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Performance Evaluation of Spectrum Sensing using Multiple Antenna in Cognitive Radio

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ABSTRACT: Spectrum monitoring and spectrum availability are identified as key requirement in dynamic spectrum allocation. Cognitive radio is used to mitigate spectrum scarcity and meet the ever increasing demand of spectrum. In this paper we explore performance analysis of energy detection for spectrum sensing using Periodogram, Welch Periodogram and Time domain method. The performance comparison is made based on the probability of detection, probability of miss detection and probability of false alarm. These parameter tells how the secondary user can use the spectrum efficiently without interfering with primary user. Multiple antenna techniques provide a promising solution for better wireless communication.

KEYWORDS: Cognitive radio, spectrum sensing, energy detection.

I. INTRODUCTION

Spectrum being the scare natural resource requires efficient utilization as many portions of licensed spectrum are not utilized during significant time periods [1]. As the number of user and data rates are increasing significantly, the traditional fixed spectrum policy is inefficient to handle large number of user. One such approach which can solve the spectrum underutilization problem is by using cognitive radio which enables higher spectrum efficiency through dynamic spectrum access. In CR the unlicensed users (SU) are allowed to utilize the spectrum band without causing interference to the licensed users (PU). Therefore it becomes important to detect the presence of primary user quickly.

The widely used spectrum sensing techniques are: energy detection, matched filter detection, and cylcostationary detection [2]. Amongst these, the energy detection is a semi-blind detection method used for detection of an unknown signal in additive noise [3]. It has the advantage that it does not require prior information of primary received signal also it has low complexity compared to the other two methods. Matched filter requires prior information of the signal and accurate synchronization. The cyclostationary method requires knowledge of cyclic frequencies of primary user. It is more robust to noise uncertainty and provides better detection in low SNR regimes and it requires less signal samples[4][5]. Spectrum sensing is difficult task because of fading, shadowing of wireless channels. The Neyman-Pearson criteria states that the spectrum sensing is binary hypothesis sensing problem. Such as given below,

$$Y(n)= w(n) \quad : H0 \qquad \text{eq. (1)}$$

$$Y(n)= x(n) +y(n) : H1 \qquad \text{eq. (2)}$$

where x(n)=h_s(n), h is the channel gain. w(n) is noise sample with mean zero and variance $2\sigma_w^2$. H0 = Absence of user, H1= Presence of user.

Multiple antenna techniques are currently used for effective communication and reliable signal transmission. The multiple antenna technique in CRs for spectrum sensing can be exploited for spatial domain observations. The efficiency of multiple antennas in terms of required sensing time and hardware can be fulfilled by using a two-stage sensing method [6]. The performance evaluation of ED using Rayleigh fading channels and unknown deterministic signal is proposed in [6][7]. Multiple antenna OFDM scheme along with square law combining energy detector provides better performance than single antenna at low SNR [7]. Overall the multiple antenna method increases spectrum efficiency and improves system performance.

