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Effects of Detection Threshold and Frame Size on Duty Cycle in GSM Bands

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Abstract—Explosion in the demand for mobile applications and services necessitates the efficient utilization of the limited radio spectrum. Determination of a suitable detection threshold is an important aspect of spectrum occupancy measurement. Inappropriate choice of the threshold value may either increase the probability of false alarm or failure detection. However, the most appropriate threshold value is not yet clearly stated, though, the International Telecommunication Union (ITU) has provided a benchmark of 10 dB above the noise level as an acceptable threshold value. In this paper, the effects of energy detection threshold techniques on duty cycle in the GSM bands are examined. Spectrum measurements were conducted in the GSM 900 and 1800 MHz bands in Ilorin, Nigeria to cover a bandwidth of 105 MHz. Experimental results based on analytical method of determining noise level (theoretical) and those obtained based on actual measurements of the noise floor (measured) were analyzed. Findings indicated that the MaxNoise overestimates the occupancy values across all bands while the ITU 10 dB was found to be too conservative. Therefore, for optimum prediction, 5 dB above the *measured average noise level* should be considered as detection threshold. Furthermore, it was found that the number of frames of the sensing data do not have significant effect on the duty cycle.

Keywords—threshold, duty cycle, spectrum occupancy, GSM

I. INTRODUCTION

Spectrum sensing is an essential technique that facilitates unused spectrum detection in Cognitive Radios (CRs) [1]. The CR is a network technology that improves radio operating behavior as a result of automatic detection of available channels in a wireless spectrum and alteration of transmission parameters [2]. It is globally observed that CR is now the goal interest to technologists and researchers due to the continuous rise in Channel Occupation Rate (COR). This is as a result of geometric rapid growth in the use of many electronic devices

choosing wireless channel as the transmission medium and executing multimedia applications for communication, thus, necessitating the need for more spectrum resources. Allocated spectrum band congestion has been traced to speedy development in the choice of wireless channel, eventually leading to user discontentment [3]. In an effort to predict the spectrum usage, many spectrum surveys have been conducted globally and the energy detection technique is used to make decision on the spectrum usage. Energy detection algorithms are developed to detect signals whose energy levels are above a pre-determined minimum energy level based on the noise floor [4]. This was found to be the most suitable method due to its simplicity. The determination of a suitable detection threshold is an integral aspect of spectrum occupancy measurement methodology as inappropriate choice of the threshold value may either increase the probability of false alarm or failure detection. However, the universally accepted threshold value is not yet known. Though, the International Telecommunication Union (ITU) has provided a global benchmark of 10 dB above the noise level as an acceptable threshold value. Many authors adopted 3 dB [5] and 5 dB [6] above the noise level. Also, the choice of noise level computation varies from theoretical (analytical approach) and experimental (empirical approach), which may be considered most appropriate as the noise level vary with not only across frequency bands, but also with the locations.

This study seeks to understand the effects of energy detection threshold and sensing frame size on duty cycle in the GSM bands. This work also provides a more wide-ranging and painstaking spectrum measurement in specific locations, covering the GSM 900 MHz and 1800 MHz frequency bands. Studies that are related to this work are reviewed in Section 2 while the methodology for the spectrum measurement is provided in Section 3. Furthermore, the major findings of this

study are interpreted and discussed in Section 4. Finally, valid conclusions are drawn based on these findings and recommendations for future work are proposed in Section 5.

II. REVIEW OF RELATED WORKS

There are several studies and approaches in the literature that measure the average spectrum occupancy. For example, Kevin et al. [4] conducted a survey in Australia to investigate the performances of some energy detection techniques as it relates to the duty cycle of the intended user of the spectrum. Regardless of the detection method, duty cycle reduction appeared to degrade the detection ability. Lehtomaki et al. [7], proposed an algorithm that computes channel occupancy rate. The study theoretically analyzed the possibilities of false detection and correct detection. Similarly, Babalola et al. [8, 9] conducted extensive field campaign to detect spectrum occupancy in television and code division multiple access bands. Also, the authors examined the changes that occur in duty cycle within a short period of time in Very High Frequency band and Ultra-High Frequency band. Ayeni et al. [10] also used 10 dB to analyze spectrum data in the 2.4-2.7 GHz band. Generally, a threshold value of 10 dB above the noise level was used in most cases.

In [3], measurement on energy detection technique in cognitive radio system in Malaysia was conducted to find the probability of detection, P_d in particular channel. Spectrum frequency was analyzed through the random generation of Binary Phase-shift keying (BPSK) modulation signal serving as the input signal to the energy detector. P_d was obtained throughout the detection process using various samples and Signal-to-Noise Ratio (SNR) value. Faruk et al. [11] also conducted spectrum survey within the 50 MHz–6 GHz bands in Nigeria. In the work, the energy detection method can be easily modified for new cases. It was found that the choice of energy detection threshold would invariably have impact on the duty cycle as the threshold increases in the GSM bands.

