Spectrum Sensing in Cognitive Radio – A Collaborative Approach

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A review paper on Energy based detection and Cyclostationary based spectrum sensing methods followed by a collaboration of the two.

***Abstract*-Spectrum sensing is the primary feature upon which the entire functioning of the cognitive radio depends on. The cognitive radio solves the spectrum underutilization problem in a reliable and feasible manner. We require a spectrum sensor that detects spectrum holes (i.e., underutilized sub-bands of the radio spectrum), estimates the average power in each sub-band of the spectrum and identifies the unknown user (i.e. primary or secondary user).**

Cyclostationary is another desirable property that could be used for signal detection and user identification. Spectrum sensing is one of the most challenging issues in CR systems. This paper explains the collaborative sensing concept exploiting the cyclostationary features of received signals. A review of Energy based detection and Cyclostationary based sensing is covered highlighting the advantages and disadvantages of the same.

Furthermore, the collaboration of these two methodologies to form a separate algorithm for spectrum sensing is reviewed.

I. Introduction

The usable radio spectrum is a limited precious natural resource. Due to the increase in wireless devices and applications, we are facing a difficult situation in wireless communications. Currently, the licensed part of the radio spectrum is poorly utilized; this situation will only deteriorate unless we find a new practical means for improved spectrum utilization. Cognitive Radio has the potential to be the solution to this problem. The definition adopted by the Federal Communications Commission (FCC): “Cognitive Radio- A radio or system that senses it’s operational or electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets”. Hence, one main aspect of cognitive radio is related to exploiting unused spectrum to provide new paths to spectrum access.

In cognitive radio terminology, *Primary users* can be defined as users that have higher priority or legacy rights on the usage of a specific part of the spectrum.

Secondary users have low priority; exploit this spectrum in such a way that they do not cause interference to primary users. Thus, secondary users need to have cognitive radio capabilities like sensing the spectrum to check whether it is being used by a primary user and to change the parameters to exploit the unused spectrum.

As a result, spectrum sensing is the most important function of the cognitive radio. It is the task of obtaining spectrum information and list of primary users in a geographical area.

A. Spectrum Sensing

It is defined as the task of finding spectrum holes (sub-bands of the spectrum that are underutilized at a particular instant of time and specific geographic location. Specifically, the task of spectrum sensing includes:

1. Detection of spectrum holes.
2. Spectral resolution of each spectrum hole.
3. Estimation of type of user.
4. Signal classification.

The subtask of spectrum hole detection is under focus in this paper. Spectrum holes are occupied only by white noise and may also be referred to as white space. This detection can be carried out by various methodologies but we will be focusing only on Energy based detection and Cyclostationary based detection.

In both of these approaches, the detection of spectrum holes is reduced to a binary hypothesis-testing problem. Hypothesis H1 refers to the presence of a primary user’s signal (i.e. the sub-band is occupied) and hypothesis H0 refers to the presence of ambient white noise (i.e. sub-band is unoccupied).

The goal of this paper is to outline the advantages and disadvantages of the two approaches when used independently and when collaborated into one approach.

II. Energy Detector Based Sensing

This approach, also known as radiometry approach, is the most common way of sensing spectrum because of its low computational and implementation complexities. It is more generic as compared to other methods due to the fact that it does not require knowledge about the signal characteristics. The signal is detected by comparing the output of the energy detector with a threshold value that is set according to the noise floor.

Let us assume that the received signal is of the form:

$$y(n) = s(n) + w(n) \qquad ...(1)$$

Where s(n) is the signal to be detected and w(n) is the white noise (Additive White Gaussian Noise – AWGN). s(n) = 0 when there is no transmission by the primary user.

The decision metric for the energy detector can be written as:

$$M = \sum_{n=0}^{N} |y(n)|^2 \qquad ...(2)$$

Where, N is the size of the observation vector.

The decision on the occupancy of a band can be obtained by comparing the decision metric M against a fixed threshold λE.

