Spectrum Sensing Based on Cyclostationary Detector using USRP

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***Abstract*— With the rapid increment in wireless applications and due to improper utilization of spectrum band, it becomes very necessary to handle spectrum scarcity problem. Cognitive radio is one of the promising solution for handling spectrum scarcity problem; as it allows unlicensed user to use licensed band by dynamic spectrum management. Spectrum sensing is an essential part of cognitive radio, which allows it to sense the spectral band to find the presence of primary user signal. There are several methods available for spectrum sensing; one of them is cyclostationary detector having better performance than other for low SNR condition. In this paper, a real-time implementation of spectrum sensing for cognitive radio is done using Universal Software Radio Peripheral (USRP) N210 kit with VERT2450 antenna is used for hardware support and Matlab®/Simulink® software tool is used for further processing of signal. A comparative analysis of cyclic spectral density has done for different modulation scheme & SNR values and BER performance is analyzed for different E_b/N_0 Values.**

***Keywords*— Bit error rate, Cognitive radio, Cyclostationary, Cyclic spectral density, Spectrum hole.**

I. Introduction

Spectrum scarcity is one of the most challenging issues in communication. Currently major portion of the radio frequency spectrum is full of licensed users. Such licensed users are known as the primary users of the spectrum band. Most of the licensed radio-wave spectral bands are under-utilized in time and space domain, resulting in unused white spaces in the time-frequency grid at any particular location. The spectrum utilization is mainly around certain parts of the spectrum whereas a considerable amount of the spectrum is unutilized. The Federal Communications Commission (FCC) has also reported the temporal and geographic variations in spectrum utilization to range from 15% to 85% [1]. This leads to suboptimal utilization of radio spectrum band. On the other hand, fixed spectrum allocation policies do not allow for reusing of the rarely used spectrum allocated to licensed users by unlicensed users. This problem coupled with the increasing demand for wireless services and radio spectrum has led to spectrum scarcity for wireless applications. This has necessitated a new communication standard that allows unlicensed (secondary) users to utilize the vacant bands which are allocated to licensed (primary) users. However, this opportunistic access should be in a manner that does not interrupt any primary process in the band. Therefore, the secondary users must be aware of the activity of the primary user in the target band. They should spot the spectrum holes and the idle state of the primary users in order to exploit the free bands and also promptly vacate the band as soon as the primary user becomes active. Cognitive radio encompasses this awareness by dynamically interacting with the environment and altering the operating parameters with the mission of exploiting the unused spectrum without interfering with the primary users. Showing support for the cognitive radio idea, the FCC allowed for usage of the unused television spectrum by unlicensed users whenever the spectrum is free. IEEE has also supported the cognitive radio paradigm by developing the IEEE 802.22(WRAN) standard for wireless regional area network [2] which works at unused TV channels frequency band.

There are basically three types of spectrum sensing techniques as described in [3] namely, Matched filter detector, Energy detector and Cyclostationary (Feature) detector. Matched filter detector is an optimal coherent detector, which requires prior knowledge of primary signal. Therefore, it is not suitable for practical applications. Energy detector is the simplest one, but it does not provide accurate results for low SNR values. Cyclostationary detector provides accurate results at low SNR values and is capable of differentiate different signal types. In this paper, a detailed description of Energy detector and Cyclostationary detector has presented and results for cyclostationary detector has shown as its performance does not affected by noise.

II. Spectrum sensing in Cognitive Radio

Spectrum sensing enables secondary users to identify the presence of spectrum holes (Spectrum hole is defined as a licensed spectrum band that can be utilized by unlicensed users), which is a critical element in Cognitive radio design. The Secondary user can access the licensed spectrum band without interfering with primary user signal. To protect the Primary user transmission, the Secondary user transmitter needs to perform spectrum sensing to detect whether there is any primary user signal or not.

