SPECTRUM SENSING IN COGNITIVE RADIO FOR MULTI-CARRIER (OFDM) SIGNAL

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Abstract

Cognitive radio is an emerging Wireless Technology that can address the needs of the scarcity of the frequency spectrum. This will enable the efficient utilization of the radio spectrum by offering the unlicensed spectrum users to sense the spectrum, and self-adaptation capability for dynamic spectrum sharing with the licensed users. In order to share the spectrum with the licensed users, the unlicensed users have to sense the spectrum to detect the presence or absence of the licensed user. Hence, spectrum sensing is a crucial part of Cognitive Radio Technology. A Cognitive radio - A radio that can change its transmitter parameters based on interaction with the environment in which it operates, with two primary objectives in mind, highly reliable communications and efficient utilization of the radio spectrum. Hence, with efficient use of available limited spectrum band, we may able to achieve people requirements of high speed multi-media applications and audio without interruption. There are number of Spectrum sensing methods for detecting the White spectrum holes that are available for Cognitive radio but, the Performance analysis of each has not been evaluated till date. Hence, the objective of this paper is to analyze all the available Spectrum sensing methods and afterwards to implement the same for Multicarrier (OFDM) QPSK modulated transmitted signal. For detection of White spectrum holes in the radio spectrum, available spectrum sensing techniques are sub-categorized in two methods: Signal processing technique & Cooperative sensing technique. Since, our focus is on the Signal processing techniques, this paper gives the comparison between available Signal processing techniques.

Keywords: Cognitive Radio(CR), Primary User(PU), Secondary User(SU), Energy Detection(ED), Quadrature Phase Shift Keying(QPSK), Signal to Noise Ration(SNR), Probability of Detection(P_d), Probability of False Alarm(P_f), Probability of miss detection(P_m), Spectrum hole(SH), Power spectral density(PSD), Fast fourier transform(FFT).

I. INTRODUCTION

The spectrum requirements for wireless multimedia applications have increased exponentially, leading to spectrum scarcity. However, recent studies show that most of the licensed spectrum is underutilized. Cognitive radio (CR) has been proposed to bridge the gap between spectrum scarcity and underutilization of the available spectrum [1]. The concept of cognitive radio enables coexistence of the legacy systems and new users, which are called primary users (PU) and secondary users (SU) through dynamic spectrum access. CR is an intelligent radio that has two important characteristics namely, observation and adaptability.

- The observation characteristic means that the CR can observe and learn from the radio environment through spectrum sensing, channel estimation, and modulation type identification.
- The adaptability characteristic shows that the CR is able to change its communication protocols and parameters through channel allocation, power allocation, modulation and coding scheme selection and,waveform adaptation, based on its observation results.

There are three major types of cognitive radio systems: interweave, underlay and overlay CRs [02]. In the interweave type cognitive radio systems, the secondary devices detect the presence of primary users signal through spectrum sensing and transmit opportunistically only when there is no primary user transmission. In the underlay cognitive radio systems, secondary users are allowed to communicate along with primary users, as long as the interference created to the primary system is below some predefined threshold. The secondary users detect the presence of primary users and control their transmission power accordingly, in the underlay CR systems. Cognitive radio technology is the key technology that enables an xG network to use spectrum in a dynamic manner. The term, cognitive radio, can formally be defined as follows. "A Cognitive Radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates [03] ." From this definition, two main characteristics of the Cognitive radio can be defined with two primary objectives in mind [04]:

1. Highly reliable communications whenever and wherever needed;
2. Efficient utilization of the radio spectrum.

Since most of the spectrum is already assigned, the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users as illustrated in fig. 1 [05]. The cognitive radio enables the usage of temporally unused spectrum, which is referred to as spectrum hole or white space. If this band is further used by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference.

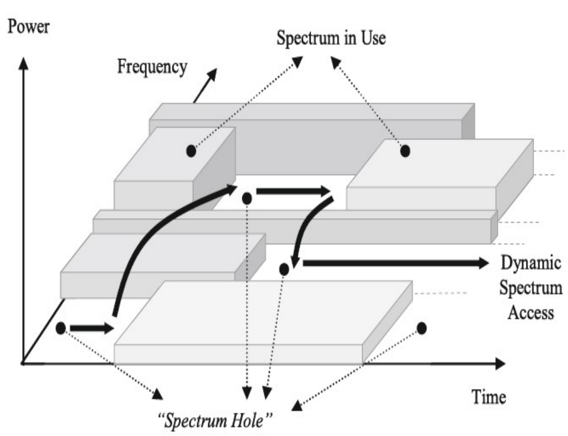

Fig. 1 Spectrum hole

The cognitive capability of a cognitive radio enables real time interaction with its environment to determine appropriate communication parameters and adapt to the dynamic radio environment. The tasks required for adaptive operation in open spectrum are shown in fig. 2[05], which is referred to as the cognitive cycle. In the next section, we will provide an overview of the three main steps of the cognitive cycle: spectrum sensing, spectrum analysis, and spectrum decision.