Thus, the two hypotheses defined earlier can now be defined as:

$$H_0 = w(n) \qquad ...(3)$$

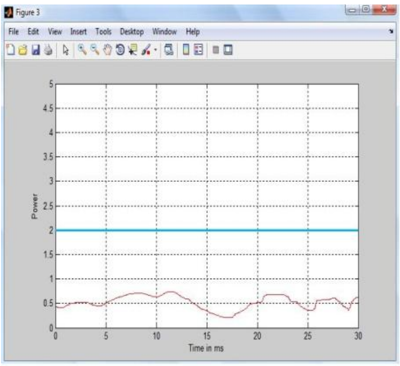

Fig. 1. Hypothesis H_0

$$H_1 = s(n) + w(n) \qquad ...(4)$$

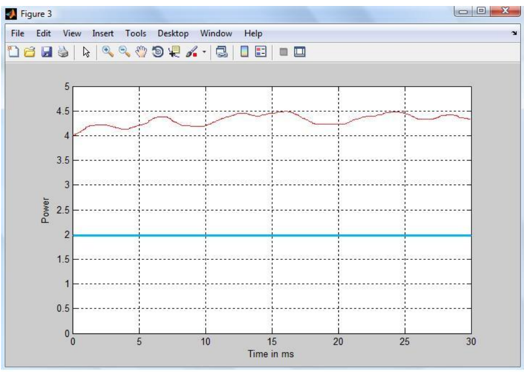

Fig. 2. Hypothesis H_1

The performance of this algorithm can be summarized by two probabilities:

Probability of detection P_D is the probability of detecting a signal when it is actually present.

This can be formulated as:

$$P_D = P(M > \lambda E|H1) \qquad ...(5)$$

- Probability of false alarm P_F is the probability of detecting a signal incorrectly when is it not present.

This can be formulated as:

$$P_F = P(M > \lambda E|H0) \qquad ...(6)$$

Obviously, P_F should be kept as low as possible in order to prevent underutilization of the spectrum. The decision threshold can be selected to obtain an optimum balance between P_D and P_F. This requires knowledge of noise and signal power present in the received signal.

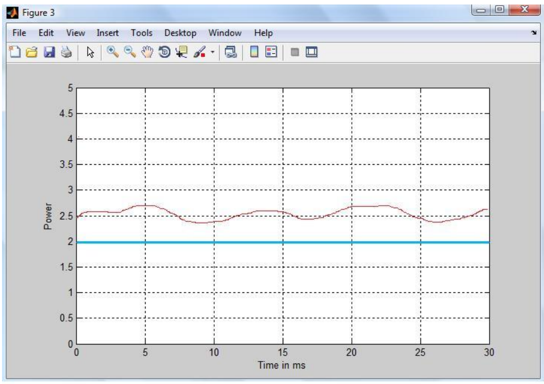

Fig. 3. False Alarm

If the value of the received signal energy is greater than the threshold, the particular spectrum is occupied and vice versa.

Fig. 3 illustrates the false detection of signal under low SNR conditions where the power of the noise is so large that it exceeds the threshold level and is falsely detected as signal whereas signal is not present in reality.

Advantages of this methodology are:-

- No particular knowledge of signal properties is required.
- Low computational and implementation complexities.

Disadvantages of this methodology are:-

- Cannot differentiate between primary user, secondary user and noise.
- Poor performance under low SNR conditions.
- If signal power is less than the threshold, PF increases.
- Does not work efficiently for detecting spread spectrum signals.

III. Cyclostationary Based Sensing

This method utilizes the cyclostationary property of the received signals. Cyclostationary features are caused by periodicity in the signal or they can also be induced intentionally to assist in spectrum sensing.

In this type of sensing, cyclic correlation function is used for detecting signals present in the given spectrum. This method can differentiate between noise and primary user signal due to the fact that noise is a Wide Sense Stationary (WSS) process with no correlation whereas modulated signals are cyclostationary with spectral correlation due to redundancy of signal periodicities. This property also helps in determining whether transmission is from a primary or secondary user.

Mathematically, the cyclic spectral density (CSD) function of a received signal can be calculated as follows:

$$S(f,\alpha) = \sum_{\tau=-\infty}^{\infty} R(\tau) e^{-j2\pi f\tau} \qquad ...(7)$$

Where

$$R(\tau) = E[y(n+\tau)y^*(n-\tau)e^{j2\pi\alpha n}] \qquad ...(8)$$

Is the cyclic autocorrelation function and α is the cyclic frequency. The CSD function outputs peak values when the cyclic frequency is equal to fundamental frequencies of the transmitted signal s(n). Cyclic frequencies can be assumed or can also be extracted and used for identifying transmitted signals.

