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NON-PARAMETRIC SPECTRUM SENSING ALGORITHM FOR TELEVISION WHITE SPACE APPLICATIONS

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Abstract*: *The ever increasing demand for wireless broadband services has imposed severe bandwidth constraints on wireless communication system. This challenge has necessitated the emergence of cognitive radio technology that implements the dynamic spectrum access for spectrum utilization by sensing and using the underutilized spectrum on co-primary basis without interference to the primary users. In this paper, an energy-based, nonparametric spectrum sensing algorithm was proposed and implemented in MATLAB. The consistent TV signal estimation was done by Blackman-Tukey windowing. The result showed the PSD in terms of dB and dBm of the free, busy and interfered instantaneous TV channels at UHF range from channel 21 through channel 69. The detectable TV signals' threshold was set to be at -114 dBm and RxLEV of the TV channels showed channel number 46 with about -117 dBm to be the best candidate channel for TVWS applications at that simulation time.

Keywords – Nonparametric, PSD, TVWS, RxLEV, UHF

I. INTRODUCTION

With the proliferation of mobile devices and diverse mobile applications, wireless operators are experiencing phenomenal mobile services' growth around the world. As reported from industry, the global mobile data/voice traffic is more than doubling each year and the mobile in needs to prepare for 1000 times as much traffic by 2020 [1]. This high demand has resulted in causing severe strain on network system capacity and makes quality of service (QoS) provisioning in mobile communication system challenging. Meanwhile, the mobile customers pay more attention to their own experience, especially in communication reliability and service connectivity at all times. The major problem is the radio frequency spectrum utilization phenomenon where the spectrum is generally agreed to be over stretched to accommodate the growing demands in terms of bandwidth availability to network operators. It has been stated in [2] that there are two ways to address this issue; one is to reschedule the whole radio frequency spectrum distribution, which is impractical due to heavy financial burdens on companies, the second option is to devise some means of accessing the underutilized spectrum band opportunistically on core primary basis without interfering with the operations of the licensed primary users.

One of such underutilized spectrum bands is the so-called Television White Space (TVWS). In [2] TVWS is defined as the leftover TV broadcast spectrum after migration from digital to analogue transmission and this phenomenon is referred to as Digital Switchover (DSO). The DSO decision was conceived at the GE-06 ITU-R conference and proposed the transition period to begin on 17th June, 2006 and to be fully completed by 17th June 2020 [3], [4], [5]. The IEEE 802.22 standard allows the application of TVWS to any unoccupied TV channel within the TV broadcast spectrum (54 – 862 MHz) provided it does not interfere with the primary users [6] [7] [8]. The spectrum occupancy status is done by TV band devices (TVBD) which can be a base station usually called an enhanced Node B (eNB) for Long Time Evolutions –Advanced (LTE_A) networks or mobile subscriber usually referred to as User Equipment (UE) or Customer Premises Equipment (CPE). The TVBD uses Cognitive Radio (CR) technology. According to the definition given by Federal Communications Commission (FCC): "Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability and access secondary markets" [9].

The concept of CR was first introduced in the software defined radio (SDR) research community and that the key functionality of CR was to satisfy the requirement of avoiding interference to the potential primary users by ensuring secondary users reliable connectivity as well as sensing the spectrum [8]. The types of the primary users of TV spectrum including; TV broadcast stations, Programme Making and Special Events (PMSE), transmission of protective devices such as IEEE 802.22.1 wireless beacon and other incumbent devices specified by FCC R and O 08.266 [7]. The chief enabling technologies for the CR systems are the Geolocation/Database, Spectrum Sensing, and Combined Spectrum Sensing and Geolocation/Database [10]. There have been some technical challenges in protecting Digital Terrestrial Transmission (DTT) channels and PMSE users in urban areas using Geolocation/Database CR

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technique [11]. Therefore, direct spectrum sensing would be the native approach to tackle this challenge. Operations in TVWS requires strict adherence to the policies of national and international regulatory bodies especially the rules pertaining to the protection of the primary. A sensing technique can be classified as either signal specific (parametric) or blind (nonparametric). A signal specific sensing technique is based on features of specific signal type while the blind does not based on signal features [7][12].

