block duty cycle is the average of the instantaneous occupancy rate of the channel over the entire period of measurement as depicted by (3).

$$\psi(f) = \frac{\sum_{i=1}^{n} B_i(f)}{n} \quad (3)$$

Where ψ(f) is the duty cycle of channel or resource block f while n is the total number of time slots the channel is sampled or observed. The duty cycle of the band spectrum is the average of the duty cycles of the channels or resource blocks within the band as given by (4). This gives the estimate of the spectrum occupancy (utilization) of the band. From the aforementioned, the maximum attainable duty cycle is 1, thus the product of the duty cycle of a band and the frequency range of the band (bandwidth) gives the estimate of utilization level of the band in Hz. The lager the value of the duty cycle of a band, the higher the occupancy or utilization level of the band.

$$\Phi(b) = \frac{\sum_{i=1}^{N} \psi_i(f)}{N} \quad (4)$$

Where Φ(b) is the duty cycle of band b and N is the total number of channels or resource blocks whose power measurements were taken in the band.

4. Results

From the spectrum occupancy survey results presented in table 1 and Fig. 5 to 10, it is obvious that based on the International Telecommunication Union (ITU) recommended standard, some bands are grossly underutilized. Table 1 gives the duty cycle of the bands examined in this study while Fig. 5 to 10 depicts the utilization level (occupancy estimate) of each of the channels within the bands. Band 50 to 110 MHz assigned to fixed/land mobile, amateur, aeronautical radio navigation, radio astronomy, broadcast, and FM services has a duty cycle of 3.38%. Only one channel (107.5MHz) within the FM band is utilized apart from possible low power devices operating within the band as shown in Fig. 5. The band assigned to meteorological satellite, mobile satellite, space research, aeronautical mobile, land mobile, maritime mobile, Astronomical mobile, Broadcasting, Radio location, Space operation, radio astronomy and meteorological aids ranging from 110 to 470 MHz was divided into two bands 110 - 250 MHz and 250 - 470 MHz, each of these two bands was found to have an estimated duty cycle of 4.29% and 3.46% respectively. Thus from 50-470 MHz, the average duty cycle is 3.71%, i.e. the averaged occupancy is 15.582 MHz of the 420 MHz bandwidth. The TV band 470-860 MHz within which there are other services such as aeronautical radio navigation, programme making and special events (PMSE) applications and mobile communication; was divided into three bands i.e. 470-600 MHz, 600-730 MHz and 730-860 MHz. Band 470-600 MHz with a duty cycle of 29.52% is much more utilized than the other two TV bands, Fig. 6. Band 600-730 MHz is grossly underutilized with an estimated duty cycle of 2.55% while that of band 730-860 MHz is 15.02% as shown in Fig. 7 and 8 respectively. The average occupancy estimate of band 470 - 860 MHz is 15.70% which is equivalent to 61.23 MHz of the total bandwidth 390 MHz. GSM 1800 band appear to be much more utilized than GSM 900 band as shown in Fig. 10 and 9. GSM 1800 band has the highest duty cycle of 43.39% followed by GSM 900 band with 31.38%. The duty cycle of GSM 900 and GSM 1800 bands shown in subplot 3 of Fig. 9 and 10 exhibit a different trend with no frequency resource block having a duty cycle of zero, contrary to those of Fig. 5 to 8 where there are many frequency resource blocks (spectrum) with zero duty cycle for the whole period of measurements (observations). Within our location of study, the ISM 2.4 GHz band has higher spectrum occupancy with a duty cycle of 18.55% than ISM 868 MHz which has a duty cycle of 14.71%. This survey confirmed the fact that the current spectrum scarcity is not the fundamental lack of spectrum, rather is the direct consequence of static spectrum allocation policy.

Table 1: Summary of Spectrum Occupancy

Band (MHz)	Services	Average Duty Cycle %	Average Occupied Spectrum (MHz)
50-110	Fixed/Land mobile, Amateur,Aeronautical radio navigation Radio astronomy, broadcast, FM	3.38	2.028
110-250	Meteorological satellite, Mobile satellite, space research Aeronautical mobile, Land mobile, Maritime mobile Astronomical mobile, Broadcasting, Radio location	4.29	5.577
250-470	Mobile satellite, Space operation, radio astronomy, Aeronautical radio navigation, Meteorological aids/Satellite	3.46	7.958
470-600	Broadcasting, TV band IV, Aeronautical radio navigation	29.52	38.37
600-730	TV Broadcast band V, Some PMSE	2.55	3.315
730-860	TV Broadcasting, PMSE, Mobile	15.02	19.526
868-890	IMS 868	14.71	3.236
890-960	GSM 900 band	31.38	21.966
1700-1880	GSM 1800 band	43.39	78.102
2400-2500	ISM 2.4GHz band	18.55	18.55