The OFDM waveform is altered before transmission in order to generate cyclic frequencies at certain intervals. The number of features generated in the signal is increased in order to make the signal more immune to multipath fading.

The magnitude of the CSD function is again compared to a threshold (which serves the same purpose demonstrated in Energy based detection) and a decision is made based on the two hypotheses H_0 and H_1.

Advantages of this methodology are:

- It can differentiate between noise and transmitted signals in the spectrum.
- It can differentiate between primary and secondary users.

Disadvantages of this methodology are:

- Signal properties need to be known in order to extract cyclic frequencies of the transmitted signal.
- High sensitive receivers, which are required to avoid multipath fading, increase the probability of false alarm and are costly. (※ This is a hardware related issue).

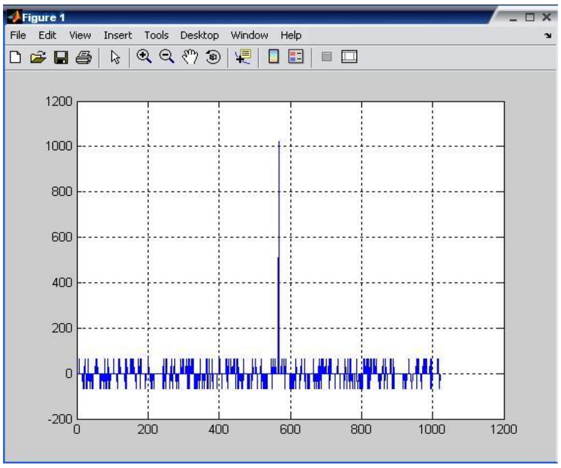

Fig. 4. Cyclic Correlation

The figure shows a high correlation value at a particular point which indicates the presence of signal at that frequency band.

IV. Collaborative Sensing

Collaboration is a solution to problems that arise in spectrum sensing due to noise uncertainty, fading and overshadowing. It decreases the probabilities of misdetection and false alarm considerably. In addition, it can solve hidden primary user problem and decrease sensing time.

It is shown analytically and through numerical results that collaborative sensing provides significantly higher spectrum capacity gains than local sensing. Furthermore, it is found that it is more advantageous to have same amount of users collaborating over a large area than over a small area.

Collaboration of two methodologies can help in nullifying the disadvantages of one method due to the advantages of the corresponding second method as illustrated above. The disadvantages of Energy based detection is overcome by the advantages of the Cyclostationary approach and vice versa.

This can be carried out by using the Energy based sensing as the primary sensing algorithm which can be used to determine the presence of spectrum holes and the Cyclostationary based sensing algorithm to determine whether the transmitting user is primary or secondary. Worst case scenario would occur when the Energy detector falsely detects white noise as a signal. This can be corrected by the Cyclostationary approach which can distinguish between noise and signals. The only effect of this scenario would be a slight increase in sensing time. This however, can be avoided by changing the threshold value of the Energy detector and pre-calculating the noise variance to achieve the desired threshold and reduce the probability of false alarm and thus increase the probability of detection.

Advantages of this methodology:

- It can differentiate between noise and transmitted signal.
- It can differentiate between primary and secondary user.
- Initial detection from the Energy detector can determine spectrum holes with very less sensing time.

Disadvantages of this methodology:

- Slight increase in sensing time when energy detector falsely detects white noise as a signal.

