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SPECTRUM SENSING ALGORITHM FOR TELEVISION WHITE SPACE APPLICATION IN MOBILE COMMUNICATION SYSTEMS

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Abstract
The ever increasing demand for wireless broadband services has imposed severe bandwidth constraints on wireless communication system. These demands have led to the technological responses such as the advancement in radio access, coding and modulation schemes as well as spectrum(carrier) aggregation and cognitive radio capabilities of Long Term Evolution - Advanced (LTE-A) and Fifth Generation (5G) networks developed by the Third Generation Partnership Project (3GPP). This aspect of spectrum or carrier aggregation uses 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 work, an energy-based, non-parametric TVWS spectrum sensing algorithm was implemented in MATLAB environment. The developed sensing algorithm was aimed at finding free TVWS frequency channel(s) that would be used TVWS applications such as the spectrum aggregation. The consistent TVWS signal estimation was done by Blackman-Tukey windowing. The result showed the instantaneous TV channels statuses; free, busy and interfered by computing the PSD expressed in dB while the estimated received power level in dBm for free channels was computed for the UHF range from channel 21 through channel 69. The detectable TV signals' threshold value was set at -114 dBm. In the five simulation cycles carried out, the developed algorithm instantaneously selected channels: 68,34,48,60 and 26 corresponding to the centre (carrier) frequencies of 850MHz, 578MHz, 690MHz, 786MHz and 514MHz, respectively as channels with the least RxLEV for each of the simulation cycle at a point and each would be dynamically used for TVWS during spectrum aggregation process.

Keywords: *LTE-A, TVWS. PSD, UHF, RxLEV*

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 (Zhang, 2015). 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. Arslan *et al*, 2015 have 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). Arslan *et al* (2015) defined TVWS 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 (Amana, 2017, Ukwela, 2017 and Elmoghazi *et al*, 2013). 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 (SOLDER 2014, IEEE 802.22, 2011 and Chakraborty *et al*, 2010). 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

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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" Arooj (2017).

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 (Chakraborty *et al*., 2010). 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 (IEEE 802.22, 2011). The chief enabling technologies for the CR systems are the Geolocation/Database, Spectrum Sensing, and Combined Spectrum Sensing and Geolocation/Database (TEC, 2008). There have been some technical challenges in protecting Digital Terrestrial Transmission (DTT) channels and PMSE users in urban areas using Geolocation/Database CR technique (Yue, 2016). 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 (IEEE 802.22, 2011).

In this paper, a nonparametric power spectrum estimation algorithm for TVWS channel sensing is proposed, evaluated and simulated under MATLAB environment. The remainder of this paper is organized as follows: Section II deals with the review of spectrum sensing algorithms; section III deals with the Methodology highlighting the system model and TVWS channel sensing algorithm; Results and Discussions are presented in Section IV and finally, Conclusion is made on Section V.

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

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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 Arooj (2017). 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).

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

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 a Universal 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 algorithm 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 Arslan *et al.* (2015). 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

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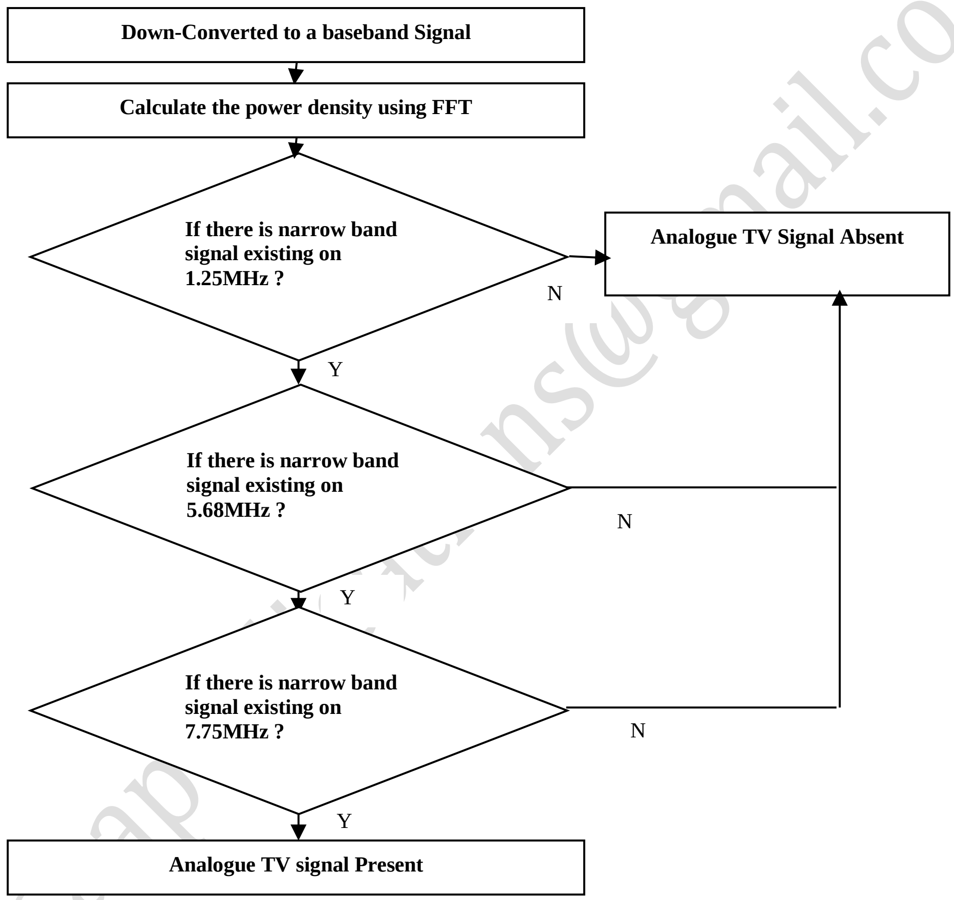
users within TV spectrum was developed in Yue *et al* (2016). The flowchart of the implemented algorithm is shown in Fig. 2. Field experiments were conducted to test the performance of their method using the Agilent N5182A MXG signal generator to generate the analog TV signals. The detection probability 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. 1: Non-Parametric Sensing Technique

