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A Novel Hybrid Approach for Spectrum Sensing in Cognitive Radio

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Abstract— Cognitive Radio (CR) is a technique used to improve utilization of the radio spectrum. It is a software controlled radio that senses the unused frequency spectrum at any time. Spectrum sensing in CR is challenged by a number of uncertainties, which degrade the sensing performance and in turn require much more time to achieve the targeted sensing efficiency. Reliable spectrum sensing is one of the most crucial aspects for the successful deployment of cognitive radio technology. Hybrid spectrum sensing scheme is proposed which obtains reliable results with less sensing time. First, the scheme determines better an energy detection method, or a combination of energy and matched filter based detectors based on the SNR of the signal. In the combined energy and matched filter detector, an energy detector with certain value of threshold is used, and the matched filter detector is applied only if user is not detected by energy detection method. Second, sensing is performed by dedicated sensing receiver that is with the use of multiple antennas which reduces sensing time. To evaluate the scheme's performance, the results are compared with those where only an energy detector, matched filter are performed. The performance metrics are the probability of detection, probability of false alarm and sensing time.

Index Terms— Cognitive Radio(CR), Energy detection, Matched Filter based detection , Primary User(PU), Secondary User(SU), Spectrum Sensing, Sensing Time.

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1 INTRODUCTION

Cognitive radio (CR) technology is a new way to compensate the spectrum shortage problem of wireless environment. It enables much higher spectrum efficiency by dynamic spectrum access [1]. It allows unlicensed users to utilize the free portions of licensed spectrum while ensuring no interference to primary user's transmissions. Cognitive radio arises to be tempting solution to the spectral congestion problem by introducing opportunistic usage of the frequency bands that are not heavily occupied by licensed users [2], [3]. FCC define cognitive radio [2] as, "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, access secondary markets".

Hence, one main aspects of cognitive radio is related to autonomously exploiting locally unused spectrum to provide new paths to spectrum access. In cognitive radio terminology, PU can be defined as the user who has license to use a specific part of the spectrum. On the other hand, secondary users (SU) or CR users do have license to use the spectrum but can use the spectrum when PU is absent. When PU is present CR user shift its transmission to another frequency or changes other modulation parameters and never causes interference to primary users. Therefore, SUs need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether it is being used by a PU and to change the radio parameters to exploit the unused part of the spectrum. Spectrum sensing [4] is the most important task among others for the establishment of CRs because they need to sense the spectrum band for a spectrum hole [5], decide to use the spectrum band or not. A number of different techniques are proposed for identifying the presence of the PU signal transmission.

The existing spectrum sensing techniques are broadly divided into three categories [5]: energy detection, matched filter detection, and cyclostationary detection. Matched filter energy detection and cyclostationary detection are widely used techniques as detection techniques. Among them, energy detection has been widely applied since it does not require any a priori knowledge of the primary signals and has much lower complexity than the other two schemes. In addition, it does not need any priori information about the PUs' signals. Therefore, it has been thoroughly studied both in local spectrum sensing [4], [5], [6]. In this paper energy detection technique is studied to view its performance in sensing.

This paper is organized as follows: Section 2 explains the related work, Section 3 briefs about the system model. Section 4 describes simulation result and discussion and finally conclusion is drawn in section 5.

2 SPECTRUM SENSING

The Secondary User (SU) will continuously monitor the Primary User (PU), and if it is free it will engage otherwise, SU will quit that particular PU and switch to another frequency band to avoid intrusion. This technique is known as spectrum sensing. Spectrum sensing can be classified as: transmitter detection, cooperative detection and interference based detection [7].

2.1 Cooperative Detection

It works by combining the observations of several CR users. It improves the performance of spectrum sensing [6]. Centralized and Decentralized coordinated technique is one of

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the important classifications of this. In centralised technique, One CR will identify the presence of a primary transmitter or receiver. This information will be conveyed to the CR controller which is a wired immobile device or can be a new CR user. The CR controller monitors all the users in its range by a control message. In Decentralized coordinated technique there is absence of the controller. Decentralized uncoordinated technique is also one of the type of cooperative detection. In this method, the cognitive users don't have cooperation. Each user will independently identify the channel. When a CR user detects a primary user it will vacate the channel immediately without intimating the other users. Hence, CR user's experience bad channel realizations and spot the channel imperfectly thus causes interference at the primary receiver [7].

2.2 Non Cooperative or Primary Receiver based Detection

Primary users are detected based on the signal received at CR User-receiver.