Several signal detection approaches have also been proposed in literature. These include: Energy Detector (ED), wave-bond sensing, and cyclostationarity feature detection [4]. More methods can be found in [12].

III. METHODOLOGY

A. Measurement Campaign and Data Processing

The spectrum occupancy measurement was carried out at the University of Ilorin, Kwara State in Nigeria, within the dense urban area with the coordinate of 4°38'47"E 8°27'49"N, using a spectrum analyzer, a global positioning system, an antenna that radiates power in all directions, and a media storage

device with 32 GB capacity. The evaluation of spectrum occupancy was based on duty cycle. Table I provides the service bands considered. MATLAB was used to determine the kernel distribution, in computation of the duty cycle, 52 frames across the variant selected bands were considered.

The data acquired during the field measurement campaign were presented in matrix form. Each element of the matrix represents the signal power measured in decibel-metre $S(a_i, b_j)$. In this case, b_i is the frequency while a_i is the time slot. Three steps were involved as process to evaluate the occupancy statistics. First, the primary data collected were processed into useable input format. Secondly, the minimum detection value was set. Finally, the mean duty cycle was calculated. The resulting matrix is given by Equation (1).

$$X = \begin{pmatrix} S(a_1, b_1) & . & . & . & S(a_1, b_j) \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ S(a_i, b_1) & . & . & . & S(a_i, b_j) \end{pmatrix} \quad (1)$$

The expression in Equation (1) can be modified as given by Equation (2).

$$X = x(m) \quad (2)$$

Where $x(m)$ represents the value of the signal power at point m .

C. Energy Detection Techniques

Energy Detector (ED), among other sensing approaches, has been prioritized among the researchers globally because it is simple to implement, provided that the noise power can be ascertained. Nevertheless, the estimation of the noise power may be difficult because it may depend on the location and frequency. The ED depends on the Neyman-Pearson (NP) lemma, and this may raise the chances of detection for certain instances of incorrect detection cases. ED is based on satisfying a certain hypothesis to depict the presence of signal, $\{H_1\}$, provided that the minimum λ is lesser than the power of the detected signal. However, if the minimum λ is greater than the power of the detected signal, the signal may be considered to be a form of noise $\{H_0\}$. The mathematical expression of this case is given by Equation (3). In this case, X denotes the energy measured over k data points.

$$X = \sum_{i=m}^k |x(m)|^2 \quad (3)$$

The decision 'D' of energy detection was obtained by Equation (4) such that the result confirmed the hypotheses given by Equation (5).

$$D = \begin{cases} H_1, & \text{if } X > \lambda_j \\ H_o, & \text{if } X < \lambda_j \end{cases} \quad (4)$$

$$\begin{aligned} H_1 : X[m] &= W[m] + Z[m] && \text{Signal detected} \\ H_o : X[m] &= Z[m] && \text{Signal is not detected} \end{aligned} \quad (5)$$

$m = 1, 2 \dots M$; where M is the stated interval.

The channel is “in-use” if and only if a receiver detects the energy above a certain threshold, else, it is presumed to be unoccupied. This technique is regarded as clear channel assessment (CCA) when employed in wireless networks.

D. Determination of Detection Threshold

Although different methods were proposed in [13, 14], the PFA technique that was presented in [6] was adopted. Three different methods were put in place to set the threshold; this was due to varied algorithms used. For the measured value, average of the received signal power for each frame is measured; the threshold is set (e.g. 3 dB, 5 dB) after which is added to the average value. In the determination of theoretical value, an adopted formula in Eq. (6) was used to calculate the theoretical noise level. While using the MaxNoise technique, the maximum noise level is obtained for each frame and the average is set as threshold.

Table I. Spectrum Coverage Data.

Spectrum Band	Interval (MHz)	Bandwidth (MHz)
GSM 900 DL	925 – 960	35
GSM 1800 DL	1810–1880	70

$$N_p(\text{dBm}) = -174 + 10 \times \log(f) \quad (6)$$

Where f represents the channel bandwidth as shown in Table 1.

E. Duty Cycle Model

Equation (5) provides the hypotheses that determined the duty cycle while Equation (7) expresses the indicator function $1_D(x)$: $S(a_i, b) \rightarrow \{0, 1\}$ while the duty cycle may

$$\Omega_D(a_i, b_j) = \begin{cases} 0, & \text{if } S(a_i, b_j) < \lambda_j \\ 1, & \text{if } S(a_i, b_j) \geq \lambda_j \end{cases} \quad (7)$$

Then, the duty cycle can be obtained as:

$$\Psi_j = \frac{1}{M_t} \sum_{i=1}^{M_t} \Omega(a_i, b_j) \quad (8)$$

where Ψ_j represent the duty cycle and $\Omega(a_i, b_j)$ is a sample of power, when $S(a_i, b_j) > \lambda_j$. Ψ_j is computed for each frequency.