In this paper, a nonparametric power spectrum estimation algorithm for TVWS channel sensing is proposed, evaluated and simulated under MATLAB environment. The overall objective of the work is to obtain free TV channel(s) to be used for TV white space applications especially in wireless communication industry. The remainder of this paper is organized as follows: the implication of Digital Switch Over on radio frequency spectrum (RFS) is discussed under Sub-section I. Section II deals with the review of spectrum sensing algorithms. The proposed system model and TVWS channel sensing algorithm are presented as materials and methods (methodology) in Section III. Result and discussions are presented in Section IV. Finally, conclusion is made in Section V.

A. Implication of Digital Switch- Over (DSO) on Radio Frequency Spectrum

The International Telecommunication Union–Radio Section (ITU-R) has divided the world into three regions, namely: Region 1 comprises of Africa, Europe, former Soviet States, Middle East and Islamic Republic of Iran; Region 2 comprises of North and South America, Greenland and the Caribbean; Region 3 comprises of Asia and Oceania. The GE-06 ITU-R conference was organized for Region 1 countries on DSO implementation [5]. From the presentation of [3] the DSO is implemented on ultra high frequency (UHF) band ranging from 470MHz to 862 MHz comprising of 48 TV channels numbering from channel 21 to 69. The World Radio Conferences in 2007 and 2012 (WRC-07and WRC-12) have modified the decision of GE-06 with the implication of operating Digital Terrestrial Television (DTT) on frequency band between 479 MHz and 694 MHz ranging from channels 21 to 48 only as depicted in Fig. 1. The remaining channels are to be used on co-primary basis pending when the analogue transmitters are finally switched off and are allocated for wireless communication and other services [5].

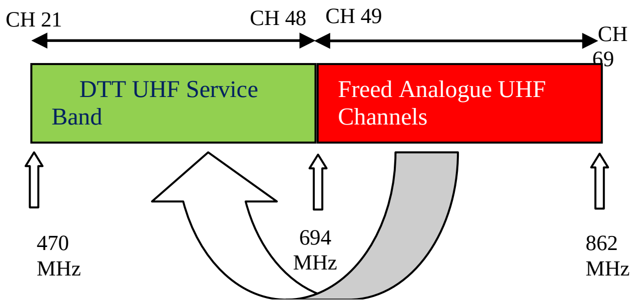


Fig. 1: Implication of WRC-7 and WRC-12 on UHF Spectrum

However, with the advent of dynamic spectrum access of cognitive radio technology, all TV UHF channels except channel 36 to 38 could be used on co-primary basis to offer wireless broadband service provided there is no interference with the primary users. In [14] it has been stated that based on Federal Communication Commission (FCC) rules, mobile (portable) devices are not allowed to operate on Very High Frequency (VHF) band. The channels obtained through DSO or dynamic spectrum accesses (also called open access) are referred to as the TVWS. The benefits that would be derived from using the TVWS include maximizing economic benefits, maximizing the social values, provision of broadband for all by bridging the digital divide, media and audiovisual policy objectives, and promoting innovation and competition [12][13] [30].

[2], [15], [16] and [17] have conducted quantitative TVWS channel availability investigation across many cities/countries of the world and found on average that the TV spectrum is underutilized with low average occupancy values of less than ten percent (10%). This makes TVWS to serve as the effective way for spectrum utilization by offering application for various services including wireless broadband deployment [7] [18] [19] [20].

II. Reviews of Spectrum Sensing Algorithms

The major function of TVWS spectrum sensing by a CR is to find free channel (s) for application as well as avoiding harmful interference with the primary users specified in IEEE 802.22. Subsequent paragraphs discuss the reviews of the spectrum sensing algorithms.