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).

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

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 (Yasin, 2002. Leopoldo et al., 2013, Shazad *et al* 2013, Fatima 2015). 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 (Shazad *et al* 2013)

Methodology

This work is implemented under MATLAB environment for both the system modelling and algorithm development. The source codes for the work is shown on Appendix I

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

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using Fast Fourier Transforms (FFT) as shown in Fig. 2. 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.

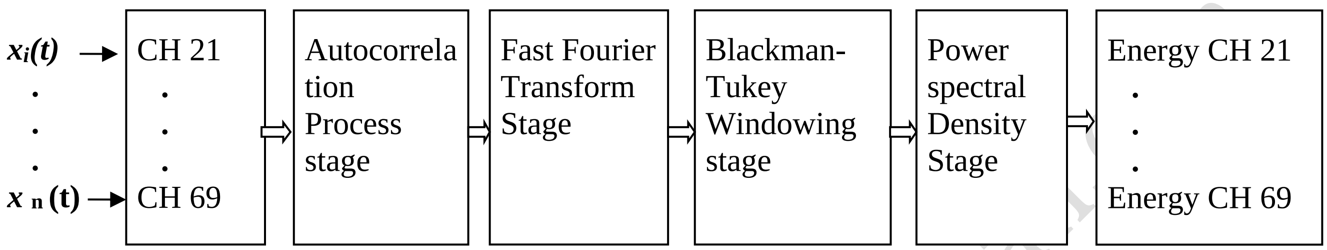

Fig.2: Block Diagram of Nonparametric Energy-Based PSD Computation

$\boldsymbol{x(t)}$ represents the discrete baseband stochastic received signal in time domain during the TVWS channel scanning cycle. This signal could be noise or TV signals. At the autocorrelation stage, the MATLAB program produces $\hat{r}_x(k)$ which is the autocorrelation of the received signals $x(n+k)$ *and* $x^*(n)$ its conjugate pair. n *and* k are the sample number and size respectively. At the receiver, it was assumed that the noise was an independent and identically distributed (IID) Gaussian variable and N the total number of sampled received signals in frequency domain, then $\hat{r}_x(k)$ was computed thus (Shazad 2013);

$$\hat{r}_x(k) = {}^{1}/_{N} \sum_{n=0}^{N-k-1} x(n+k)x^*(n) \qquad 0 \le k \le N-1 \qquad \text{... (3)}$$

The FFT stage performs the Fast Fourier Transform function which changes the signal from time to frequency domain. FFT size has been chosen based on the channel bandwidth (SACRA, 2010). Finding the FFT of equation (3), the PSD of TVWS sensed signal with M<*N-1* where M is the figure of merit having the same size as that of the windowing function (Hassanpour, 2016) is obtained thus;

$$\text{PSD } of\ sensed\ signal = \sum_{k=-M}^{+M} \hat{r}_x(k) e^{-jk\omega} \qquad \text{... (4)}$$