In general, it is difficult for the secondary user to differentiate the Primary user signals from noise and other interfering signal from secondary user. Therefore, we treat them all as one received signal, s(t). Consider two hypotheses, first H_0 when signal is absent and H_1 when signal is present. The received signal at the Secondary user, x(t), under two hypotheses can be expressed as:

$$x(t) = \begin{cases} n(t), & under H_0 \\ s(t) + n(t), & under H_1 \end{cases}$$

Where n(t) is the additive white Gaussian noise and s(t) is the primary user signal. The objective for spectrum sensing is to decide between the two hypothesesH_0 and H_1 based on the receiving signal x(t).

A. Energy Detector

Energy detector is the most common spectrum sensing method. It is easy to implement and requires no prior information about the Primary user signal. The block diagram for energy detection technique is given in Fig. 1 .

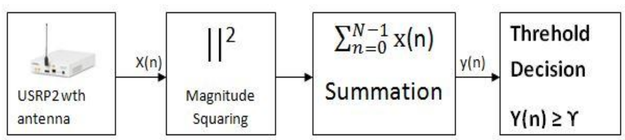

Fig. 1 Energy Detector

However, the uncertainty of noise power imposes fundamental limitations on the performance of the energy detector. Below an SNR threshold, a reliable detection cannot be achieved by increasing the sensing duration. This SNR threshold for the detector is called SNR wall. The decision statistics of the energy detector [4] are defined as the average energy of the observed samples is given as:

$$Y = \frac{1}{N}\sum_{t=1}^{N} |x(t)|^2$$

The decision is made by comparing Y with a threshold ϒ. If Y≥ϒ the secondary user makes a decision that the primary user signal is present (H_1); otherwise, it declares that the primary user signal is absent (H_0).

B. Cyclostationary Detector

Cyclostationary detector utilizes the cyclostationary characteristics of transmitted signal for spectrum sensing, which allows it to differentiate the signal from wide-sense stationary noise. It is also known as Feature detector. The transmitted signal exhibits cyclostationary nature (its mean and autocorrelation function exhibit periodicity) due to modulation, pulse spreading sequences and cyclic prefixes, all these operations at transmitter lead to built-in periodicity in transmitted signal [5]. The block diagram for cyclostationary detector is given in Fig. 2.

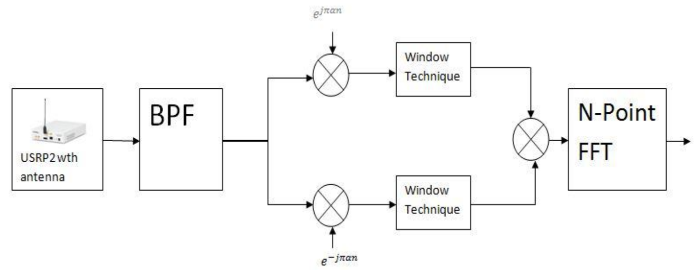

Fig. 2 Cyclostationary Detector

It can be realized by analysing the cyclic autocorrelation function (CAF) of the received signal x(t) and it can be expressed as in [6]:

$$R_t^{\alpha}(\tau) = E\left[x(t)x^*(t-\tau)e^{-j2\pi\alpha t}\right] \qquad (1)$$

Where E[.] is the expectation operator, * denotes complex conjugation and α is the cyclic frequency. CAF can also be represented by its Fourier series expansion, called cyclic spectrum density (CSD) function and it is given by equation 2:

$$S(f,\alpha) = \sum_{t=-\infty}^{\infty} R_x^{\alpha}(\tau)e^{-j2\pi f\tau} \qquad (2)$$

.

Under hypothesis H_1, the CSD function exhibits peaks when the cyclic frequency (α) equals the fundamental frequencies of the transmitted signal. Under hypothesis H_0, the CSD function does not have any peaks except α= 0 since the noise is, in general, non-cyclostationary.