Energy Detection:
The input signal is filtered using the band pass filter to select the bandwidth of interest [8]. The output signal is squared and then integrated over the observation interval. The output of integrator is compared to a threshold level to find out the presence of primary user [9].It does not need former knowledge of primary user signal, and it can be implemented easily. The limitations are the sensing time is high, and the performance of the energy detector is highly susceptible to noise. The major challenge in this technique is to set the right threshold for detection.

Matched filter detection:
This is a linear filter used to maximize the output SNR for a given input signal. The input signal x(t) is passed through a band-pass filter. It measures energy around the related band. The output is convolved with the matched filter whose impulse response is same as the reference signal. The matched filter output value is compared to a threshold value to detect the presence or absence of primary user. This method can be used in case when the primary user's information is known [7]. It needs less detection time and the limitation is that it requires prior knowledge of every primary signal. If no information is accurate, this technique works poorly. Also each CR needs a dedicated individual receiver for every type of primary user [10], [11].

Cyclostationary feature detection:
In this detection technique, CR can distinguish between noise, and user signal by analyzing its periodicity [10]. The periodicity is embedded in sinusoidal carriers, pulse trains of the primary signals. The filter is used to measure the energy around the related band and then FFT is computed. Correlation block will correlate the signal and feature [7].

The main advantage of the feature detection is robustness to noise and it can categorize the noise energy from the modulated signal energy. The technique requires long observation time and more complex, which results in high cost [10].

In Covariance based signal detection, the main idea is that to exploit the covariance of signal and noise because the statistical covariance of signal and noise will be different [11].This is complex and requires more sensing time. Random hough transform based detection Can be used for primary user detection. The Hough transform is used for pattern detection in image processing. If some patterns related to primary users are identified, CR users assume that PU uses the spectrum. Otherwise, CR users will assume that the band is idle for given time and location. Radio identification based detection technique is based on extracted features such as transmission range, transmission frequency, and modulation technique from the received Signal. Users can select suitable transmission parameters by exploiting those features according to the Sensed information. One method is known as waveform-based detection. In this approach, the patterns corresponding to the signal, such as transmitted pilot patterns, preambles are used in wireless systems for synchronization or to detect the signal presence [5], [6], [7], [10].

2.3 Interference based Detection

Primary receiver detection:
When receiving the data from the primary transmitter the receiver will emit the local oscillator leakage power from its RF front end. Primary signal can be detected using this leakage power [7]. By mounting a low-cost sensor close to a primary user's receiver the presence of primary user can be detected. The leakage power expelled by the RF of the PU's receiver, which presents within the CR system range, will be detected by the sensor. The local sensor informs the sensed report to the CR users in order to identify the spectrum occupancy status.

Interference temperature management method is the best technique for shielding the licensed users from the interferences caused by secondary users which can avoid the hidden terminal Problem. The primary and secondary users co-exist and transmit their data simultaneously.

There are some Other Signal Processing Approaches such as multi-taper spectrum sensing, wavelet-based detection and filter bank based spectrum sensing. In *Multi-taper spectrum sensing and estimation* technique, the last N received samples are collected in a vector form and are represented as a set of slepian base vectors. The Slepian base vectors are used to identify the spectrum opportunities in the targeted spectrum band. Filter bank based spectrum estimation (FBSE) is considered as simplified version of MTSE. MTSE is better for small samples whereas FBSE is better for the huge number of samples [5], [6], [7], [10]. For the detection of wide-band signals, the wavelet approach is advantageous in terms of both implementation cost and flexibility. The spectrum is decomposed into smaller sub-bands to apply the wavelet based approach called as *Wavelet detection* to detect the edges in PSD. In this, the edges on the PSD are the separator of occupied bands and spectrum holes for a given time and location. Based on this information, SU users can identify spectrum holes [7].

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2.4 Dedicated Sensing Receiver

A multi resolution sensing technique is used, where the parallel sensing employed to reduce the total sensing time. This system requires multiple data-chains at the receiver and, hence, is amenable to multiple-antenna receivers. In the case of an M antenna receiver is used, the total sensing time is reduced by an approximate factor of M [13]. Both the main receiver and the DSR in Fig.1 perform the coarse sensing in essence sharing the work between the two receivers [14]. Once the initial results in the look up table (LUT), the DSR performs the fine sensing on the candidate channels in order to avoid conflict with a primary user (PU) or another secondary user (SU), continuous channel monitoring is done via detectors in the analog domain because of their fast response time. Also, to take full advantages of the

