URSI AP-RASC 2019, New Delhi, India; 09 - 15 March 2019

Experimental Studies on Energy / Eigenvalue based Spectrum Sensing Algorithms using USRP Devices in OFDM Systems

Abhishek Kumar*(1), Amir Suhail Khan(1), Nitesh Modanwal(1), Seemanti Saha(1)
(1) Wireless Propagation Lab, National Institute of Technology Patna, Patna, Bihar, 800005, India

Abstract

In this paper, we implement energy detection (ED) based spectrum sensing using NI USRP 2942R software defined radio platform. It is observed that in practical scenario ED scheme gives poor performance at low gain (G) values. To overcome the shortcomings of energy detection, we propose eigenvalue based detection of the primary user (PU) signal, where, the ratio of the maximum eigenvalue to the average eigenvalue is used to detect the PU signal. Further, the experimental studies show that proposed technique gives optimum probability of detection. It has been observed that the proposed technique outperforms the ED based detection even if the Tx-Rx separation increases.

1 Introduction

The demand for the radio spectrum has been increased dramatically with the rapid development of different wireless communication applications, and accommodation of any new technologies within limited frequency spectrum seems very tough as the allocation of frequency resource is already very packed [1]. Actual measurements show that most of the allocated spectrum is vastly underutilized with utilization ranging from 15% to 85% in the bands below $3GHz$ at any specific location and time [2]. Recently cognitive radio is emerging as a novel technology to improve the spectrum utilization, in a manner to allow opportunistic spectrum access to unlicensed or secondary user (SU) [3].

The conventional spectrum sensing techniques are: matched filter detector, energy detector (ED) and cyclostationary feature detector. A significant drawback of the matched filter-based detection is that a cognitive radio would need a dedicated receiver for every PU class [4]. Cyclostationary feature detection method is recognized as a more effective way for the detection of very weak signals in the presence of background noise but suffers from high computation complexity [5]. ED is a sub-optional technique which performs non-coherent detection. There are several drawbacks, such as threshold setting, vulnerability to the noise uncertainty, e.t.c., the ED technique is widely used owing to its easy implementation and low computational complexity [6]. Eigenvalue based detection of PU signal is presented in [7], where the ratio of maximum eigenvalue to the minimum eigenvalue is compared to the predefined threshold value. But in practical scenario sometimes the minimum eigenvalue may become $-ve$ which leads to increase in a probability miss detection (P_{md}) of the PU signal.

Figure 1. A system model setup using USRP

In this paper, first we implement ED based spectrum sensing on NI USRP 2942R (400 MHz-4.4 GHz) software defined radio (SDR) platform. USRP RIO provides an integrated hardware and software solution for rapidly prototyping high-performance wireless communication systems using LabVIEW software interface. Further, the performance metric, probability of detection P_d is plotted with respect to USRP gain (G) and the distance (d) between transmitter and receiver in the indoor radio environment. It is observed that in practical scenario ED scheme gives poor performance at the lower G values. Next, to overcome the shortcomings of energy detection, we propose eigenvalue based detection, where, the ratio of the maximum eigenvalue to the average eigenvalue is used to detect the presence of the PU signal. The experimental studies show that the proposed eigenvalue based spectrum sensing outperforms the conventional energy detection based spectrum sensing technique, even if the transmitter receiver separation increases.

2 System Model and Problem Statement

A CR test-bed structure using NI USRP RIO is considered for the spectrum sensing problem as represented in Fig. 1. Here, one USRP is considered as a PU user, which is transmitting the OFDM signal and the other USRP is considered as the SU. The primary goal of the SU is to detect the presence of PU signal in the lab indoor radio environment. Therefore, the received signal at SU can be given as:

$$\begin{aligned} H_0 &: y[n] = w[n] && \text{signal absent} \\ H_1 &: y[n] = x[n] + w[n] && \text{signal present.} \end{aligned} \quad (1)$$