The performance evaluation parameters for cyclostationary detector are probability of detection and probability of false alarm. These can be calculated for a particular value of threshold ϒ as given in [7]. The probability of detection is defined as the probability of deciding H_1, when signal is present. It is given in equation 3:

$$P_d = Pr(H_1|H_1)$$

$$P_d = Q\left(\frac{\sqrt{2\Upsilon}}{\sigma_w}, \frac{\lambda}{\sigma_A}\right) \quad (3)$$

The probability of false alarm can be defined as the probability of deciding H_1, when signal is absent. It is given in equation 4:

$$P_f = Pr(H_1|H_0)$$

$$P_f = exp\left(\frac{-\lambda^2}{2\sigma_A^2}\right) \quad (4)$$

III. EXPERIMENTAL MODEL

The goal of this spectrum sensing system is to detect the presence of transmitted signal at a particular frequency and further analyze it to find the characteristics of signal. The experimental model consists of the two USRP N210 kit with VERT2450 antenna connected to different workstations using gigabit Ethernet cables and kits are interfaced through Matlab/Simulink software tool. One of them is used for transmitting the data at a particular frequency and other one is used for receiving the data at same frequency. The received signal is further processed through detector block to detect the signal presence at that frequency. The received signal is passed through cyclostationary detector and cyclic spectral density (CSD) is plotted for different SNR values. A picture for experimental setup is shown in Fig 3.

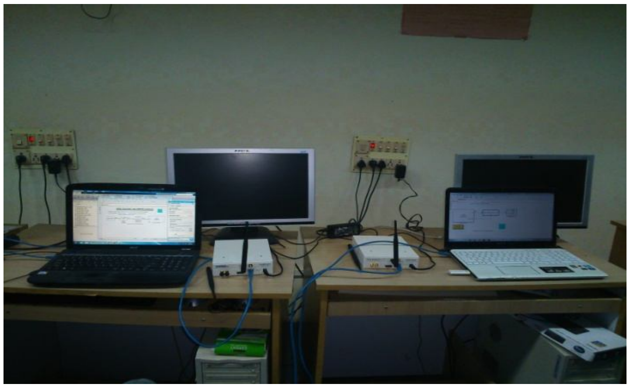

Fig. 3 Cognitive Radio Experimental Setup

The data is first modulated at transmitter using QPSK modulator and then pulse shaping is done with raised cosine filter and finally it is transmitted through USRP device at a center frequency of 2.415 GHz frequency. The transmitted signal is received through another USRP kit with center frequency of 2.415 GHz and passed it through cyclostationary detector to analyze its cyclic spectral density in order to check the presence of signal. The received signal is then passed through QPSK demodulator to demodulate the signal and calculate the Bit error rate (BER).

IV. SIMULATION RESULTS

The cyclic spectral density using cyclostationary detector has been plotted for white Gaussian noise, QPSK modulated signal for different SNR values. By observing the cyclic spectral density of signal, the decision about the signal presence and its modulation scheme can be made. The bit error rate is calculated experimentally for QPSK modulated data transmitted using USRP for different values of separation between transmitter and receiver, also bit error rate is plotted for different values of SNR. The CSD of white Gaussian noise of power 2dBW and number of samples equal to 16384 is plotted in Fig 4.

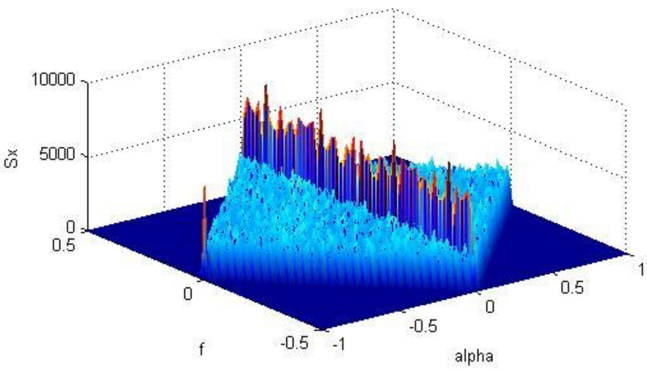

Fig. 4 CSD of white Gaussian noise

Fig 4 shows that the value of spectral density at α=0 is comparatively much higher than at any other value of α and peaks are observed only for α=0. The CSD of QPSK modulated signal is plotted for SNR values of 5dB and -5dB in Fig. 5(a) and 5(b) respectively.