IV. RESULTS AND DISCUSSIONS

The duty cycle for measured, MaxNoise, and theoretical values across 3 dB, 5 dB, and 10 dB were obtained. Fig. 1 revealed that GSM 1800 has increasing duty cycle values across theoretical and measured values, respectively, as the signal strength scaled down from 10 dB to 3 dB despite the fact that duty cycles of the theoretical are higher than the measured ones. It is affirmed that maxNoise value has the highest duty cycle; this could be due to the algorithm employed. It is worthy to note that, the GSM 1800 MHz duty cycle is higher than that of the GSM 900 MHz for theoretical method across all the thresholds. Interestingly, the reverse is the case for the measured method where the GSM 900 MHz's duty cycle was found to be higher except for the 3 dB threshold value.

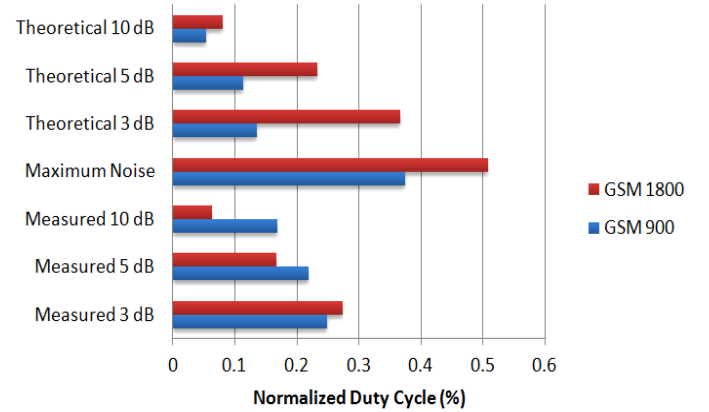


Fig. 1. Normalized Duty Cycle distribution across GSM bands

Fig. 2 provides the Kernel distribution for GSM 1800 MHz band. The Kernel estimates the probability density function of the duty cycle for all the detection thresholds algorithms. The impact of frame size (number of samples) on the duty cycle was investigated and the result is provided in Fig. 3. It can be seen that across all the algorithms, the frame size does not have significant effect on the average duty cycle. The results showed that ten (10) frames can provide satisfactory prediction as there isn't significant deviation of the DC.

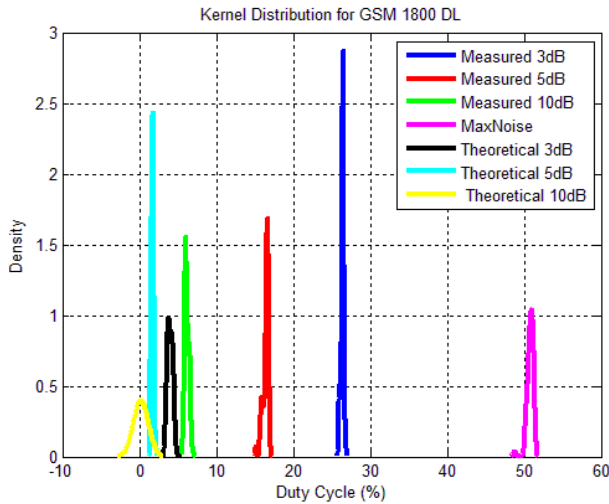


Fig 2: Kernel distribution for GSM 1800 DL

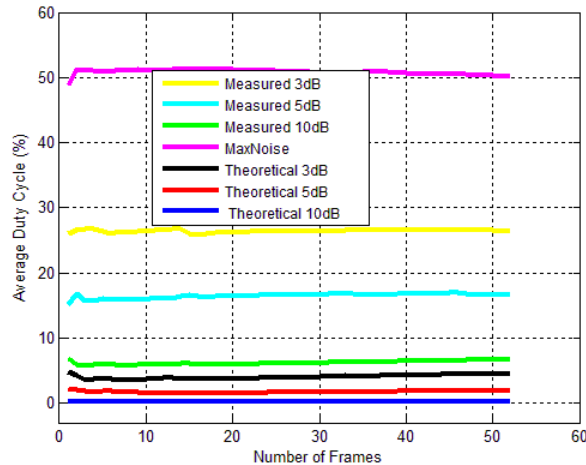


Fig 3: Average duty cycle of GSM 1800 DL

V. CONCLUSIONS

The GSM 900 and 1800 were mainly focused to conduct spectrum occupancy measurements. Three major algorithms (i.e. the PFA, MaxNoise and Adaptive threshold) were applied to deduce and analyse the average duty cycle. The results across the board show that the maxNoise has the highest occupancy value and average duty cycle. The ITU 10 dB was found to be too conservative as it gives the least occupancy prediction. However, the 5 dB above the measured noise level provides optimum prediction. Furthermore, the frame size was found to have insignificant impacts on the average duty cycle as an average of 10 frames can still provide satisfactory results. The findings from this work also indicated that there are vast amount of radio spectrum unoccupied, particularly in the GMS 900 MHz band and therefore, cognitive radio devices could be deployed to maximize the usage.

VI. FUTURE WORK

This work intends to extend the study of these effects across multiple bands in various locations.

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