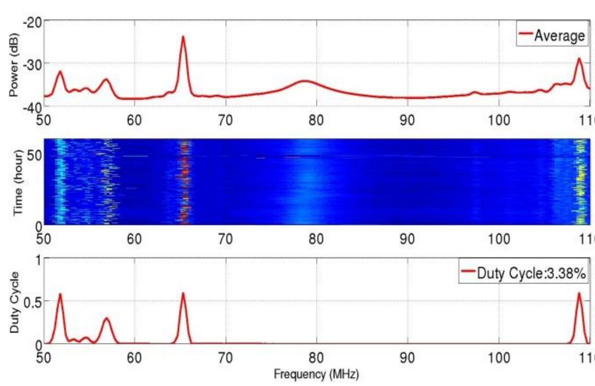

Fig. 5: Duty cycle and spectrogram of 50 to 110 MHz band

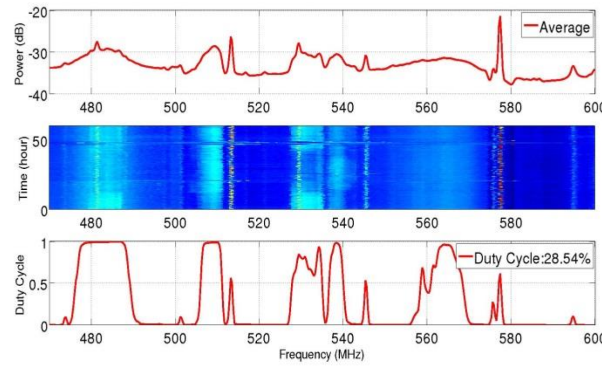

Fig. 6: Duty cycle and spectrogram of TV band 470 to 600 MHz

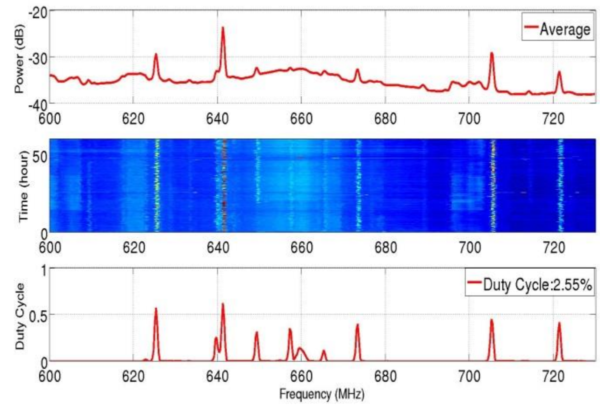

Fig. 7: Duty cycle and spectrogram of TV band 600 to 730 MHz

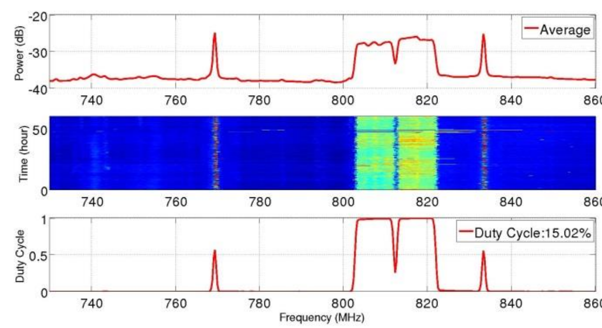

Fig. 8: Duty cycle and spectrogram of TV band 730 to 860 MHz

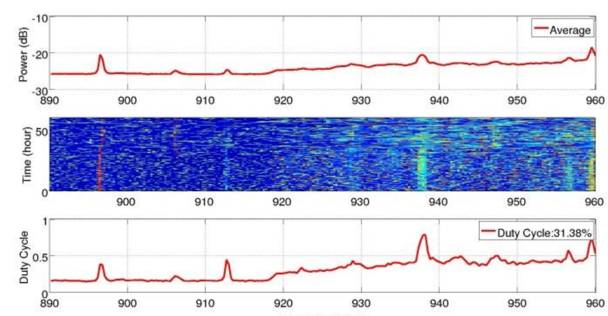

Fig. 9: Duty cycle and spectrogram of GSM 900 band

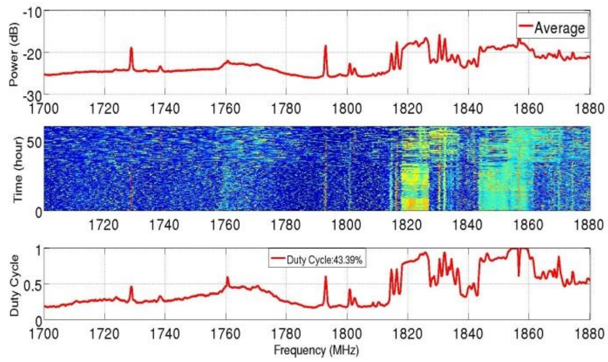

Fig. 10: Duty cycle and spectrogram of GSM 1800 band

5. Conclusion

Spectrum occupancy survey presented in this paper aimed at detecting underutilized bands that can serve as potential candidate bands to be exploited by cognitive radios (CR). This paper demonstrates that bands 50 - 470 MHz is grossly underutilize with an average occupancy of 3.71%. The duty cycle of band 470 - 860 MHz is 15.70%. GSM 900 and GSM 1800 bands are heavily utilized as compared with other bands examined in this paper. Based on the findings of our studied location, bands 50 - 860 MHz are potential candidate bands for CR application. Feature work will involve measurements conducted simultaneously in more than one geographical location at different heights within the same period of time. This will help in providing a wider view of spectrum occupancy estimate that can facilitate cognitive radio network implementation.

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