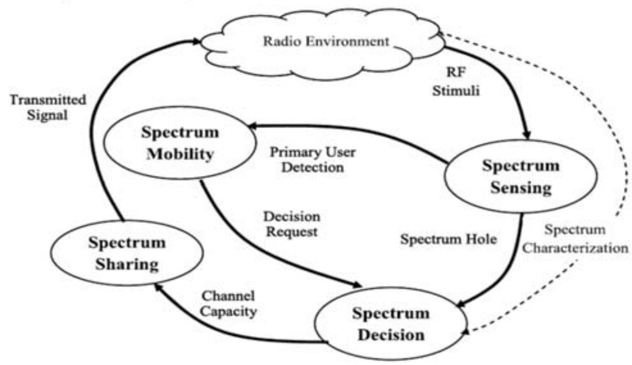

Fig. 2 Cognitive radio cycle

Spectrum sensing: A cognitive radio monitors the available spectrum bands, captures their information, and then detects the spectrum holes.

Spectrum analysis: The characteristics of the spectrum holes that are detected through spectrum sensing are estimated.

Spectrum decision: A cognitive radio determines the data rate, the transmission mode, and the bandwidth of the transmission. Then, the appropriate spectrum band is chosen according to the spectrum characteristics and user requirements. Once the operating spectrum band is determined, the communication can be performed over this spectrum band. However, since the radio environment changes over time and space, the cognitive radio should keep track of the changes of the radio environment. If the current spectrum band in use becomes unavailable, the spectrum mobility function is performed to provide a seamless transmission. Any environmental change during the transmission such as primary user appearance, user movement, or traffic variation can trigger this adjustment.

The remainder of this paper is organized as follows: The available Spectrum Sensing Techniques are provided in Section II. The introduction of Signal processing techniques is provided in Section III. In the Section IV, simulation results are presented for Signal processing techniques for Multi-Carrier (OFDM)

QPSK modulated transmitted signal over Rayleigh fading channel. The conclusions are drawn in the Section V.

II. SIGNAL PROCESSING TECHNIQUES

The available Spectrum Sensing Techniques are sub-categorized in two methods [02]; 1. Signal processing techniques and 2. Cooperative sensing as shown in fig. 3. The Signal processing techniques includes Match filter detection, Energy detection, Cyclostationary feature detection, Wavelet based detection etc. while Cooperative sensing includes Centralized spectrum sensing, Decentralized spectrum sensing and Hybrid spectrum sensing. Since our focus is on Signal processing techniques, this paper provides you the comparison of available simulated Signal processing techniques.

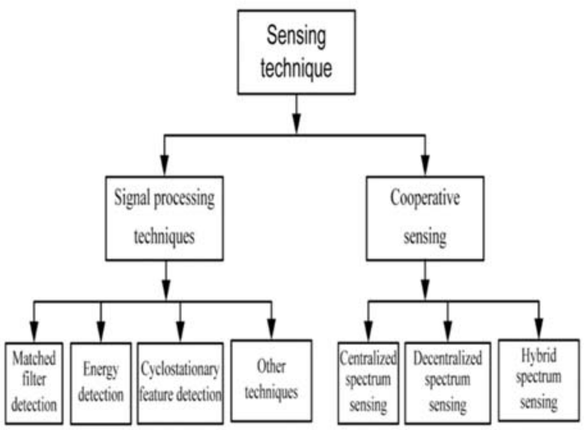

Fig. 3 Available Spectrum Sensing Techniques

III. SYSTEM MODEL

There are number of Spectrum sensing methods for detecting the White spectrum holes that are available for Cognitive radio but, the Performance analysis of each has not been evaluated till date. Hence, the objective of this paper is to analyze all the available Signal processing techniques.

Spectrum sensing enables SUs to identify the SHs, which is a critical element in CR design. Fig. 4 [02] shows the principle of spectrum sensing. In the figure, the PU transmitter is sending data to the PU receiver in a licensed spectrum band while a pair of SUs intends to access the spectrum. To protect the PU transmission, the SU transmitter needs to perform spectrum sensing to detect whether there is a PU receiver in the coverage of the SU transmitter.