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II. Related work

TABLE 1. LITERATURE SURVEY

YEAR	AUTHOR	TITLE	TECHNIQUES USED
2004	Cabric,D.,S.Mishra & R. Brodersen	Implementation Issues In Spectrum Sensing For Cognitive Radio	Discusses the implementation challenges in design of CR. Identifies two key issues: 1.) dynamic range reduction. 2.) wideband frequency agility
2005	Ghurumuruhan Ganesan & Ye(Geoffrey)	Co-Operative Spectrum Sensing In Cognitive Radio	Cognitive users are allowed to operate in same band to cooperate and thereby reduce detection time and increase overall agility.
2005	Amir Ghasemi & Elvino S.Sousa	Collaborative Spectrum Sensing For Opportunistic Access In Fading Enviornment	Discusses spectrum sharing between between primary licensee and secondary users. Collaborative approach is used for spectrum sensing
2007	Digham ,F., M.Alouini & M. Simon	On The Energy Detection Of Unknown Signals Over Fading Channels	Addresses the problem of energy detection of an unknown signal over multipath channel. Square law combining and square law selection diversity schemes.
2008	Hamed Sadeghi, Paeiz Azmi	A Noval Primary User Detection Method For Multiple Antenna Cognitive Radio	Uses multiple antenna receiver diversity scheme based on cyclosationary detection to improve reliability.
2009	Ben Letaif, K. Wei Zhang	Cooperative Communication For Cognitive Radio Networks	Cooperative spectrum sensing is considered to deal with the hidden terminal problem. Various solutions to address fading/ shadowing effects are presented.
2010	Abbas Taherpour, Masoumeh Nasiri-Kenari & Saeed Gazor	Multiple Antenna Spectrum Sensing In Cognitive Radio	Discusses spectrum sensing using multiple antenna when noise & PU signal are complex zero mean Gaussian random signals. GLR detectors are derived having low computational complexity.
2010	Robert Lopez Valcarce and Gonzalo Vazquez –Vilar & Joseph Sala	Multiantenna Spectrum sensing for Cognitive Radio: overcoming noise uncertainty	Novel detector is proposed based on an approximation to generalized likelihood ratio(GLR).
2011	Suman Rathi, Rajeshwar Lal Dua, Parmender Singh	Spectrum Sensing In Cognitive Radio Using MIMO Technique	Co-operative and non-cooperative spectrum sensing techniques are discussed. Multiple antennas are described in detail with mathematical calculations.
2013	Atapatta S., Tallambura C., Jiang H	Energy Detection For Spectrum Sensing In Cognitive Radio	Energy detection is investigated over channels with multipath fading and shadowing. Two fusion strategies are used:-data fusion and decision fusion.
2013	Ashish Bagwari, Geetam Singh Tomar, and Shekhar Verma,	Cooperative Spectrum Sensing Based on Two-Stage Detectors With Multiple Energy Detectors and Adaptive Double Threshold in Cognitive Radio Networks	Paper presents two-stage detectors for spectrum sensing in cognitive radio networks The detection performance of the proposed scheme is compared with a cyclostationary-based sensing method and adaptive spectrum sensing scheme
2014	Wang Yong-feng , Li Ou	Multi-Channel Coordinated Spectrum Sensing Strategy in Multiple Antennae Based Cognitive Radio Networks	Branch and bound based method and greedy based heuristic method are used.

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III. PROPOSED WORK

In this paper we investigate the spectrum sensing problem in CR using multiple antenna method. The primary signal can be random signal with Additive White Gaussian Noise (AWGN). We derive the structure and investigate its performance. The energy detection can be done in time domain as well as frequency domain. Periodogram and Welch periodogram method are used in frequency domain energy detection. The TD-ED method is explored in detail. ED measures the energy received from PU during time interval. If energy is less than the threshold value then it states that the PU is absent. The threshold value is set to meet the target probability of false alarm Pfa according to the noise power.

IV. ENERGY DETECTION METHOD

One of the most widely used spectrum sensing technique is energy detection. It provides excellent way to detect the primary signals when prior information of the signal is unknown to secondary users. It takes into account the energy of received signal over fixed time interval. This technique can be used in time domain as well as frequency domain using FFT. The energy detector is a non-coherent detector. Whenever we have an unknown primary signal, we will use energy detector to detect that signal. Fig shows block diagram of energy detection method.

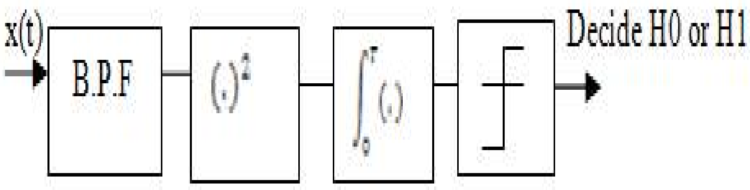

Figure 1 Energy Detection

Energy detector consists of band pass filter, an ADC, square law device and an integrator. X(t) is the unknown signal which is band pass. The signal is then passed through the non linear squaring device where energy of signal will be determined. Squaring device output is passed through an integrator over a time interval T. Finally output is compared with threshold to determine whether primary signal exists or not.
The test statistics is given by,

$$\epsilon_{time} = \sum_{n=1}^{N} |X(n)|^2 \qquad \text{eq. (3)}$$

The above equation is compared with threshold (λ) to determine whether the signal is present or absent.

$$\lambda \lesseqgtr \epsilon_{time} \qquad \text{eq. (4)}$$

Various fading channels are applied to energy detector. These include Rayleigh fading channel, Rician fading channel and MIMO fading channel. The formulae to calculate the probability of detection Pd and probability of false alarm Pfa are as follows [8]:

$$P_{fa} = P\left\{Y > \frac{\lambda}{H0}\right\} = Q_m(\sqrt{2y}, \sqrt{\lambda}) \qquad \text{eq. (5)}$$

$$P_d = P\left\{Y > \frac{\lambda}{H1}\right\} = \frac{\Gamma(n, \lambda/2)}{\Gamma(n)} \qquad \text{eq. (6)}$$