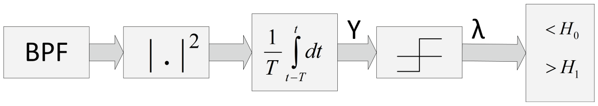

Figure 2. A block diagram representation of the energy detection based spectrum sensing technique

where, H_0 and H_1 represent the null hypothesis (i.e absence of the PU signal) and alternate hypothesis (i.e. the presence of the PU signal) respectively, $y[n]$ is the received signal at SU, $x[n]$ is the sample of the PU signal, w[n] is the i.i.d Gaussian noise samples $w \sim \mathcal{N}(0, \sigma^2)$, $n = 1, 2 \ldots N$ is the total number of observed sample in a particular sensing observation. To calculate the statistical covariance matrix, L consecutive samples are defined. Where,L is called the smoothing factor. Therefore the following vectors can be defined:

$$\begin{aligned} Y[n] &= \quad y[n]y[n1]...y[n(L+1)] \\ X[n] &= \quad x[n]x[n1]...x[n(L+1)] \\ W[n] &= \quad w[n]w[n1]...w[n(L+1)] \end{aligned} \tag{2}$$

The main objective of this work to sense the PU signal using USRP when the information about PU signal is completely unknown.

3 ED and proposed eigenvalue based spectrum sensing

3.1 ED based spectrum sensing technique

In energy based spectrum sensing technique, the energy of the received signal $y[n]$ is compared with the predefined threshold value to give the decision about the presence and absence of the PU signal. The decision test statistic for energy detector at a particular sensing observation is given by,

$$T = \sum_{n=1}^{N} (Y[n])^2$$

The block diagram of energy based implementation is presented in Fig. 2. There are several disadvantages of energy detection, such as selection of threshold, inefficient detection of the PU signal and not suitable for correlated signal detection. To overcome these flaws of energy detection, we have propose eigenvalue based spectrum sensing and tested it using USRP.

3.2 The proposed eigenvalue based spectrum sensing

In [7] eigenvalue based detection is presented, where, the ratio of the maximum eigenvalue to the minimum eigenvalue of the covariance matrix of the received signal vector is compared with a threshold to detect the absence or the presence of the primary signal. It has been observed that, in practical scenario sometimes the minimum eigenvalue may become $-ve$, resulting the ratio of test statistic below the threshold value which leads to increase in P_{md}. To overcome this issue we propose the decision test statistic as the ratio of maximum eigenvalue to the average eigenvalue. The system model of eigenvalue based spectrum sensing is presented in Fig. 3. In the eigenvalue based detection, the covariance matrix of the received signal is given by;

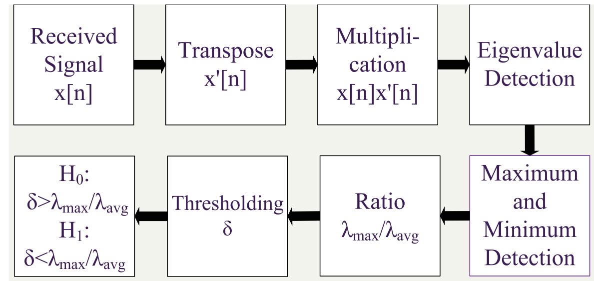

Figure 3. A system model of the proposed eigenvalue detection based spectrum sensing technique

$$\begin{aligned} \mathbf{R}_y &= \mathbf{E}\left[Y[n]Y^H[n]\right] \\ \mathbf{R}_y &= \frac{1}{N}\sum_n y[n]y^\dagger[n], \end{aligned} \tag{3}$$

here, $(.)^H$ is the hermitian transform. Next, maximum eigenvalue (λ_{max}) average eigenvalue (λ_{avg}) of the covariance matrix R_y are obtained. λ_{max} is the maximum value and λ_{avg} is the average value of eigenvalue of the $\mathbf{R}_y$ respectively. The test statistic of the proposed eigenvalue based detection is given by;

$$T(y) = \frac{\lambda_{max}}{\lambda_{avg}} \underset{H_0}{\overset{H_1}{\gtrless}} \delta \tag{4}$$

where, $\delta \geq 1$ is a threshold value, which is computed as follows [7]:

$$\delta = \frac{1 + Q^{-1}(P_{fa})\sqrt{2/N}}{den} \tag{5}$$

4 Experiment setup and performance study

In the first experiment, we ran both the ED based and eigenvalue based spectrum sensing algorithm using NI USRP 2942R device for OFDM channels, which is transmitted through the other USRP device and created a spectrum sensing database of the Lab environment channels for the varying G on the test-bed shown Fig. 1. In the second experiment, with the same setup we create database for both ED and eigenvalue based spectrum sensing by varying the separation between transmitting and receiving USRP at variable G.