In order to reduce the likelihood of fake signal estimates, a Blackman-Tukey (BT) windowing function has been applied to equation (4) (Shazad *et al.*, 2013). The Blackman-Tukey window $(w(k))$ is extended over the spectral signal samples from –M to M sides of the power spectrum. Application of BT window on equation (4) yields equation (5)

$$\text{PSD } of\ sensed\ signal = \widehat{P_{BT}}(e^{i\omega}) = \sum_{k=-M}^{+M} \hat{r}_x(k)w(k)e^{-jk\omega} \quad \ldots (5)$$

Equation (5) represents the PSD stage where the program computes the received signal power spectral density of the received signal in dB or dBm and the energy estimate is equivalent to computing the second moment (variance) of the signal (Saeed, 2000; McNames, 2017)
The noise term in equations (4) and (5) have not appeared because an independent and identically distributed (IID) Gaussian signals were uncorrelated having expected (mean) value of zero. That is;

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

Where σ^2 is the noise variance.
The PSD obtained was then subjected to some decision metrics featuring the three scenarios 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.3.
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 SACRA (2010), Steve (2010) and Hassanpour *et al* (2016) 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.3, the PSD_{int} and PSD_{frree} represent PSD threshold values in dB for interfered and free UHF TV channels.

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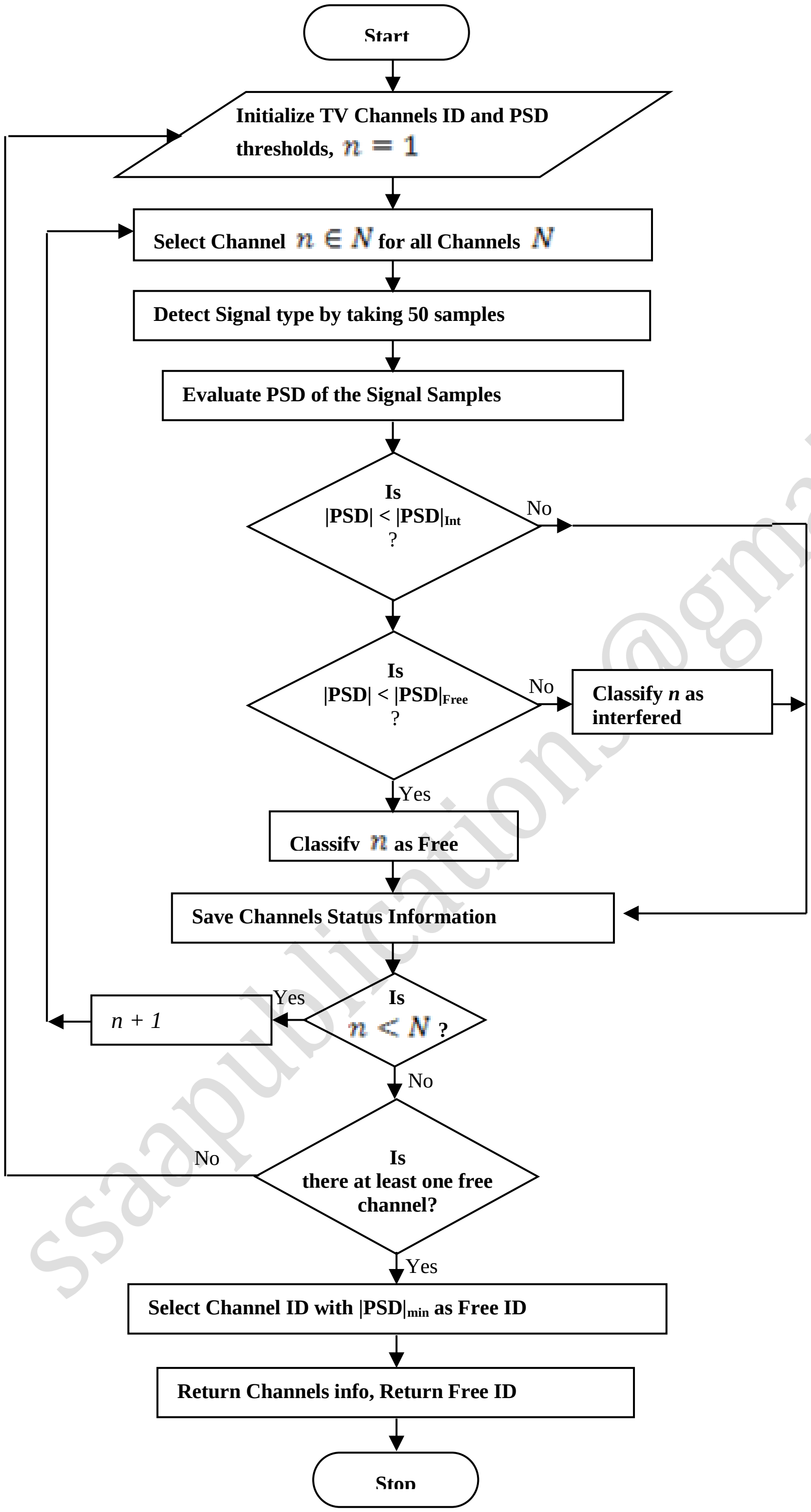

Fig. 3: Proposed Nonparametric TVWS Sensing Algorithm.