V. Program Output

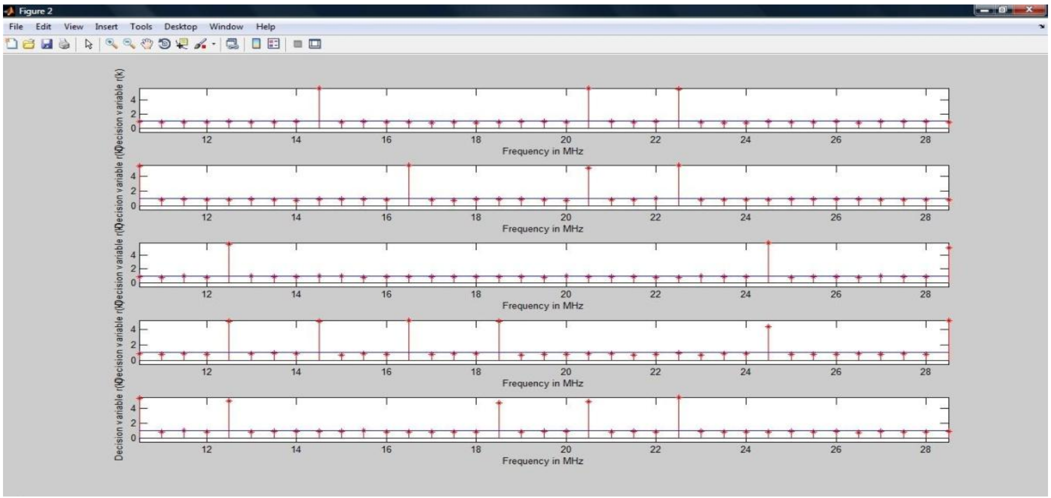

Fig. 5. Decision Variable

I have emulated an environment in MATLAB by creating 10 different users and each user is allotted a band to transmit the data signals which is also generated with carriers. Since this is a simulation environment, noise has been induced in the carrier to emulate the actual transmission.

Fig. 5 shows 5 different observations at 5 different intervals of time. It displays the decision variable and the threshold which has been set according to the noise floor. Wherever the value is above the threshold, signal is present in that band

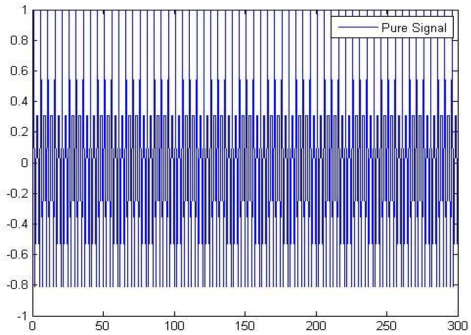

Fig.6. Generated signal (without noise)

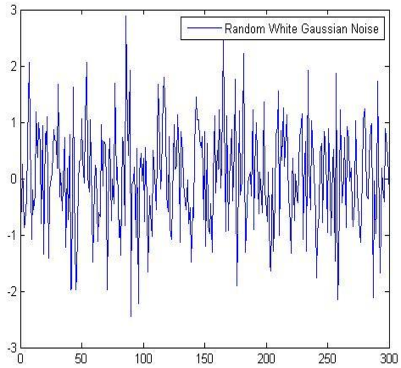

Fig. 7. Noise signal

Fig. 6 shows the carrier signal generated for a particular user. This is an ideal signal without noise. Since this is not possible in a real time environment, noise has to be induced in the signal (shown in Fig. 7).The final transmitted signal is shown in Fig. 8 which has noise along with data signal. This emulates the actual environment when data transmission takes place.

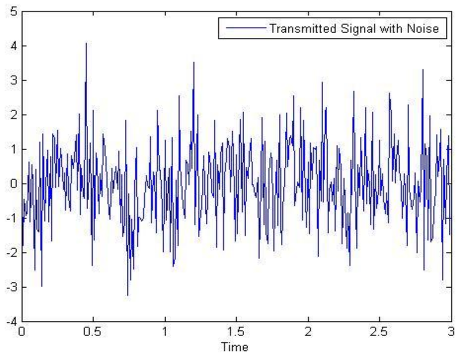

Fig. 8. Transmitted signal with induced noise.