A.) Periodogram

Periodogram method is a DFT based approach used for energy detection in frequency domain. It is most widely used method to estimate the power spectral density(PSD). Periodogram determines possible hidden periodicities in time series. Fast fourier transform is used instead of DFT for simulations. Formula for periodogram [9]

$$X(k) = \sum_{n=1}^{N} X(n) e^{-j2\pi(k-1)(n-1)/N} \qquad \text{eq. (7)}$$

Where $1 \le k \le N$

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Where x(n) is the discrete received signal, N is the FFT size. Then we apply X(k) to an energy detector as follows:

$$€_{\text{periodogram}} = \frac{1}{N}\sum_{k=1}^{N}|X(k)|^2 \qquad \text{eq. (8)}$$

From above equation, we sum N components of the output of square law device where X(k) is applied to, hence the variance of the statistics fluctuates with respect to FFT size. To avoid this fluctuation, we divide the statistics with FFT number in order to hold the variance constant.

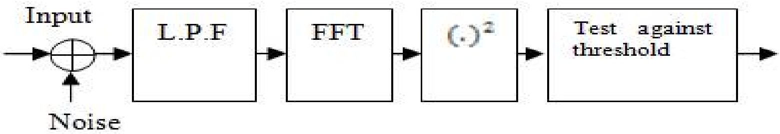

Figure 2 Spectrum Sensing using Periodogram

The process for test value calculation varies for time domain and frequency domain along with threshold calculation. Therefore the probability of detection will be different. Threshold depends on probability of false alarm(Pfa) i.e Pfa increases threshold decreases proportionally and as threshold decreases probability of detection (Pd) increases exponentially.

B.) Welch's Periodogram:

Another energy detection method is welch's periodogram. It divides the data sequence into segments that are used will either be overlapping or non overlapping.fig shows the block diagram of Welch periodogram. First the input data sequence is down converted and low pass filtered. The sequence of data is partitioned into M non overlapping segments and processed with FFT. Later the samples are applied to square law device. L samples are taken from M segments, followed by a summation of L samples. Finally the output values which are in the band of interest are compared with the threshold. The decision is done whether the signal is absent or present.

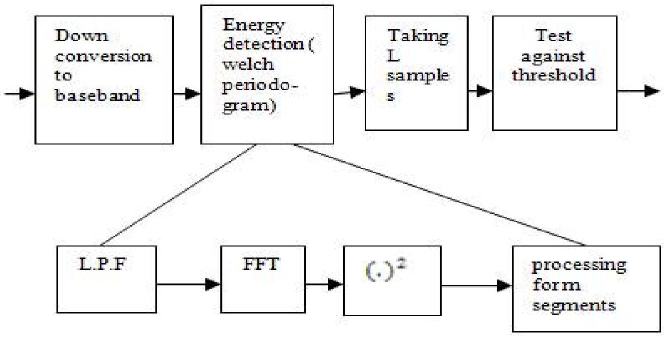

Figure 3 Energy detection with Welch's Periodogram

V. Multiple Antenna

For performance enhancement of system the multiple antenna technique are used. This helps to improve the bit error rate. The different antenna techniques are SISO, SIMO, MISO, MIMO. MIMO technology serves as the basic building block for wireless communication systems with higher data rates. The MIMO systems consist of multiple antenna at transmitter end and multiple antennas at receiver end. The antenna selected in MIMO systems are used for improving data transmissions. Multiple antenna techniques are further classified into two types: spatial multiplexing and diversity techniques. In MIMO systems, the transmitter transmits signal over multiple channel through multiple antennas, the receiver acquires information about the channel between transmitter and receiver, and then performs signal processing to estimate the signal received through each antenna. A general MIMO system model is shown in fig. the communication systems consists of N_T transmit antennas and $N_R$receive antennas.