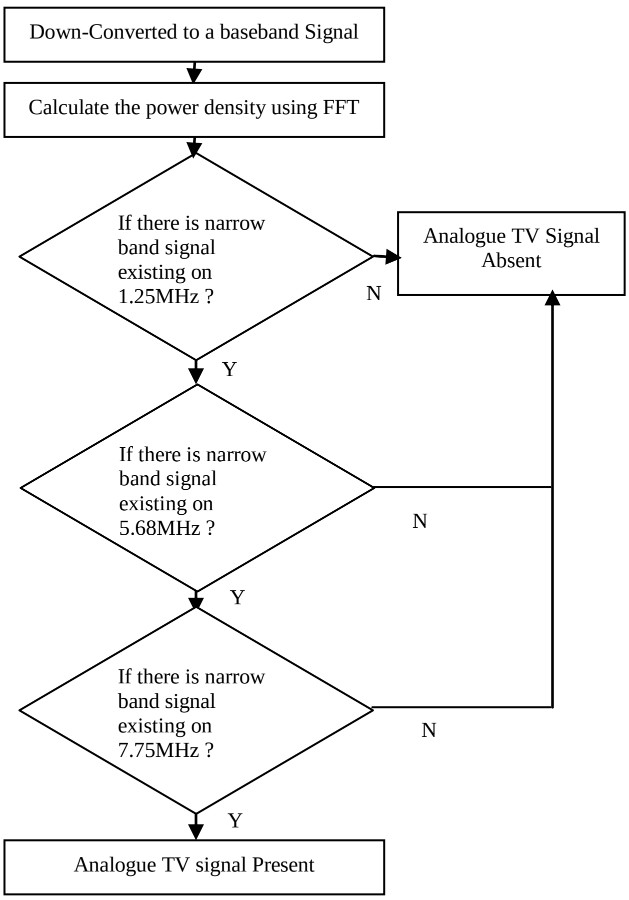
A two stage (hybrid) sensing algorithm to detect the presence of primary user (PU) in a TVWS within the 500 – 698 MHz spectrum using a so called pilot-tone and energy detection technique was implemented in [9]. This technique was used to initially detect the presence of incoming pilot signal that conforms to Advanced Television Systems Committee (ATSC) TV standards. The decision made on the presence of this type of signal is passed to the second stage where the signal's energy was computed and compared with some threshold value. The final decision on whether a PU was present or not was computed using equation (1).

$$\text{Signal detection } (d) = \begin{cases} 0, & \lambda < \gamma \\ 1, & \lambda \geq \gamma \end{cases} \quad \text{--- (1)}$$

Where λ is the average energy of the incoming signal and γ is the predefined threshold. A "0" and "1"decisions indicated the absence and presence of primary users respectively. Their algorithm was tested on the data collected during a simulated real-time environment with aUniversal Software Radio Peripheral (USRP) hardware and radio software written in C++. The performance of this method was measured by its probability of detection (*Pd*) and the probability of false alarm (*Pf*). The advantage of this al gorithm is in the simplicity of its implementation but it has the following limitation; in pilot detection phase, only digital TV (ATSC) signal was of concern whereas in many places analogue TV signals may also present. Also, the detail kind of energy detection method was not specified since there are different type energy detection methods with different levels of estimation accuracy.

An experimental blind energy spectrum sensing technique on the Universal Software Radio Peripheral 2 (USRP2) hardware interfaced with MATLAB for cognitive radio applications was conducted in [2]. The amount of energy present in a channel was computed from the Fast Fourier Transform (FFT) of incoming signal. The channel was assumed to be free if the energy level was below a specified threshold and occupied otherwise. The algorithm that was developed was aimed at finding the available TVWS channels; simulation results showed that about 83% of the allocated TV spectrum band was unoccupied. Accommodation of broadband services on the free TV channels was made as future recommendation of the work.

A parametric spectrum sensing algorithm to detect the presence of signals from Phase Alternating Line – Delay (PAL-D) analogue TV signals primary users within TV spectrum was developed in [11]. The flowchart of the implemented algorithm is shown in Fig. 2. Field experiments were conducted to test the performance of their method using the Agilent N5182A MXG signal generator to generate the analog TV signals. The detection probability P_d achieved over 90%. Their algorithm improved the weak signal detection ability significantly compared to the energy detection method under the same condition. The major limitation of this technique is long time sensing duration and computational complexities.



Source: Yue *et al.* (2016)

Fig. 2: Parametric Spectrum Sensing Algorithm

Ikuma and Mort (2010) presented an autocorrelation-based spectrum sensing algorithm to detect the presence of primary users (PUs). In this work, the TV channel signal underwent the processes of down conversion, low-pass filtering and sampling in order to obtain the complex baseband signal. The Power Spectral Density (PSD) of the autocorrelated signal ($\boldsymbol{X}$) was computed and then subjected to the decision statistics by comparing it with threshold value λ as shown in equation (2).

$$\text{Sensing Algorithm} = \begin{cases} \text{PSD(X)} < \lambda, & \text{PU Absent} \\ \text{PSD(X)} \geq \lambda, & \text{PU present} \end{cases} \quad \ldots(2)$$

The results showed remarkable performance improvement when compared with covariance-based detector. Although the autocorrelation-based sensing technique has the ability of differentiating between signals and noise, which makes it less sensitive to noise uncertainty, passing the $PSD(\boldsymbol{X})$ through a window function would reduce spectral losses and improve the sensing performance.