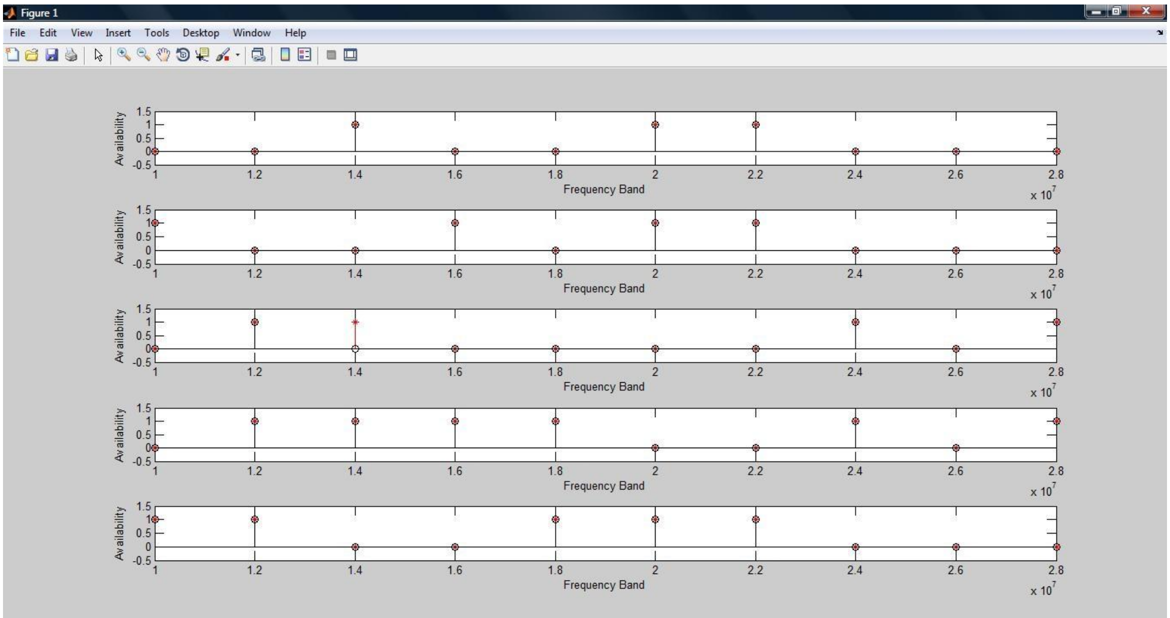

Fig. 9. Availability of Spectrum

Fig. 9 shows the availability of the spectrum. Binary '0' indicates that the band is free Binary '1' indicates that the band is occupied.

Each observation has 10 availability markings corresponding to 10 users defined in the program.

VI. Conclusion

Spectrum is a very valuable natural resource and is being underutilized. Cognitive Radio has the capability to overcome this issue. In this paper, a review of two spectrum sensingmethodologies is done highlighting their advantages and disadvantages. Finally, a collaborative approach has been suggested which helps in overcoming the disadvantages of the aforementioned techniques.

References

[1] E^3 White Paper, *"Spectrum Sensing",* November 2009

[2] V. Sharma and A. Jayaprakasam, "An Efficient algorithm for cooperative

[3] Spectrum Sensing in Cognitive Radio Networks", in *Proc NationalCommunications Conference (NCC)*, Jan 2009.

[4] V. V. Veeravalli and J. Unnikrishnan, "Cooperative spectrum sensing for primary detection in Cognitive Radio", *IEEE Jnl. on Selected Topics inSignal Processing*, Feb 2008, pp. 18-27.

[5] R. Viswanathan and P.K. Varshney, "Distributed Detection with Multiple Sensors I. Fundamentals", *Proc. IEEE*, Vol. 85, No. 1, pp. 54-63, 1997.

[6] W. Wang, L. Zhang, W. Zou and Z. Zhou, "On the distributed cooperative spectrum sensing for Cognitive Radio", *Intl. Symposium on Commn. AndInfo. Technologies*, Oct 2007, pp 1496-1501.

[7] Simon Haykin, David Thompson, Jeffrey Reed, "Spectrum Sensing for Cognitive Radio", Invited Paper.

[8] Stephen J. Shellhammer, "Spectrum Sensing in IEEE 802.22", IEEE Paper.

[9] Tevfik Yucek and Huseyin Arslan, "A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications", IEEE Paper.

[10] Maziar Nekovee, "Dynamic Spectrum Access with Cognitive Radios: Future Architectures and Research Challenges", IEEE Paper.

[11] Simon Haykin, "Cognitive Radio: Brain Empowered wireless communications", IEEE Paper.

[12] E3 White Paper, "Spectrum Sensing", November 2009