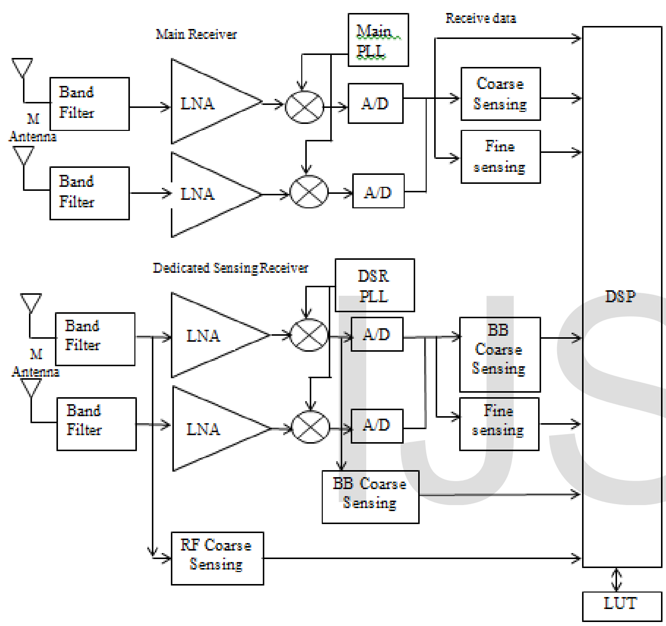


Fig. 1.Dedicated Sensing Receiver Architecture

DSR, radio architecture and especially the phase locked loop (PLL) must be able to quickly hop and settle onto the desired frequency.

Without an agile PLL, the system scan time would be gated by the radio hardware. The overall PLL design is critical to the performance, cost and complexity of the CR specifically across wideband operation. One important aspect of the cognitive radio network is to insure that the CR does not interfere with a PU or another SU in the band. There are many challenges in radio such as receiver sensitivity, dynamic range, frequency generation (synthesizers) and other RF impairments [15]. These challenges can be solved by using “RF Coarse Sensing” as shown in Figure 1 and the analyses in the next sections.

3 System Model and Framework

3.1 Energy Detection Method

If the secondary user cannot gather sufficient information about the PU signal, the optimal detector is an energy detector, also called as a radiometer. It is common method for detection of unknown signals. The block diagram of the energy detector is shown in Figure 2.

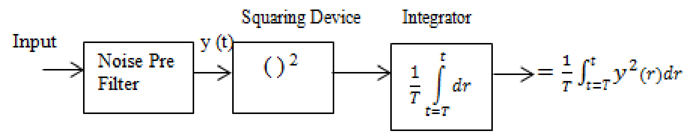


Fig. 2.Energy based Detection

First, the input signal y(t)is filtered with a band pass filter (BPF) in order to limit the noise and to select the bandwidth of interest. The noise in the output of the filter has a bandlimited, flat spectral density. Next, in the figure there is the energy detector consisting of a squaring device and a finite time integrator [8].

The output signal V from the integrator is

$$V = \frac{1}{T}\int_{t-T}^{t} |y(r)|^2 dr \qquad (1)$$

Finally, this output signal V is compared to the threshold n in order to decide whether a signal is present or not. The threshold is set according to statistical properties of the output V when only noise is present. The probability of detection Pd and false alarm Pf are given as follows [9].

$$Pd = p\{y > \lambda \backslash H1\} \qquad (2)$$
$$Pf = p\{y > \lambda \backslash H0\} \qquad (3)$$

From the above functions, while a low Pd would result in missing the presence of the primary user with high probability which in turn increases the interference to the primary user, a high Pf would result in low spectrum utilization since false alarm increase the number of missed opportunities. Since it is easy to implement, the recent work on detection of the primary user has generally adopted the energy detector. However, the performance of energy detector is susceptible to uncertainty in noise power. In order to solve this problem, a pilot tone from the primary transmitter is used to help improve the accuracy of the energy detector. The energy detector is prone to the false detection triggered by the unintended signals [8], [9].

3.2 Matched Filter based detection

To enrich the SNR, a matched filter is often used at the receiver front end as shown in Fig. 3. Matched filter coefficients are basically given by the complex conjugated reversed signal samples in terms of discrete signals [11]. Two types of coherent or non-coherent receivers are used based on signal analysis either as complex signals or noises.

