Performance Comparison of Matched filter and Energy Detector for Cooperative Sensing Model

Samrat C. Shinde
Assistant Professor, Department of Electronics Engineering,
D. Y. Patil College of Engineering and Technology
Kolhapur, Maharashtra, India.

Dr. A.N. Jadhav
HOD, Department of Electronics Engineering,
D. Y. Patil College of Engineering and Technology
Kolhapur, Maharashtra, India.

Prof.Dr. S.V.Sankpal
Professor, Department of Electronics Engineering,
D. Y. Patil College of Engineering and Technology
Kolhapur, Maharashtra, India.

Ajitkumar M. Kasabe
Assistant Professor, Department of Electronics Engineering,
D. Y. Patil College of Engineering and Technology
Kolhapur, Maharashtra, India.

Sayali S. Mane
Assistant Professor, Department of Electronics Engineering,
D. Y. Patil College of Engineering and Technology
Kolhapur, Maharashtra, India.

Abstract

In this paper we focus on spectrum sensing in cognitive radio to sense the presence of primary user. Cognitive users are allowed to utilize the licensed spectrum when the primary user is absent. Here Energy detection technique and Matched Filter detection are compared under Additive White Gaussian Noise (AWGN) channel for local spectrum sensing. To enhance the detection capability of primary user, the data of neighboring cognitive radios is collaboratively collected at global sensing, and a decision is made depending upon the unanimous decision of all the cognitive radios. The final decision may differ depending upon level of co-operation between the neighbors.

Keywords: cognitive radio, Energy detection, matched filter, cooperative sensing.

Introduction

The available radio spectrum is limited and it is getting crowded day by day as there is increase in the number of wireless devices and applications. The issue of spectrum under-utilization in wireless communication can be solved in a better way using Cognitive Radio (CR). A cognitive radio is a system capable of sensing several spectrum bands, determine if there are unused portions, and adapt to operate in the vacant bands [1]. The spectrum sensing mechanisms implemented by CRs should reliably detect the presence and absence of primary signals in real time. If the primary user is not using the available bandwidth then it should be allotted to secondary cognitive users, to increase the efficiency of network. Once cognitive radios detect the presence of a primary user in their operating band, they must vacate the band immediately, and must not hamper the primary users functioning. Hence, accurate spectrum sensing is an essential feature of CR systems[3].

However, the effect of fading and shadowing on the spectrum sensing process can be very negative. These two problems can result in a secondary user failing to detect a primary signal, which is known as the hidden node problem. In order to avoid this problem, cognitive radio systems must be somewhat more sensitive in detecting the primary transmissions than the primary receivers. In order to reduce the individual sensitivity requirements of CRs, the technique that has been used is collaborative spectrum sensing.[2]

Our objective is to minimize the interference to the primary radio while meeting the requirement of opportunistic spectrum utilization. For this purpose performance of an Energy detector which is one of the spectrum sensing techniques is studied. The study includes behavior of detector under different channels like Additive White Gaussian Noise (AWGN) Channel and Rayleigh fading channel. Further to improve spectrum sensing efficiency, collaborative spectrum sensing is considered. This technique increases the probability of sensing the spectrum holes and avoiding the interference to primary user. Collaborative spectrum sensing is based on combining the sensing results of multiple cognitive radio nodes to reach the final decision.

System Model

The system model considered for cooperative sensing is described in this section. The sensing of spectrum is divided into parts one is Local spectrum sensing, which consists of CR users sensing the radio channel which is indented for primary user (licensed user). The second part consists of Global sensing, which deals with collecting the decisions of all the CRs at central decision fusion center. The availability of spectrum holes is then decided by this block. Here we assume that there are 'N' CRs in the vicinity which are interested in detecting spectrum holes and utilize the spectrum to its fullest extent.