First the baseband energy of the noise is obtained by switching off the transmitting USRP to calculate the appropriate threshold value for the energy based spectrum sensing. The

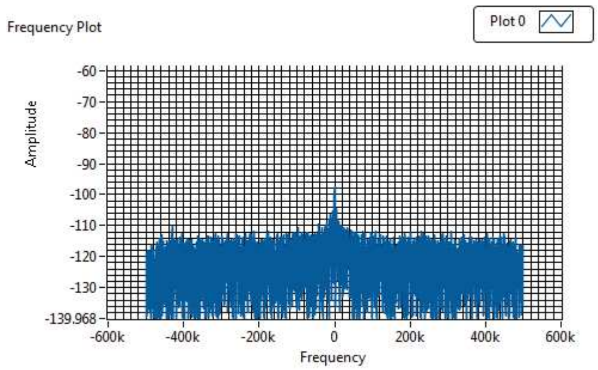

Figure 4. The measured noise power spectrum through USRP

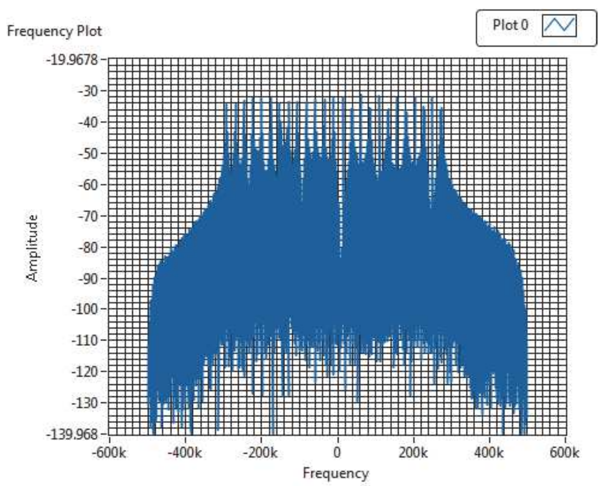

Figure 5. The measured received OFDM subcarrier power at USRP

received noise baseband power obtained around $-110dBm$, which is shown in the Fig. 4. The received PU signal OFDM subcarrier power at USRP is around $-30dBm$ as represented in Fig. 5 The performance of the ED based and eigenvalue based detection is measured in two different scenario. In first scenario, the detection performance is measured with respect to G of the USRP device, as the G is directly proportional to the received SNR of the signal. In the second scenario, the performance is measured with respect to both d and G between transmitting and receiving USRP. The simulations were performed for 1000 monte carlo simulations.

Fig. 6 to Fig. 8 illustrate the performance of both the ED based and proposed eigenvalue based spectrum sensing techniques using USRP. Fig. 6 illustrates the detection performance of both the ED based and eigenvalue based detection with respect to G of the transmitting USRP, which clearly shows that the eigenvalue based spectrum sensing technique outperforms the energy based spectrum sensing technique and eigenvalue based spectrum sensing technique

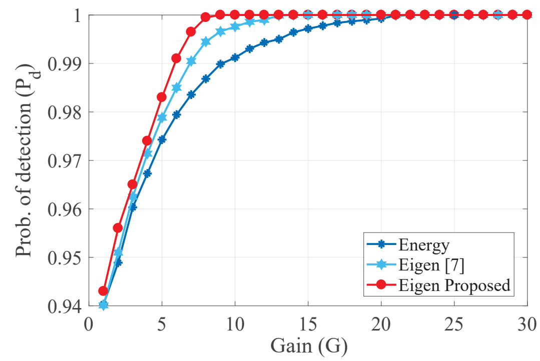

Figure 6. P_d vs. G plot for both ED and eigenvalue based detection.

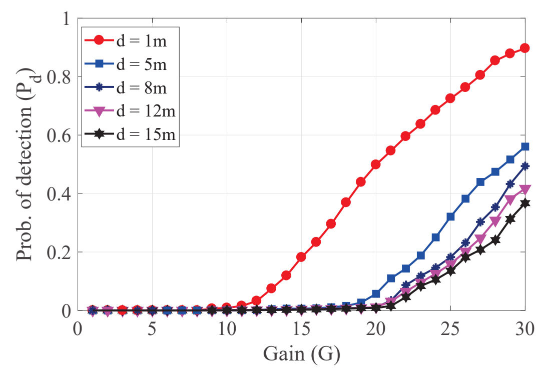

Figure 7. P_d vs. G plot for both ED based detection with different d value.