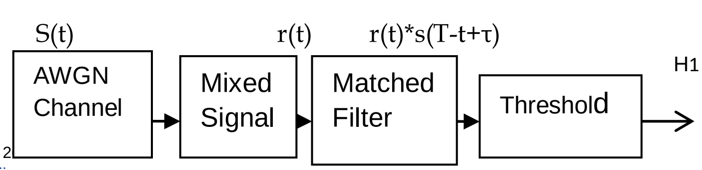


Fig. 3.Matched Filter based Detection H0

If the amplitude and phase of the received signal are known coherent receivers are used results in a perfect match between the matched filter coefficients and the signals. In case of a noncoherent receiver, the received signal is modelled as a replica of the original signal with a random phase error. With a noncoherent receiver the detection after the matched filter is generally based on the power or magnitude of the signal since we need both real and imaginary parts to define the signal entirely [12]. Power Spectral Density (PSD) of the AWGN signals is given

$$PSD_{AWGN}(f) = \frac{No}{2} \tag{4}$$

Where N0 is the noise signal and AWGN channel Signal to Noise Power measured at the output of the matched filter is given by [11],

$$SNR = \frac{|S(t)|^2}{|N(t)|^2} \tag{5}$$

The output noise power P_n calculated of n^{th} primary user is found to be [11]

$$P_n = \frac{N_0}{2}\int_{-\infty}^{+\infty} |H_n(f)|^2 df \tag{6}$$

The output signal power Ps primary user is found to be calculated of the nth [11],

$$P_s = \int_{-\infty}^{+\infty} \left|H_n(f)S_i(f)^{e^{j\omega t}} df\right|^2 \tag{7}$$

Output signal power Ps is decomposed in terms of input signal power Si using Schwartz inequality [11],

$$P_s = \int_{-\infty}^{+\infty} |H_n(f)df|^2\, P_{is} \tag{8}$$

Now the SNR of the primary user is simplified to SNRo

$$SNR_0 = \frac{2P_{is}}{N_o} \tag{9}$$

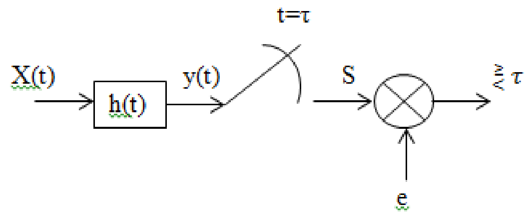
The above equation represents the PU signal over the noise.

Detection of Primary User Signal In Additive White Gaussian Noise Channel: [11]

The reason behind introducing Matched Filter implementation is to model the evolution of PU signal in the spectrum band considered over time by measurements using CR. In this section, we consider the basic functional model of linear matched filter. Primarily matched filter implementation is best suitable for radar, sonar, wireless communication systems, Intelligent Radio Systems and binary detection of AWGN channel as shown in Fig. 4.

Binary detection problem is used to identify the state of PU signal presence or absence in AWGN channel in the time interval of 0 = t = T. The binary hypothesis specified by H_1 and H0 indicates the presence and absence of PU signal [11], [12] in the channel considered.

Fig. 4.Matched Filter Implementation



$$H_0 : Y(t) = N(t) \tag{10}$$

$$H_1 : Y(t) = s(t) + N(t) \tag{11}$$

Here N(t) is the AWGN with zero mean and co-variance of s d(t-s), where s is the power density of intensity of the AWGN signal [11], [12]. In order to detect the PU signal an orthonormal basis function in signal space {Fi (t), i *E* I} of space S [0,T] integrable over the function [0,T]. As the first element of the basis, we select the function as

$$\phi_1(t) = \frac{s(t)}{E^{\frac{1}{2}}} \tag{12}$$

$$E = \|s^2\| = \int_0^T s^2\, dt \tag{13}$$

If we identified orthonormal basis {F (t), i *E* I}, using Karhunen-Loeve decomposition [11] AWGN noise N(t) decomposed to

$$A = \int_0^T N(t)\, \phi_i(t) dt \tag{14}$$

Similarly in [11], received signal Y(t) can be de-composed to

$$Y_i = \int_0^T Y(t)\, \phi_i(t) dt \tag{15}$$

Under signal space domain, the detection problem reduces to one dimensional problem as [11],

$$H_0 : Y_1 = N_1 \tag{16}$$

$$H_1 : Y_1 = E^{\frac{1}{2}} + N_1 \tag{17}$$

Now the Binary Hypothesis theory in terms of Generalized Likelihood Ratio Test (GLRT) [11], [12] statistics established as

$$L(y_1) = \frac{exp\left(-\frac{1}{2\sigma^2}\left(y_1 - E^{\frac{1}{2}}\right)^2\right)}{\exp\left(-\frac{1}{2\sigma^2} y_1^2\right)} \gtrless \tau \tag{18}$$

where t denotes the threshold and taking logarithms and reorganizing the resulting identity gives