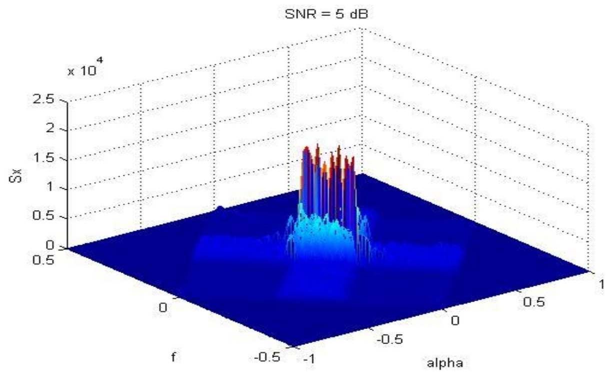

Fig. 5(a) CSD of QPSK signal for SNR=5dB

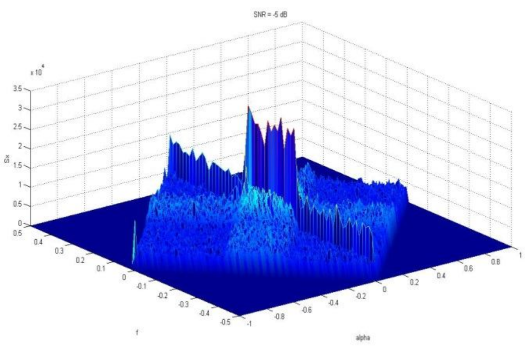

Fig. 5(b) CSD of QPSK signal for SNR=-5dB

As seen in Fig. 5(a) and 5(b), the change in SNR values does not affect the position of peaks in cyclic spectral density. For SNR=5 dB case, the peak values of CSD is much higher than the other CSD values; while for SNR=-5 dB case, the peak values of CSD is comparatively less higher than the other CSD values. By comparing the peaks position of both CSD, the modulation type of received signal can be estimated.

The Bit error rate (BER) is calculated for different SNR values using Monte Carlo simulation for real-time transmission and reception of data. The BER is calculated for 1 million samples of received signal using equation 5.

$$P_e = \lim_{N\to\infty} \frac{N_e}{N} \qquad (5)$$

In equation 5, P_e represents the bit error rate (BER), N_e represents number of samples in which error has occurred and N is the total number of samples for which Monte Carlo simulation has done. The experimentally calculated BER graph is shown in Fig 6.

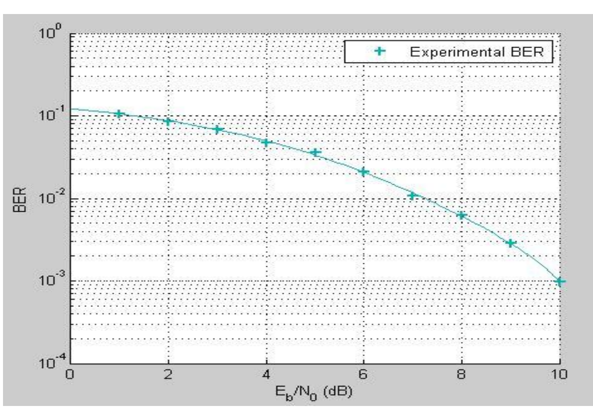

Fig. 6 BER vs SNR plot

Fig 6 shows that for higher value of SNR, BER is very less. The variations in BER value with respect to separation between transmitter and receiver is shown in Table I.

TABLE I
BER VS TX-RX DISTANCE

Tx-Rx distance (in metre)	BER value (in percentage)
1 m	0.14
3 m	0.53
5 m	0.91
8 m	1.47

V. CONCLUSION

This paper demonstrates the cyclostationary detector based spectrum sensing using USRP N210, a low-cost software defined radio platform from Ettus Research LLC. The simulated results show that cyclostationary detector provides reliable signal detection in high SNR conditions. It can be observed that the change in SNR does not affect much the cyclic spectral density. Therefore, cyclostationary detector can be a reliable option for spectrum sensing in cognitive radio. The effect of SNR and separation between transmitter & receiver over BER is also analyzed in the paper.

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