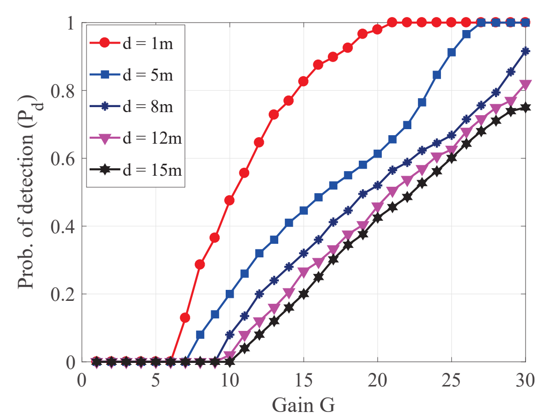

Figure 8. P_d vs. G plot for both eigenvalue based detection with different d value.

reported in [7]. It is noted that the P_d reaches to 1 at the low $G = 5$ in the proposed technique, whereas, in ED based technique P_d reaches to 1 at $G = 7$.

Fig. 7 and Fig. 8 show the detection performance with respect to both d and G, which clearly show that the detection performance is decreases when the d between transmitting and receiving USRP increase. From the experimental observations illustrated in Fig. 6 to Fig. 8, we can conclude that the proposed eigenvalue based spectrum sensing always outperforms the energy detection and previous eigenvalue based spectrum sensing technique, as in the propose algorithm the P_d approaches to 1 at a very low $G = 7$, which is sufficient for the practical application scenario.

5 Conclusion

In this paper, the experimental performance study of energy and eigenvalue based spectrum sensing are compared using USRP. Through the performance analysis it is shown that the proposed eigenvalue based spectrum sensing technique always outperforms the energy detection based spectrum sensing technique using USRP with an additional increase of little computation complexity.

Acknowledgment

The author would like to acknowledge the Ministry of Electronics & Information Technology (MeitY), Government of India for supporting the financial assistant during research work through Visvesvaraya PhD Scheme for Electronics & IT.

References

[1] Abhishek Kumar, Seemanti Saha, and Rajarshi Bhattacharya, "Wavelet transform based novel edge detection algorithms for wideband spectrum sensing in CRNs," *AEU–International Journal of Electronics and Communications*, **84**, Feb. 2018, pp. 100–110, doi: 10.1016/j.aeue.2017.11.024.

[2] Fcc, Et, "Docket No 03-222 Notice of proposed rule making and order," Dec. 2003.

[3] Muhammad Amjad, Mubashir Husain Rehmani, and Shiwen Mao, "Wireless multimedia cognitive radio networks: A comprehensive survey,"*IEEE Communications Surveys & Tutorials*, **20**, 2, Jan. 2018, pp. 1056–1103, doi: 10.1109/COMST.2018.2794358.

[4] Deepa Bhargavi, and Chandra R Murthy, "Performance comparison of energy, matched-filter and cyclostationary-based spectrum sensing," *IEEE Eleventh International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, Marrakech, Morocco, Jun 2010, pp. 1–5, doi: 10.1109/SPAWC.2010.5670882.

[5] Jarmo Lundén, Visa Koivunen, Anu Huttunen, and H Vincent Poor,"Collaborative cyclostationary spectrum sensing for cognitive radio systems,"*IEEE Transactions on Signal Processing*, **57**, 11, Nov. 2009, pp. 4182–4195, doi:.10.1109/TSP.2009.2025152.

[6] Saman Atapattu, Chintha Tellambura, and Hai Jiang,"Energy detection for spectrum sensing in cognitive radio," 2014, ISBN: 978-1-4939-0494-5.

[7] Yonghong Zeng, and Y-C Liang,"Eigenvalue-based spectrum sensing algorithms for cognitive radio" *IEEE transactions on communications*, **57**, 6, Jun 2017, 1784 – 1793, doi: 10.1109/TCOMM.2009.06.070402.