$$Y_1 \gtrless \tau \tag{19}$$

Hence the optimum filter expressed [12] in terms of sufficient statistics S as,

$$S = \frac{1}{E^{\frac{1}{2}}} \int_0^T Y(t)s(t)\,dt \tag{20}$$

Under binary hypothesis it is observed that Y1~N(0, s2) based on H0 and Y1~N(E1/2, s2) based on H1. If r denotes the distance between the two hypotheses measured in terms of noise standard deviation [11], [12].
Different types of responses based on old stimulus to a correct response, called detection whereas a yes response to a new stimulus is a miss, called a false alarm (FA). A No response given to a new stimulus is a true response, called a Correct Rejection whereas a No response to an old stimulus is a false response called a Miss or a false alarm (FA). It is shown that the probability of detection PD and Probability of false alarm PF for the test are given by

$$P_D = 1 - Q\left(\frac{r}{2} - \frac{\ln(\tau)}{r}\right) \tag{21}$$

$$P_F = Q\left(\frac{r}{2} - \frac{\ln(\tau)}{r}\right) \tag{22}$$

By using Neyman-Pearson (NP) test [11], [12] and eliminating the threshold from the above identities we achieve

$$P_D = 1 - Q\left(r - Q^{-1}(P_F)\right) \tag{23}$$

3.3 Proposed Hybrid Sensing Approach

Without any prior knowledge of primary user the best and simplest technique of sensing is energy based detection. In this method energy of the received signal is measured and if it is

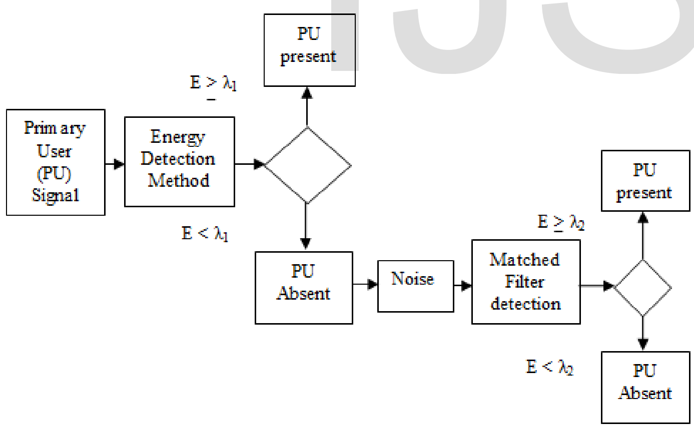


Fig. 5.Hybrid Sensing Approach

above threshold value then presence of primary user is assured otherwise it is declared as a noise. The disadvantage of this method is low SNR that is weak signals considered to be noise remains undetected. This drawback can be overcome by matched filter method which gives better sensing in terms detection of primary users even if they are of low SNR. Matched filter needs priori information about the user to work upon.

Proposed Hybrid approach of sensing combines energy based detection and matched filter method such that advantages of both the methods of detection get beneficial. The proposed approach is detailed in Fig .5. Each Primary user (PU) is first detected by energy based detection (EBD). If signal is weak, EBD gets unsuccessful and declares it to be noise. Then that PU signal is passed on to Matched filter detection. The output of matched filter is expressed in terms of values of probability of detection for values of probability of false alarm (Receiver operating characteristics curve)

3.4 Scanning Time Analysis

Assume that overall system band width $Bsys$ is divided into coarse bins B_{crs}. Each coarse bin is further divided into a fine bins $Bfin$ as shown in Fig. 6. As shown in Figure 2 shows that the system bandwidth and coarse resolution sensing bandwidth should be an integer multiple of $Bcrs$ *and* $Bfin$ respectively as given by equations (24) and (25)

$B_{sys} = \beta B_{crs}$ where $\beta = 1, 2, 3, 4, \dots$ (24)
$B_{crs} = \alpha B_{fin}$ where $\alpha = 1, 2, 3, 4, \dots$ (25)

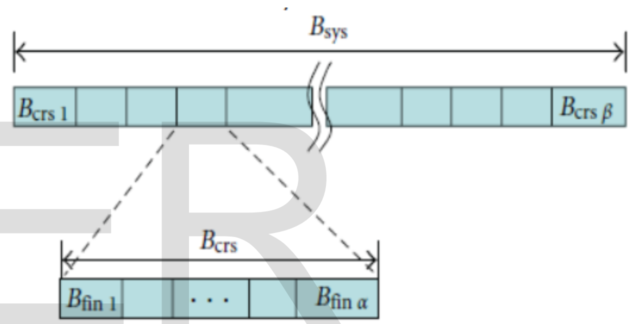


Fig. 6.System Scan time Analysis

In order to compare the sensing time for the new parallel, multi-resolution sensing approach to the serial, fixed resolution approach, we first define the bandwidths of the coarse and fine resolution sensing modes, $Bcrs$ and $Bfin$ respectively [14].
is set by the number of points in the FFT, N, as well as the minimum sensing frequency resolution, $Fres$, and is given by:
$Bfin = NFres$ where $Fres$ is the resolution of the sensing. The total time to perform a discrete Fourier Transform (DFT) is given [15] as:

$TDFT = (1/F_{DSP})\ (4N\log_2 N - 6N + 8)$ (26)

where $FDSP$ is the DSP operating frequency. For simplicity, assume that the DSP is capable of performing one addition and one multiplication per clock cycle, the total sensing time for coarse and fine sensing of the total bandwidth are given by: [13],[14]

$$T_{crs} = \frac{B_{sys}}{\propto NMF_{res}F_{DSP}}\left[4\frac{N}{M}\log_2\frac{N}{M} - 6\frac{N}{M} + 8\right] \tag{27}$$

$$T_{fin} = \frac{\propto}{F_{DSP}}\left[4N\log_2(N) - 6N + 8\right] \tag{28}$$

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The overall system sensing time requires including the radio tuning time which is mostly dominated by the PLL lock times. Let us define three different PLL locks times: T_{init} the initial lock time, $T_{PLL_{crs}}$ the PLL lock time for a coarse step, and $T_{PLL_{fin}}$ to indicate to the PLL lock time for a fine step. So, the total PLL sweep time $T_{PLL_{crs}}$ during the sensing operation is given by: [13], [14]
And, the overall system scan time is descriptive as: [13], [14]
where N_{crs} and N_{fin} are the number of FFT points used in coarse and fine mode, respectively.

$$T_{PLL_{sys}} = T_{init} + \alpha\beta T_{PLL_{fin}} + \beta T_{PLL_{crs}} \tag{29}$$

$$T_{sys} = \frac{B_{sys}}{\propto M N_{crs} F_{crs} F_{DSP}}\left[4N_{crs}\log_2(N_{crs}) - 6N_{crs} + 8\right] + \frac{\propto \beta\rho}{F_{DSP} M}\left[4N_{fin}\log_2(N_{fin}) - 6N_{fin} + 8\right] + T_{init} + \frac{\propto \beta\rho}{M} T_{PLL_{fin}} + \frac{\beta}{M} T_{PLL_{crs}} \tag{30}$$

4 Results and Analysis

4.1 Simulation Results and Discussion

In order to increase the performance of spectrum sensing, it allow various SU to cooperate by sharing their information and to reduce the communication overheads, users share their decision statistics based on the binary hypothesis testing. In signal estimation theory, a receiver operating characteristic

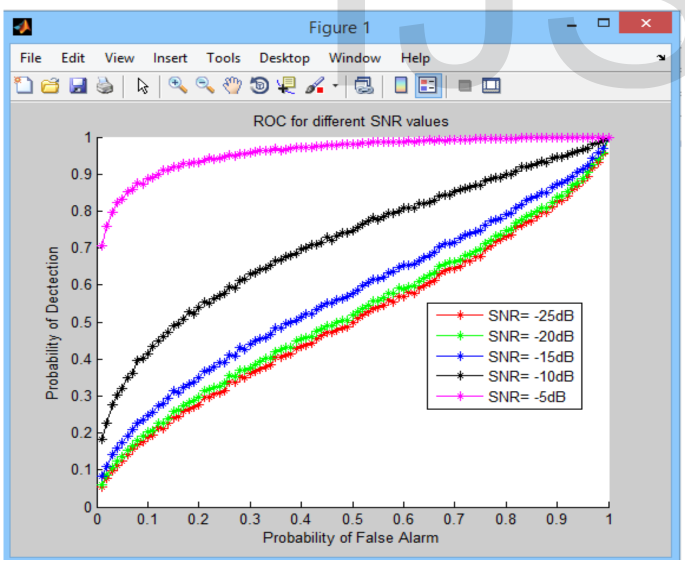

Fig. 7.Receiver Operating Characteristics curve for Energy detection

(ROC) curve is a graphical plot which demonstrates the performance of a binary classifier system as with threshold variation. It is created by plotting the probability of detection (PD) vs. Probability of False alarm (PF), at various threshold values. In general, if both of the probability distributions for detection and false alarm are known, the ROC curve can be generated by plotting the Cumulative Distribution Function of the detection probability in the y-axis versus the Cumulative Distribution Function of the false alarm probability in x-axis. The sensing performance of the proposed scheme, in terms of its ROC curve is evaluated using Monte Carlo simulations.
It is assumed that the PU signal is likely-equally Binary Phase Shift Keying (BPSK) signal and noises at CUs are AWGN with zero mean and unit variance. Under the above assumptions the ROC curve of the proposed scheme is compared with individual methods Curve.
Receiver Operating Characteristics curve for Energy based detection has been plotted in Fig.7 for different values of SNR's. As SNR increases like -25,-16 to -7 dB, Probability of detection increases for fixed values of probability of false alarm Pf. For higher SNR of -7 dB, Probability of detection 0.9 is achieved for 0.1 probability of false alarm.