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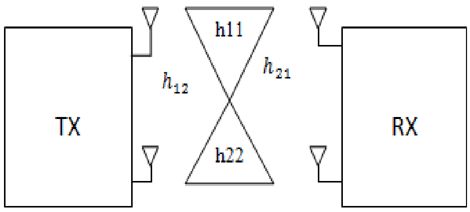

Figure 4 MIMO system model

Mathematically ,

$$Y=HS+N \qquad \text{eq. (9)}$$

H is channel matrix and its elements are independent. S is signal and N is the noise.
Channel matrix is given by,

$$H=\begin{pmatrix} h_{11} & h_{12} & \cdots & h_{1N_T} \\ \vdots & \vdots & & \vdots \\ h_{N_R1} & h_{N_R2} & \cdots & h_{N_RN_T} \end{pmatrix}$$

Another approach with GLRT detector is also used with multiple antenna based spectrum sensing in [10].
Advantage:

- Improved bit error rate performance.
- Increased coverage
- Enhanced transmission reliability.

Multiple Antenna methods for Energy Detection.

A. Selection combining:

Selection combining method is applied to an energy detector. In this method cognitive radio is assumed to have the knowledge of channel state information and thus chooses the branch with the highest channel gain and receives the data from that antenna. Then simply the received data is applied to an Energy Detector.

One of the most promising advantages of this method can be the fact that the threshold does not change as the noise level remains constant. As cognitive radio chooses one of the branches, it acts like a SISO system, that's why the threshold remains exactly as same as it is set for SISO systems.

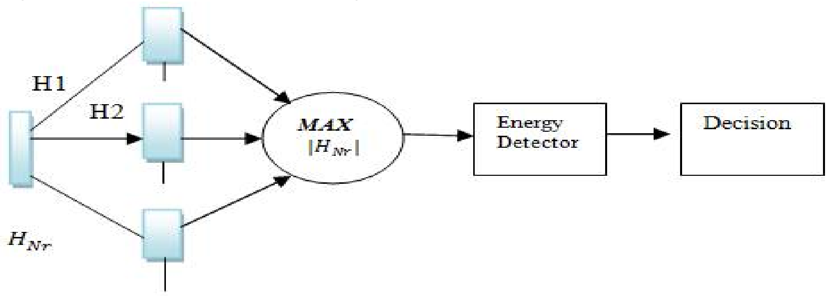

Figure 5 Selection Combining

$$j_{max} = {}^{max}_{j}(|h_j|) \qquad \text{eq. (10)}$$

Then the received signal at $\boldsymbol{j_{max}}$ th antenna is applied to the energy detector.

$$€_{SC} = \sum_{k=1}^{N} |X_{j_{max}}(k)|^2 \qquad \text{eq. (11)}$$

Where N is the symbol length to be sensed by cognitive radio.

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B. Maximum ratio combining:

Maximum ratio combining is used to improve the spectral efficiency of cognitive radio. In this method, CR is assumed to have perfect channel state information. It receives data from each antenna and multiplies them with the conjugate of each channel gain. it then sums all the multiplied data and applies it to energy detector. The received data at each antenna is mulitipled with conjugate of channel gain and summation is applied as follows:

$$€_{MRC} = \sum_{K=1}^{N} | (\sum_{j=1}^{Nr} xj(k) h * j)^2 \quad \text{eq. (12)}$$

C. Equal gain combining:

EGC is used to improve BER performance, normalized data which is multiplied with conjugate of channel gain and then divided by its absolute value is applied to only one energy detector.

$$€_{EGC} = \sum_{k=1}^{N} | (\sum_{j=1}^{Nr} x_j(k) \cdot h_j^* \; / |h_j|)^2 \quad \text{eq. (13)}$$

D. Square law combining:

The outputs of square law device are combined and compared with threshold to set a certain level of false alarm probability.

$$€_j = \sum_{k=1}^{N} |x_j(k)|^2 \quad \text{eq. (14)}$$

$$€_{SLC} = \sum_{j=1}^{Nr} €_j \quad \text{eq. (15)}$$

VI. Simulation Results

In this section, we present some numerical results to evaluate the performance of system. The simulation studies involve comparison of Probability of miss detection (Pmd) , probability of detection (Pd), and probability of false alarm (Pfa) with respect to SNR. The modulation techniques such as BPSK and QPSK are used. Symbol length N, is assumed to be 20. Energy detection is applied in time domain. Pfa is set to 0.1 and 0.5 respectively for both modulation techniques. The AWGN channel is considered as the performance of detectors degrades slightly in fading channel.

Figure 4.1 show the Probability of miss detection versus SNR for varying probability of false alarm. Here two cases are considered i.e. when Pfa=0.1 and 0.5. Similarly figure 4.2 show probability of detection Vs SNR for varying probability of false alarm.