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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

RESULT AND DISCUSSIONS

B. *Simulation Results*

The result of the instantaneous channel status for channels from UHF channel number 21 to 69 is shown in Figs. 5 through 12 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

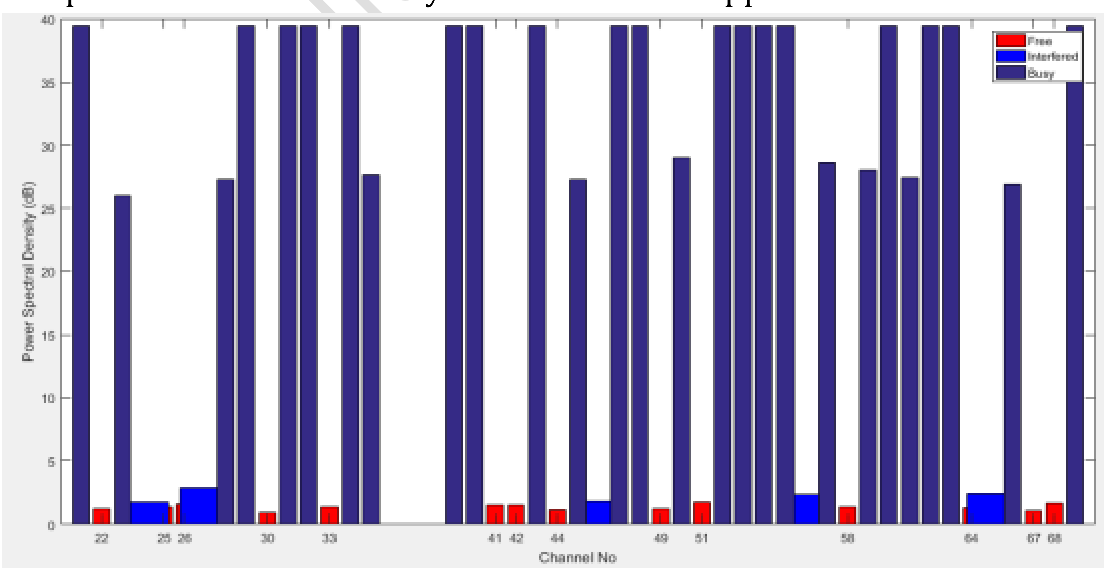

Fig.5: TVWS Channel Sensing Status for simulation number 1

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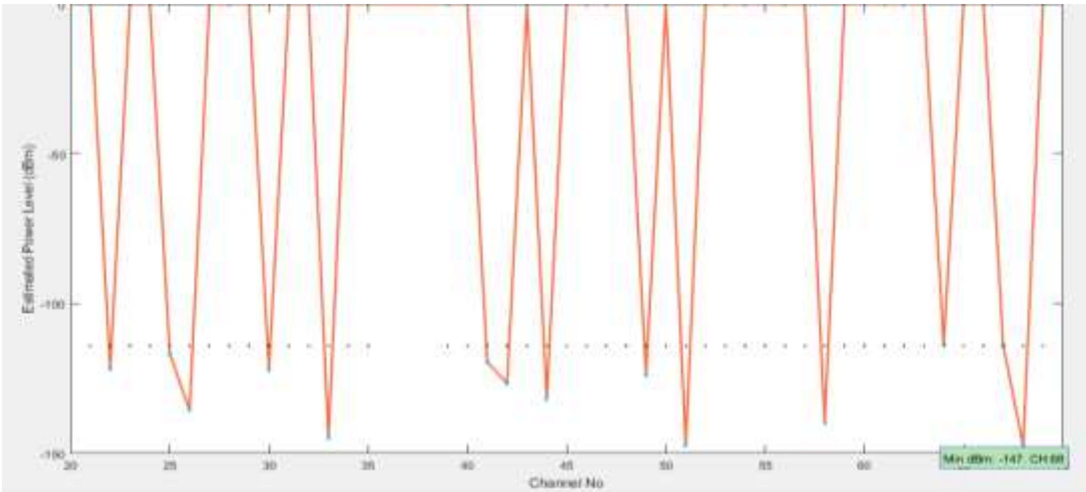