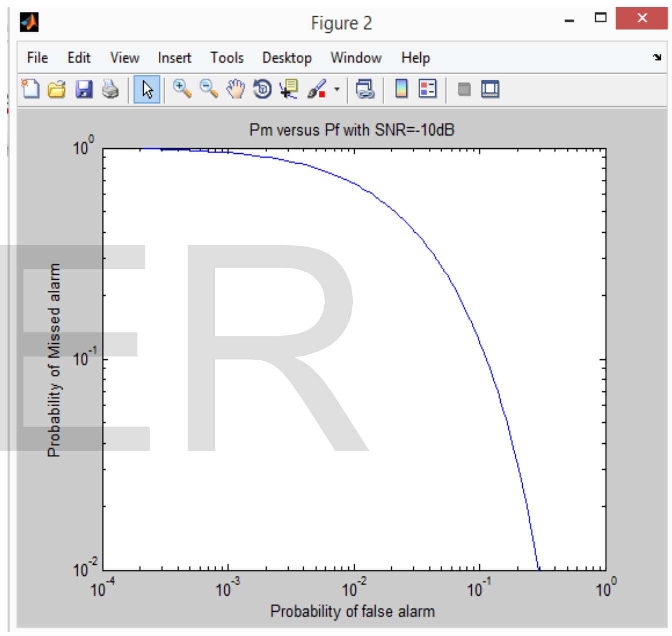

Fig. 8.Receiver Operating Characteristics curve for Energy detection

Complementary Receiver Operating Characteristics curve for Energy detection algorithm is shown in Fig.8. It consists of Probability of missed alarm versus false alarm for SNR of -10dB. Probabilities of missed and false alarm are used in calculation of total error rate of the system.
Receiver Operating Characteristics curve for Matched filter based detection has been plotted in Fig. 9 for different values of time bandwidth factor (u).In this, SNR = 20dB and time bandwidth factor (u) is varied from 1000 to 2000 are used.
Probability of detection is measured for different values of probability of false alarm to plot its ROC curve. When u is 1000, then the probability of detection is better than the other used time bandwidth factor. When u is 2000, the probability of detection is worse than the other used time bandwidth factor.

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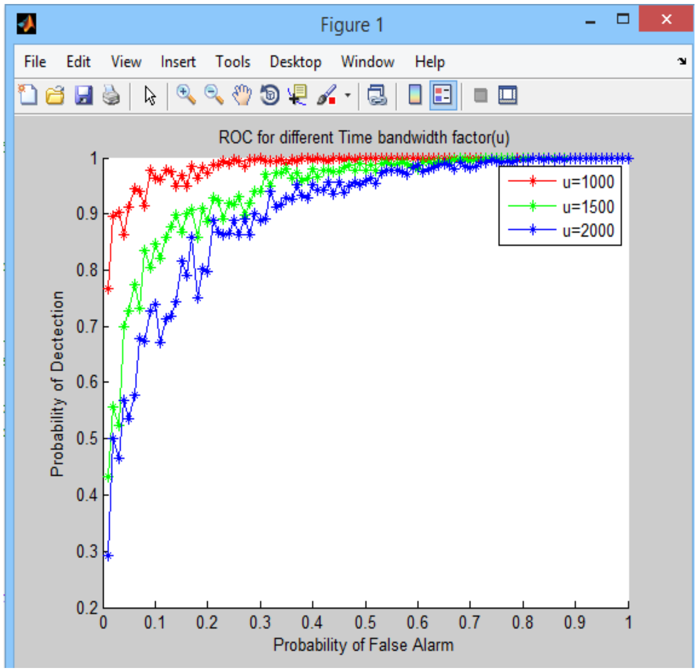

Fig. 9.Receiver Operating Characteristics curve for Matched Filter based Detection

It shows that probability of detection is increased when false alarm probability is increased and probability of detection is decreased when the time bandwidth factor is increased.