There are many other energy–based spectrum sensing techniques in literature which are based on periodogram with different degrees of enhanced capabilities in terms of spectral estimation through applications of different window functions [22] [23][24][25]. These windowing functions were used to reduce spectral losses (leakages) and improve estimation accuracy. In spectrum energy sensing techniques, implementation of Blackman-Tukey windowing function provides a consistent estimate of the transmitted signal by eliminating signal samples with high variance at the receiver, thereby, providing the power spectrum with small variance values [24].

III.METHODOLOGY

This work is implemented using MATLAB for both the system modelling and algorithm development.

A. *Proposed Channel Sensing System Model*

The energy–based non parametric sensing approach is proposed to sense the presence of signal(s) TVWS without considering any feature of the sensed signal contained in a given channel. This is achieved by computing the power spectral density (PSD) of the auto- correlated received signal using Fast Fourier Transforms (FFT) as shown in Fig. 3. In order to reduce unreliable received signal estimates, a Blackman-Tukey (BT) window is extended to cover from –M to +M spectral signal samples. Reference or threshold values of the PSD are set to give decision metrics according to the developed algorithm.

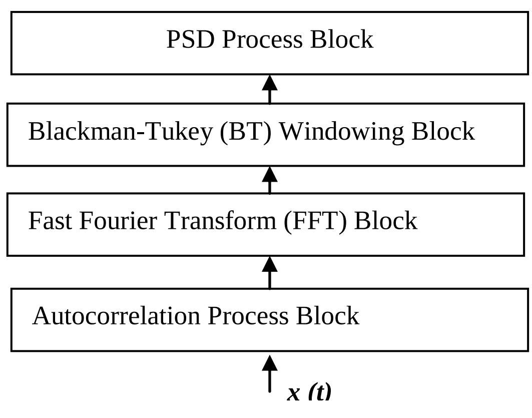


Fig.3: Nonparametric Spectrum Sensing Process

Where $x_n(t)$ is the discrete baseband stochastic received signal in time domain and the autocorrelation block produces $\hat{r}_x(k)$ which is the autocorrelation of the signals $x(n+k)\ and\ x^*(n)$. The FFT block performs the Fast Fourier Transform function in continuous frequency domain and the Blackman-Tukey window $(w(k))$is extended over the spectral signal samples from –M to M. The PSD block processes the power spectral density of the received signal in dB or dBm. The mathematical system model of Fig. 3 is as follows;

Assuming at the receiver, the noise is an independent and identically distributed (IID) Gaussian variable and N to be the total number of sampled received signals in frequency domain such that M<*N-1*, then $\hat{r}_x(k)$ is computed thus;

$$\hat{r}_x(k) = {}^1/_N \sum_{n=0}^{N-k-1} x(n+k)x^*(n)$$

$$0 \le k \le N-1 \qquad \dots (3)$$

$k\ is$ the sample size (bins)

Finding the FFT and multiplying equation (3) by the BT window, the PSD ($\widehat{P_{BT}}$) is obtained thus;

$$\widehat{P_{BT}}(e^{i\omega}) = \sum_{k=-M}^{+M} \hat{r}_x(k)w(k)e^{-jk\omega} \qquad \dots (4)$$

In equation (4) the noise term has not appeared because IID Gaussian noise is uncorrelated with expected (mean) value of zero. That is;

$$E\{|n(k)|^2\} = \sigma^2 = 0 \qquad \dots (5)$$

Where σ^2 is the noise variance.

Equation (4) is the PSD of the sensed signal communication channel having the largest variance being set zero due to BT windowing and consequently, the power spectrum estimation will have a smaller variance. The PSD obtained is then subjected to some decision metrics according to the proposed channel sensing algorithm for TVWS channel assignment

B. *Proposed Non parametric TVWS Sensing Algorithm*

The flowchart for the proposed TVWS sensing algorithm is presented in Fig.4.

In this procedure the PSD of received signal was compared with the reference (threshold) values to give decision metrics. These reference values and simulation parameters needed for the algorithm are obtained from [26][27][28] so as to decide whether the TVWS channel is busy when the channel is already occupied by a primary user, interfered when there is an incoming primary user signal or free when no detectable primary users' signal.. With reference to Fig.4, the PSD_{int} and PSD_{frree} represent PSD threshold values in dB for interfered and free UHF TV channels.