Fig.6: Received Power level for simulation 1

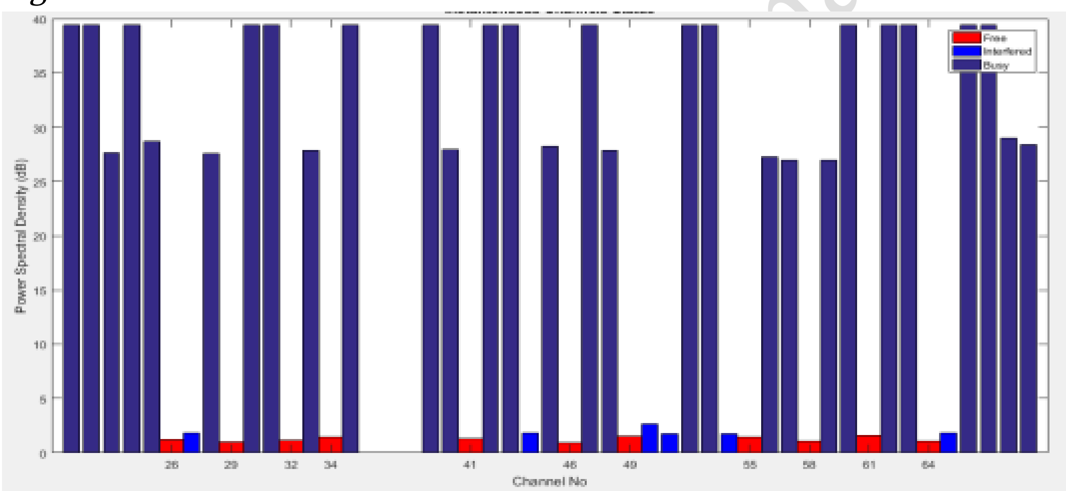

Fig.7: TVWS Channel Sensing Status for simulation number 2

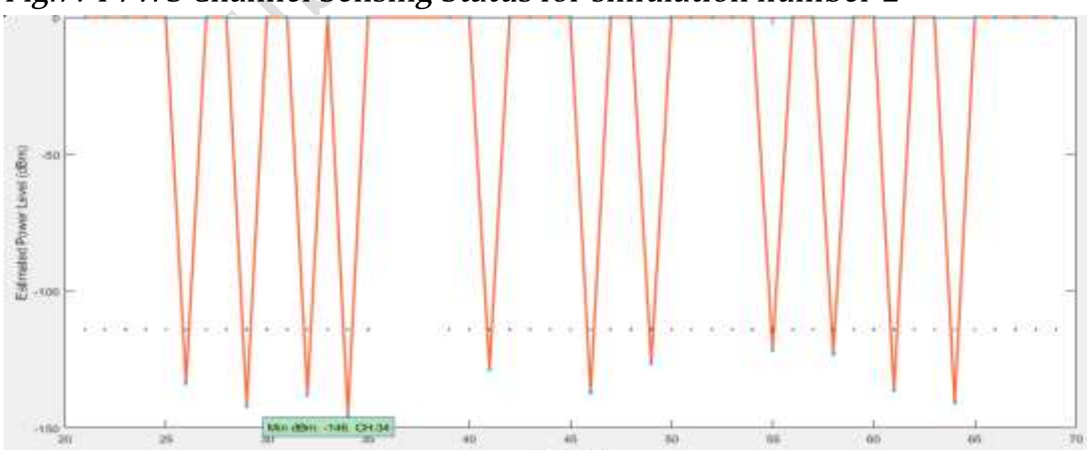

Fig. 8: Received Power level for simulation 2

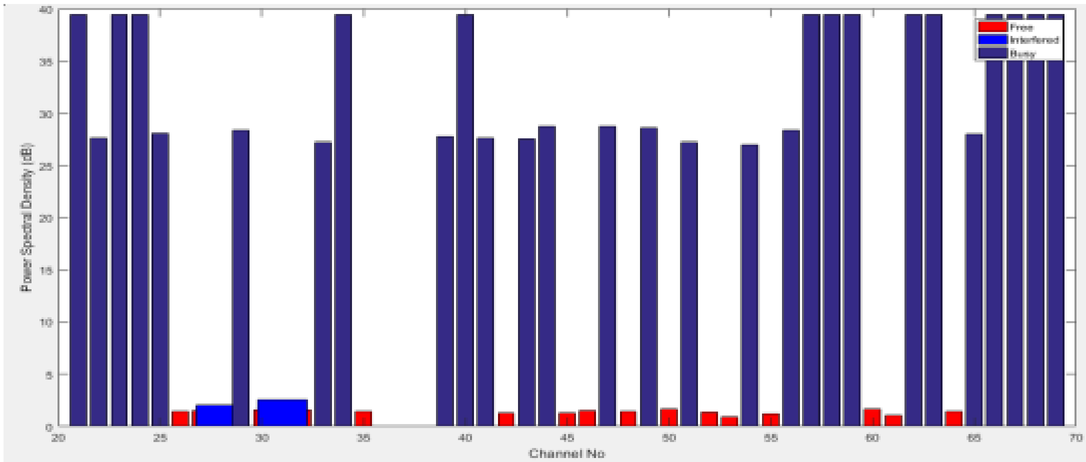

Fig. 9: TVWS Channel Sensing Status for simulation number 3

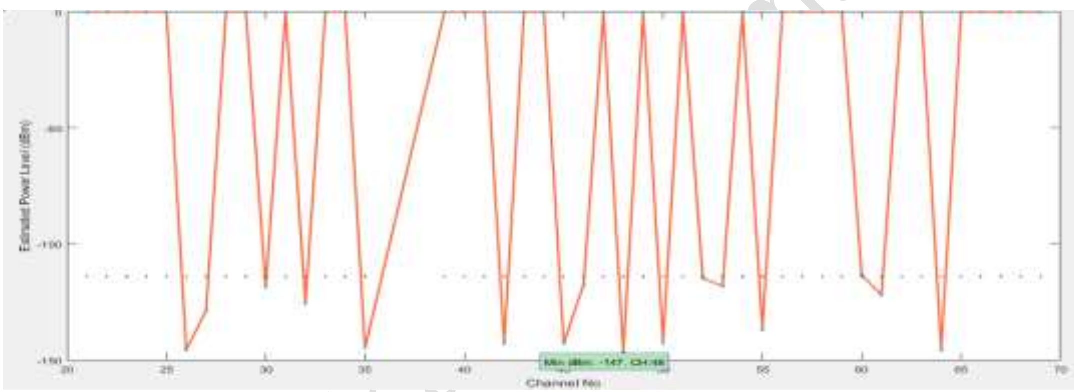

Fig.10: Received Power level for simulation 4

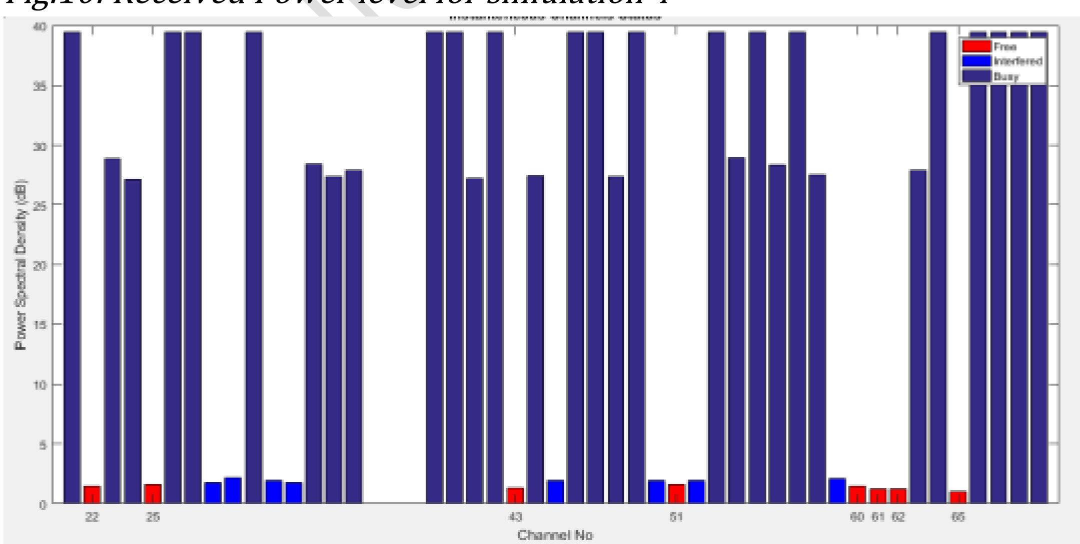

Fig. 11: TVWS Channel Sensing Status for simulation number 4

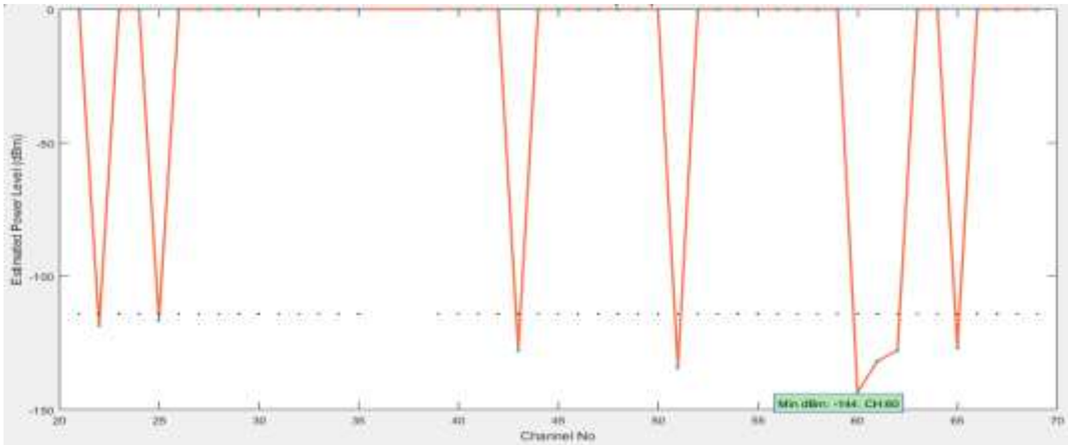

Fig.12: Received Power level for simulation 4

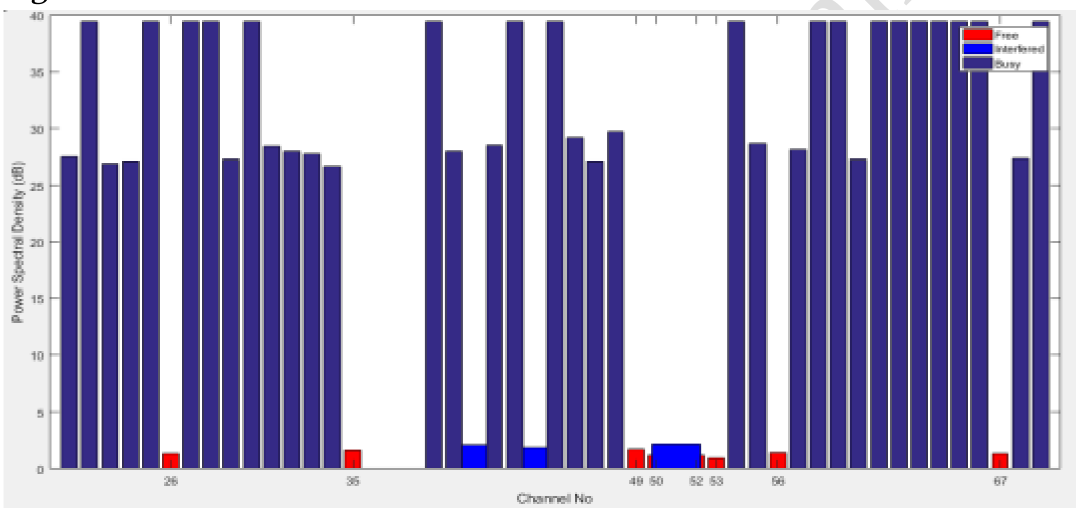

Fig.13: TVWS Channel Sensing Status for simulation number 5

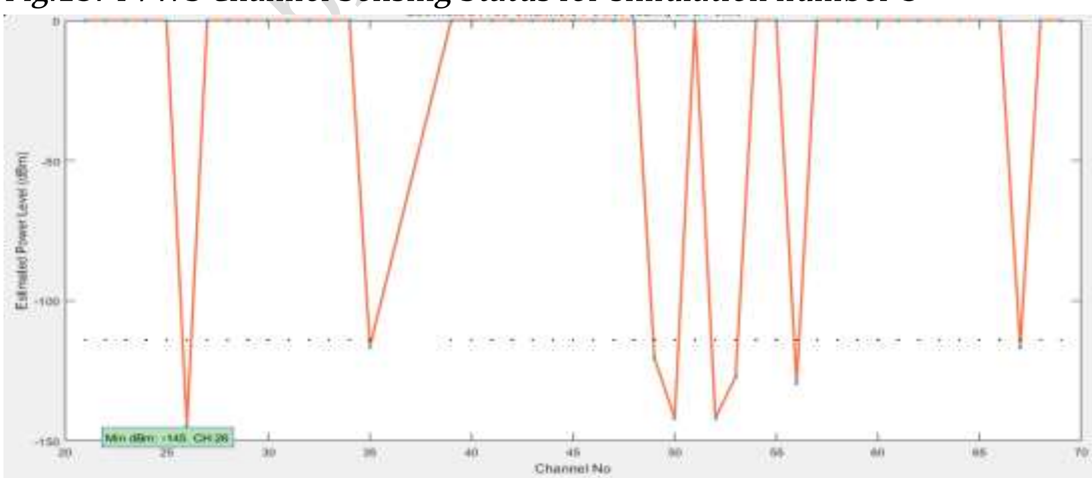

Fig.14: Received Power level for simulation 5

The summary for the ten simulation cycles is shown on Table II

Table II: Summary of Simulation Test Cycles

Test Cycle Simulation number	Free TV channel Number with least Received Power Level (PSDmin)	Value of the Received Power Level (dBm)	Center Frequency (MHz)
1	CH 68	-147	850
2	CH 34	-145	578
3	CH 48	-147	690
4	CH 60	-144	786
5	CH 26	-145	514

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Discussions