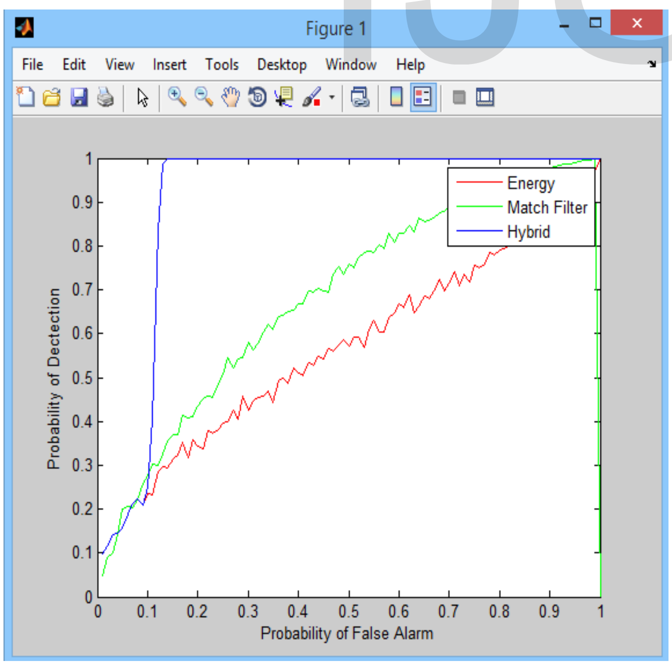

Fig. 10.Receiver Operating Characteristics curve for Hybrid Sensing Approach

Energy detection and Matched filter detection can be combined together. On the basis of comparison of set threshold value and received signal, presence of primary user (PU) is decided which is measured in terms of probability of detection (Pd). For SNR= - 20dB and time bandwidth factor (u) = 1000, combined energy detection and matched filter that is Hybrid detection method is proposed. Received signal is first sensed by energy detection method by comparing with the threshold value and if not detected it is given to matched filter detection.

For High signal to noise ratio Hybrid sensing acts on the basis of energy detection and for low SNR signal, matched filter is performing in hybrid sensing. ROC curve for proposed approach is shown in Fig.10.

It can be observed that, proposed approach gives probability of detection of 0.9 for probability of false alarm of 0.1.

According to the concept of Dedicated Sensing Receiver, Total frequency slot to be scanned is divided into M slots which will be scanned by M number of antennas. Total sensing time Tsys is plotted versus number of antennas (M) varying from 100 to 500. For M=100, sensing time of 4.5ms and 1.8ms of time required for M=500.Sensing time reduces with increase in number of antennas.

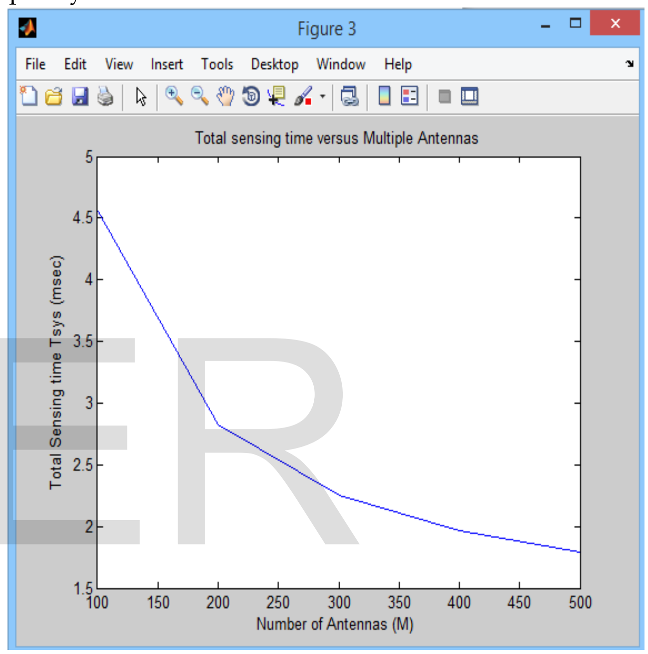

Fig. 11.Total Sensing time Analysis with Multiple Antennas

5 Conclusion

In this work, hybrid sensing approach is proposed to improve spectrum efficiency of the radio spectrum by improving detection reliability and reducing sensing time. Each primary user signal is given to energy detection method and if method gets unsuccessful, PU is detected by matched filter detection. Use of an dedicated sensing receiver architecture is also mentioned in this system and each stage has a multiple number of antennas.

Receiver operating characteristic curve has been plotted for Energy detection and matched filter method. Matched filter provides higher probability of detection of primary users for less probability of false alarms as compared to energy based detection. But it does not need priori information of user so energy detection is simplest method of detection. Proposed hybrid approach of sensing uses combination of both methods and higher probability of detection is achieved. So it works well than individual methods. In this case M antenna receiver is used (Dedicated sensing receiver), the total sensing time is reduced by approximate factor of M. For future work, Cyclostationary method also can be tried in combination to achieve higher reliability of sensing.

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