Local Sensing

The sensing of signals through the radio environment which are intended for primary user is very challenging job. There are many proposed techniques such as Matched filter, Energy detector, Cyclostationary feature detector, but out of them Energy detector [2] is best as, it requires no prior knowledge of the signal and complexity is also very low. Hence Energy detector technique is implemented in our system for local sensing. The local spectrum sensing is carried out by using binary hypothesis testing.

$$x(t) = \begin{cases} n(t) & H_0 \text{ Primary user is absent} \\ h\, s(t) + n(t) & H_1 \text{Primary user is present} \end{cases}$$

Where $x(t)$ is signal received by CR, s(t) is signal transmitted for primary user, $n(t)$ is AWGN introduced and h is amplitude gain .

Matched Filter

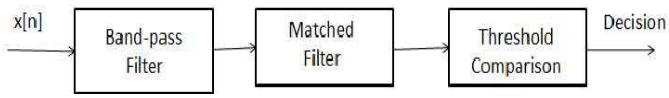

Fig. 1. Matched Filter Detection

The local sensing can be carried out using either Matched filter detection or Energy detection. Each detector has its own advantage and disadvantages. The Matched Filter Technique is very important in communication as it is an good filtering technique which maximizes the signal to noise ratio (SNR). It is a linear filter and prior knowledge of the primary user signal is very essential for its operation. The operation performed is equivalent to a correlation. The received signal is convolved with the filter response which is the mirrored and time shifted version of a reference signal. The operation of matched filter can be shown using Fig.1 and the probability of detection and Probability of missed detection can be given using Eq. (1), which depend upon threshold value and sifnal to noise ratio[2].

$$P_{FA,MFD} = Q\left(\frac{\tau_{MFD}}{\sigma_w\sqrt{E}}\right), P_{D,MFD} = Q\left(\frac{\tau_{MFD} - E}{\sigma_w\sqrt{E}}\right) \quad (1)$$

Energy Detector

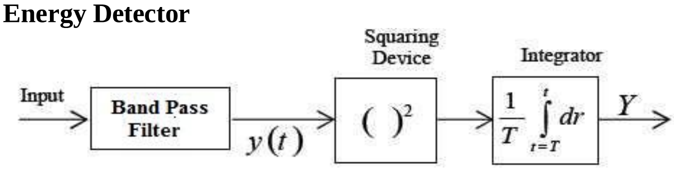

Fig. 2. Energy Detection

Energy detection is based on measuring the energy received over an observation interval. The received signal on the secondary terminal passes through a band pass filter and it is integrated over the time of observation as shown in Fig.2. The output signal is the test statistic and is compared with a threshold. This method cannot discriminate between the primary signal and noise, and hence makes it difficult to set the threshold used for primary user detection, especially at low SNR. However, energy detectors are widely used because of their simplicity [4]. (2)

$$P_{FA,ED} = 1 - P(\frac{\tau_{ED}}{2}, L)$$

$$P_{D,ED} = 1 - Q_{\chi^2}(\tau_{ED}, 2L, \frac{MLP_s}{2\sigma_w^2}) \quad (3)$$

The probability of detection and probability of false alarm for energy detector can be given by Eq. (2) and Eq. (3) respectively. The probability of false alarm for given threshold is given by $P(a, x)$ is a incomplete gamma function. The probability of detection is given by $Q(x, v, d)$ is non cumulative distribution function. The detection probability of energy detector is less compared to matched filter as it is non-coherent type of detection. The advantage of energy detection is that it does not require any prior knowledge of the channel.