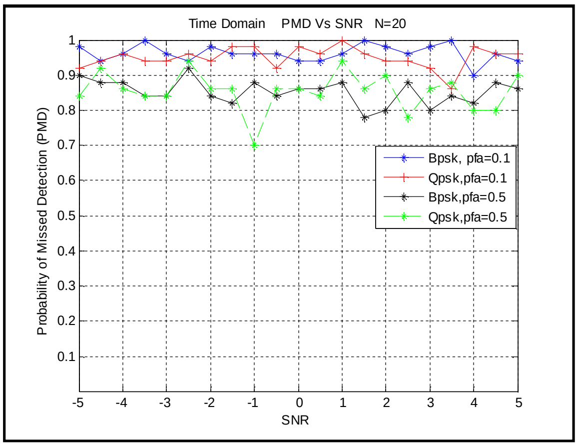

Figure 4.1 PMD Vs SNR for varying Pfa

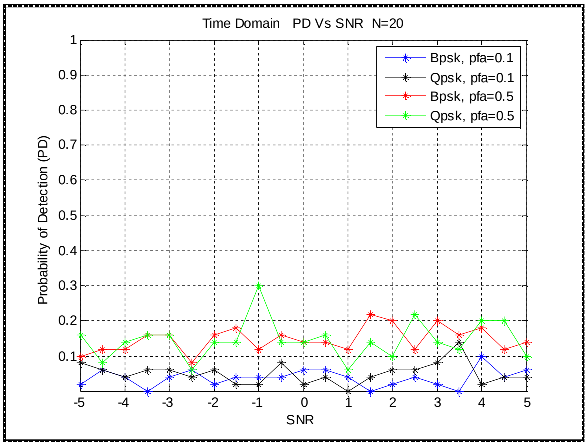

Figure 4.2 PD Vs SNR for varying Pfa

Figure 4.3 show the Probability of miss detection versus probability of false alarm. Figure 4.4 show the Probability of detection versus probability of false alarm. Here the SNR has fixed value i.e. SNR=1.25db, M=10.

To improve the performance in fading channels, collaborative spectrum sensing can be used. In collaborative spectrum sensing the secondary users use the available spatial diversity to improve its performance.

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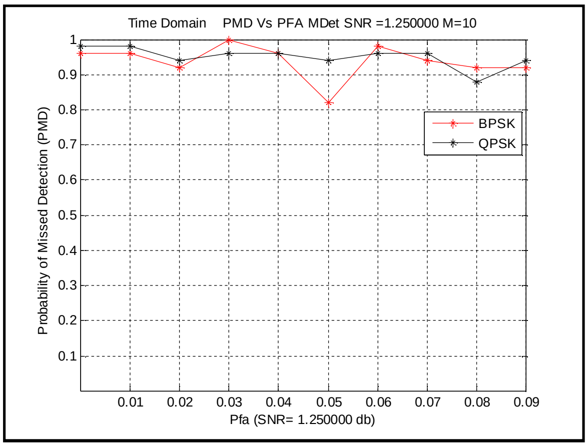

Figure 4.3 PMD Vs Pfa for fixed SNR

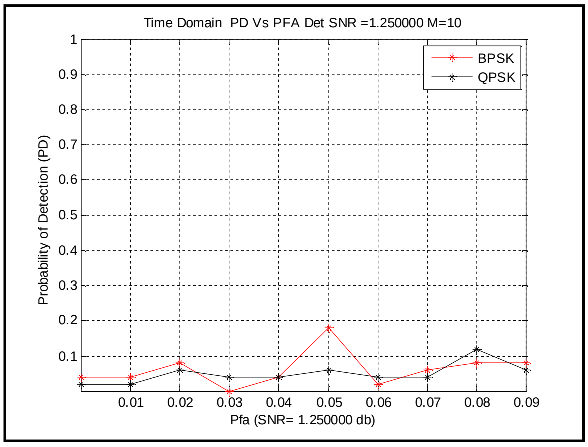

Figure 4. 4 PD Vs Pfa for fixed SNR

VII. CONCLUSION AND FUTURE WORK

In this paper, we considered the spectrum sensing for CRs using Energy detection in time domain and frequency domain with multiple antenna. We evaluated the performance in terms of false alarm and detection probabilities. If any of parameter such as Pfa, SNR, Sample count is increased by keeping remaining two constant, the probability of detection will increase exponentially and probability of miss detection will decrease. The Threshold is calculated using conventional Energy detection method.

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