The result of the instantaneous TVWS channels sensing status and the estimated received power level (in dBm) are shown from Figs. 5 through 12. Channels 36, 37 and 38 were excluded in the sensing process because channel 37 has been reserved for radio astronomical measurements while channels 36 and 38 are being used for portable devices only (Steve, 2010). The other UHF channels are used by both fixed and portable devices and were used in this work to obtain free channels for the spectrum aggregation.

The main requirement of spectrum sensing is that a sensing device (eNode B system) should be able to detect the presence of (digital and analogue) TV signals and wireless microphone signals at a power received level (RxLEV) of −114 dBm (Stephen *et al.* 2009). This means that the overall average energy level of the signal at a point should lie above the threshold energy value of -114 dBm for occupied channels (busy or interfered) and below for the free channels. Table II showed the prospective channels with the least estimated power received levels (PSD_{min}), channel number and channel centre frequency for each of the five simulation test cycles. Therefore, for the five simulation test cycles; channels 68,34,48,60 and 26 corresponding to the centre (carrier) frequencies of 850MHz, 578MHz, 690MHz, 786MHz and 514MHz respectively as the chosen channels for TVWS applications.

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, five simulation Test cycles were conducted and during each simulation cycle, UHF channel with least RxLEV was chosen for TVWS applications such as 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.

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Appendix I

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%                          APPENDIX I
%$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
% Codes for Non-Parametric Spectrum Sensing of TVWS Applications
%$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
clc;
close all;
echo off;

disp ('Spectrum Sensing of TVWS for Spectrum Aggregation');
disp ('=====================================================');
disp (' ');


OffChans = input ('Please input OFF Channels for the program e.g: [21,24,40:45] = ');
OnChans = input ('Please input ON Channels for the program e.g: [21,24,40:45] = ');

if (isempty(OffChans) | OffChans(1) == 0)
      OffChansVal = 0;
else
      OffChansVal = 1;
end


if (isempty(OnChans) | OnChans(1) == 0)
      OnChansVal = 0;
else
      OnChansVal = 1;
end

PSD_free = 1.7; %Free channel threshold in dB