Cooperative spectrum sensing

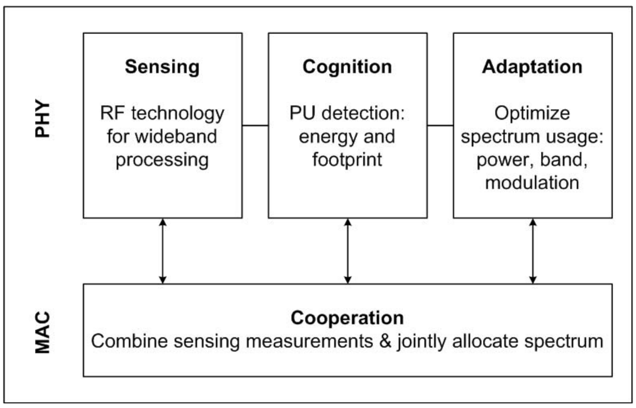

Fig. 3. Cross layer functionalities related to spectrum sensing

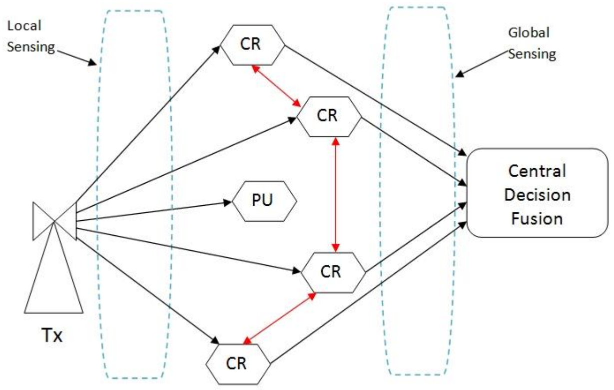

Fig. 4. Cooperative spectrum sensing: Cognitive Radios (CR) senses the radio channel by local sensing, intended for Primary user (PU) .Here each CR is sharing information with each other and then sends the status of channel to central fusion block as global sensing.

To increase the sensing capability of individual cognitive radio all the cognitive radios in the network send the sensed data to the centralized fusion center as shown in Fig.4. The transmitter is transmitting for the primary licensed user the channel is continuously monitored by all the cognitive radios for the free spectrum. When free spectrum is available all the CR's in the network send the sensed data to the fusion center and decision is made regarding the availability of spectrum. The decision generated by each CR at local sensing is one bit decision {0, 1} is transmitted to the central decision fusion center transmitted in binary form. {0} indicated that primary user is absent and {1} indicates that primary user is present. At central fusion center one bit decisions of all the CR's are clubbed together. Here H1 and Ho is the processed decision of central fusion center whether primary user is present or absent [5] [6].

In cooperative sensing all the cognitive radios monitor the spectrum and send the sensed data to the centralized fusion center for processing. Even though their positions are different they maintain same signal to noise ratio and threshold level, this leads to robust decision at fusion center. Considering the same threshold (λ) level at each CR, the false alarm probability (Q_f) and missed detection probability (Q_m) for cooperative sensing can be found using Eq.(4) and Eq.(5)

$$Q_f = 1 - \prod_{i=1}^{K} [(1 - P_{f,i})] \tag{4}$$

$$Q_m = \prod_{i=1}^{K} P_{m,i} \tag{5}$$

Where $Pf_{,i}$, $Pm_{,i}$ are the probability of false alarm and probability of missed detection for local spectrum sensing of *i*th CR respectively.

The data send by all the cognitive radios in the network is collected at the central fusion center. This data needs to be processed at fusion center and the fusion center has to come to conclusion regarding the availability of vacant spectrum. For this processing we are considering hard decision combining technique. In this technique one bit locally sensed data from each cognitive radio is collected and combined using k-out-of-N rule.

$$Qd = \sum_{l=k}^{N} \binom{N}{l} (P_{d,i})^l (1 - P_{d,i})^{N-l} \tag{6}$$

Simulation Results

Local Sensing

Local sensing can be carried out using either matched filter detection or energy detection. In this paper we have used both the detection techniques for the performance analysis. We have plotted graph of number of pulses versus the detection threshold for two detection techniques, and it is found that as number of pulses goes on increasing the detection threshold required for sensing the channel also increases as seen in Fig.5. Further when we compare between the two techniques implemented as shown in Table 1, we can see that detection threshold required for energy detection is high as compared to matched filter detection for same number of pulses of integration [7].