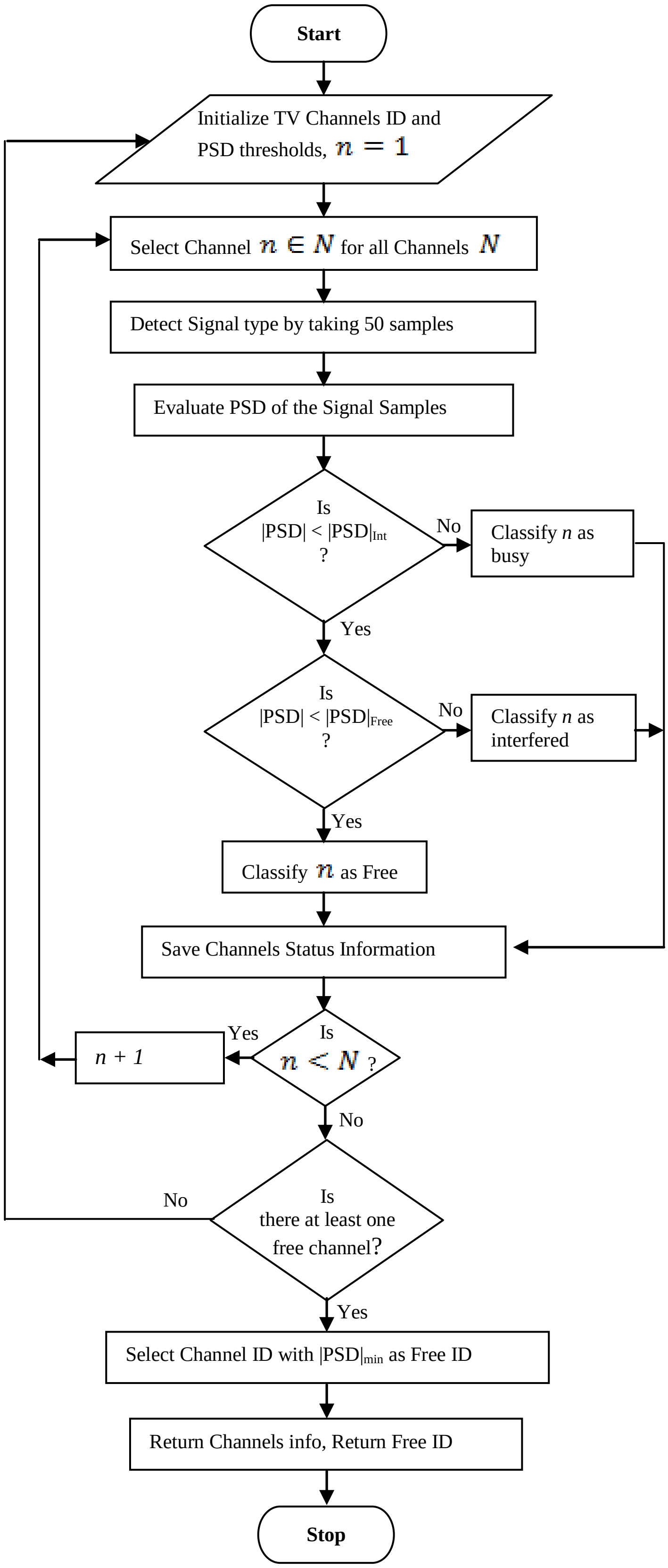


Fig. 4: Proposed Nonparametric TVWS Sensing Algorithm.

The MATLAB simulation parameters are presented on Table I.

Table I: Channel Sensing Simulation Parameters

Channel Numbers (UHF)	21 - 35, 39 - 69
N	512
M	64
$\|k\|$	50 bins
$\|PSD\|_{int}$	18 dB
$\|PSD\|_{free}$	2.5 dB
FFT size	1024
Reference detectable Power Level	-114 dBm
Window Type	BT

IV. RESULT AND DISCUSSIONS

A. *Simulation Results*

The simulation result for PSD of free, busy and interfered channels using the proposed sensing algorithm is shown in Fig.5