PSD_int = 10; % Interfered channel threshold in dB

N = 512;
M = 64;

dbmthres = -114;% minimum detectable signal level(Rxlev),PSDmin in dBm at a point is < -114 dbm
   end
end


colour_p = [251 111 66] ./ 255; % peach
colour_lb = [1 191 230] ./ 255; % lightblue



figure
bar(Free_Channels,Free_Channels_Power,'Facecolor','red');hold on
bar(Interfered_Channels,Interfered_Channels_Power,'Facecolor','blue');hold on
bar(Busy_Channels,Busy_Channels_Power);hold on
legend('Free', 'Interfered', 'Busy')
xlabel('Channel No');
ylabel('Power Spectral Density (dB)');
title('Instantaneous Channels Status');

figure
h=plot(Chans,dbm,'-d','linewidth',2, 'Color',colour_p, 'MarkerEdgeColor',colour_lb, 'MarkerFaceColor',colour_lb, 'MarkerSize',2); hold on
plot(Chans, dbmthres,'-k.')
xlabel('Channel No');
ylabel('Estimated Power Level (dBm)');
title('Estimated Free Channels Power (dBm) at a Point');
x = get(h,'XData');          % Get the plotted data
y = get(h,'YData');
imin = find(min(y) == y);       % Find the index of the min and max
imax = find(max(y) == y);
text(x(imin)-4,y(imin)-4,['Min dBm: ',k],...
    'VerticalAlignment','middle',...
    'HorizontalAlignment','left',...
    'FontSize',10,...
    'EdgeColor','blue',...
    'BackgroundColor',[.7 .9 .7])
```