The advantage of energy detection over match filter detection is that, it requires no prior knowledge of channel. Thus considering the energy detector for local sensing and sending the sensed data to the central fusion center we can fuse the data of all the cognitive radios in surrounding environment.

Cooperative Sensing

A set of simulations is performed using energy detector for primary signal determination. The result of these simulations leads to concept of centralized fusion center, where all the data of each cognitive radio is combined together and depending upon the level of cooperation between cognitive radios the results differ [4] [7].

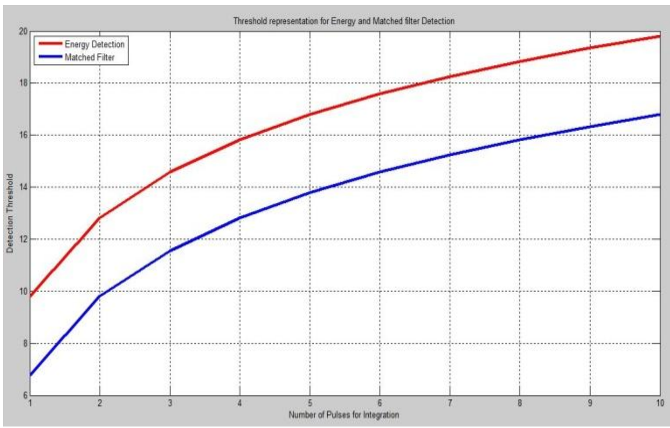

Fig.5. Plot of Number of Pulses versus detection threshold for Energy Detector & Matched filter

When we plot receiver operating characteristics of cooperative and non-cooperative spectrum sensing for false alarm probability (Qf) and missed detection probability (Qd), it can been seen that cooperative spectrum sensing has better performance compared to non-cooperative sensing as shown in Fig.6. False alarm probability (Qf) and missed detection probability (Qd), it can been seen that cooperative spectrum sensing has better performance compared to non-cooperative sensing. It can be seen from Fig.4 that after increasing the signal to noise ratio the performance of system enhances but still cooperative sensing outperforms the non-cooperative sensing.

Number of Pulses for Integration	Detection Threshold	
	Matched Filter	Energy Detector
1	6.789522612	9.799822569
2	9.799822569	12.81012253
3	11.56073516	14.57103512
4	12.81012253	15.82042248
5	13.77922266	16.78952261
6	14.57103512	17.58133507
7	15.24050301	18.25080297
8	15.82042248	18.83072244
9	16.33194771	19.34224766
10	16.78952261	19.79982257

Table 1. Represents detection threshold of Matched filter and Energy detector for different number of pluses.

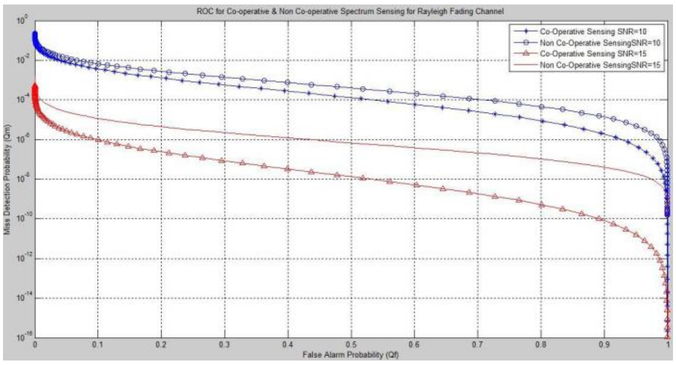

Fig. 6. ROC for false alarm probability Q(f) versus missed detection probability Q(d)

Conclusion

In wireless communication spectrum is very valuable resource. Cognitive radio is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage. One of the important elements of cognitive radio is sensing the available spectrum opportunities. The new interpretation of spectrum space creates new opportunities and challenges for spectrum sensing. To overcome individual sensing issues like fading, shadowing and hidden node cooperative spectrum sensing is suitable. Cooperative spectrum sensing is considered the best for centralized spectrum sensing.

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