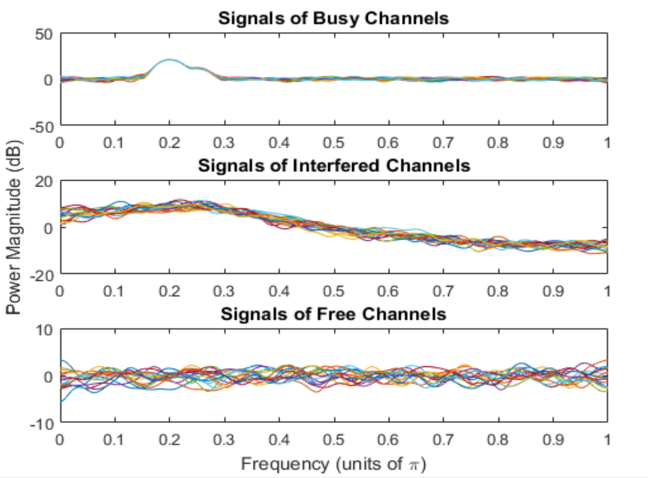
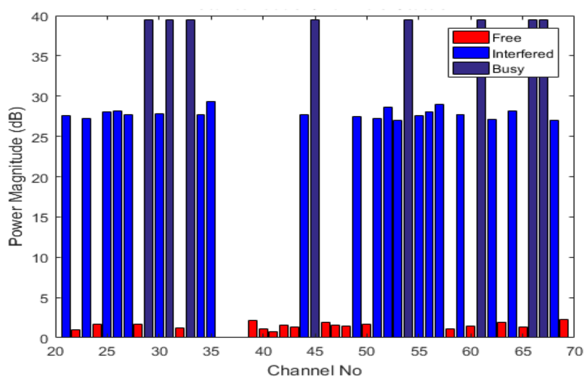


Fig. 5: PSD of busy, interfered and free instantaneous TV channels.

The result of the instantaneous channel status for channels from UHF channel number 21 to 69 is shown in Fig. 6. Channels 36, 37 and 38 are excluded in the algorithm because channel 37 is reserved for radio astronomical measurements while channels 36 and 38 are used for portable devices only. The other UHF channels can be used by both fixed and portable devices and may be used in TVWS applications



Fig, 6: Instantaneous UHF TV Channels status.

The result of the instantaneous PSD of the UHF TV channels in terms of received signal level (RxLEV) in dBm is shown in Fig.7.

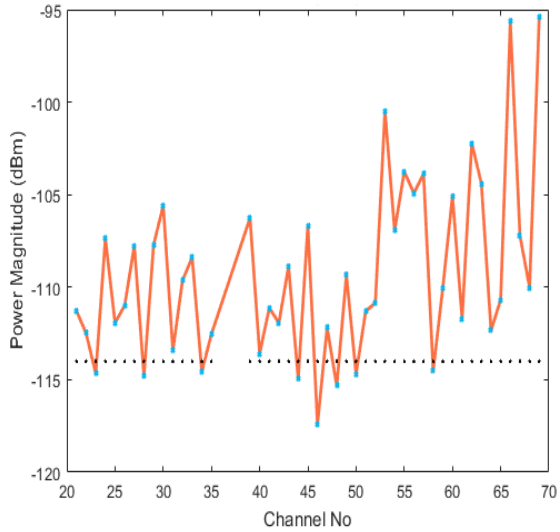


Fig. 7: RxLEV of Instantaneous UHF TV channels.

B. *Discussions*

Results obtained from Fig. 5 showed that the PSD of busy, interfered and free channels were about 40dB, 18dB and 0dB respectively. The free channels with about 0dB indicated that only noise was present with variance zero. The instantaneous channel status in dB was presented in Fig.6 with free channels indicated with bar chart having red colour (legend). According to [14], the main requirement on spectrum sensing is that a TV band device (TVBD) should be able to detect the presence of (digital and analog) TV signals and wireless microphone signals at a power received level (RxLEV) of −114 dBm. This means that the overall average energy level of the TV signal at a point should lie above the threshold energy value of -114 dBm for occupied channels (busy or interfered). The free channels are those with average energy at a point below -114 dBm for the 50 simulation runs. From Fig. 7 these channels are 23, 28, 34, 44, 46, 48, 50 and 58. Channel 46 has the lowest RxLEV of about -117 dBm and could be the best candidate for TVWS applications at that point in time

V. CONCLUSION

The proposed spectrum sensing algorithm for the availability of TVWS channels has been implemented and simulated under MATLAB environment. The results indicated instantaneous TV channel that were busy, interfered or free based on the simulation parameters. UHF TV channels with signal received level (RxLEV) less than -114 dBm were considered to be free candidates' channels that could be used for TVWS applications. In this work, UHF channel number 46 with RxLEV of -117 dBm would be chosen for such applications like the spectrum aggregation in wireless communications. Developing sensing algorithm that is based on the combination of parametric and non parametric spectrum sensing approaches especially with signal pattern recognition capabilities is recommended as future enhancement of this work.

DECLARATION OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this work. Therefore, *'declaration of interest: none'.*

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