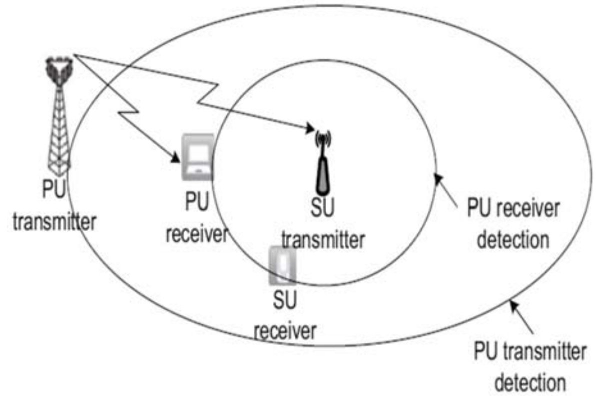

Fig. 4. Spectrum sensing concept

Instead of detecting PU receiver directly, the SU transmitter can detect the presence or absence of PU signals easily. However, as shown in fig. 4, the radius of PU transmitter and PU receiver detections are different, which lead to some shortcomings and challenges. It may happen that the PU receiver is outside the PU transmitter detection radius, where the SH may be missed. Since the PU receiver detection is difficult, most study focuses on PU transmitter detection.

It is worth noting that, in general, it is difficult for the SUs to differentiate the PU signals from other pre-existing SU transmitter signals. Therefore, we treat them all as one received signal $s(t)$. The received signal at the SU, $x(t)$ can be expressed as [02]

$$x(t) = n(t) \quad H_0,$$
$$x(t) = s(t) + n(t) \quad H_1$$

Where, $n(t)$ is the additive white Gaussian noise(AWGN). $H0$ and $H1$ denote the hypotheses of the absence and presence of the PU signals, respectively. The objective for spectrum sensing is to decide between $H0$ and $H1$ based on the observation $x(t)$. The detection performance is characterized by the probabilities of detection, Pd, and false- alarm, Pf. Pd is the probability that the decision is $H1$, while $H1$ is true; Pf denotes the probability that the decision is $H1$, while $H0$ is true. Based on Pd, the probability of miss-detection Pm can be obtained by $Pm = 1 - Pd$..

A. Energy detection

Energy detector is the most common spectrum sensing method. The decision statistics of the energy detector are defined as the average energy of the observed samples [02]

$$Y = \frac{1}{N}\sum_{n=1}^{N}|X|^2 \qquad (1)$$

The decision is made by comparing Y with a threshold, λ. If $Y \geq \lambda$, the SU makes a decision that the PU signal is present (H_1); otherwise, it declares that the PU signal is absent (H_0). The energy detector is easy to implement and requires no prior information about the PU signal. 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. With the help of the PU signal information, the SNR wall can be mitigated, but it cannot be eliminated. Moreover, the energy detector cannot distinguish the PU signal from the noise and other interference signals, which may lead to a high false-alarm probability (P_f). The decision statistics of the energy detector are defined as the average energy of the observed samples Y.

The decision is made by comparing Y with a threshold λ [02],

$\lambda = invqfunc(Pf)/\sqrt{N}+1$ (2)

Where, N is number of samples

If $Y \geq \lambda$, The PU signal is present;
else Absent

The uncertainty of noise power imposes fundamental limitations on the performance of the energy detector.

The detection probability (P_d) is given by the following formula [06];

$$P_d = invqfunc\left(\frac{\left(\lambda - (\mathrm{SNR}+1)\right) * \sqrt{N}}{\sqrt{(2 * SNR)+1}}\right) \quad (3)$$

B. Wavelet based detection

Since, Wavelet transform is a multi-resolution technique, gives good identification whether PU is present or absent. The main operations in the Wavelet transform are scaling and translation by which time and frequency resolution will be achieved as per our requirement. The complexity of this method depends upon the filter order and the number of sub-carrier used.

The block diagram of Wavelet based detection is shown in fig. 5 [7].

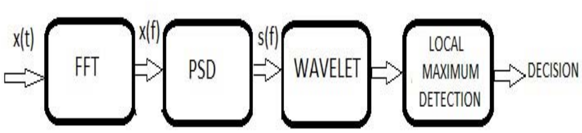

Fig. 5 Wavelet based detection technique

The Power spectral density will be calculated for the frequency domain signal by the following equation:

$$S\ xx = \frac{1}{2\pi N_B}|Y|^2 \quad (4)$$

Where, Sxx= Power spectral density, N_B=length of the signal

and Y=transmitted signal

Power spectral density function is a very useful tool if you want to identify oscillatory signals in your time series data and want to know their amplitude. Power spectral density tells us at which frequency ranges variations are strong and that might be quite useful for further analysis. The Discrete wavelet transform is performed for the PSD signal which gives two components: 1. Low frequency or Approximation components and 2. High frequency or Detail components. Convolving the signal with the scaling function we get approximation coefficients and Detail coefficients, are produced by applying the wavelet to the sampled signal. They express the higher frequency components in the signal. We are using Detail coefficients with Daubechies wavelet in our simulation environment. Based on the received signal the decision will be made whether PU is present or not.

C. Cyclostationary feature detection

Cyclostationary detector is one of the feature detectors that utilize the Cyclostationary feature of the signals for spectrum sensing. It can be realized by analysing the cyclic autocorrelation function (CAF) of the received signal $x(t)$, expressed as:

$$R_x^{(\beta)}(\tau) = E\left[x(t)x^*(t-\tau)e^{-j2\pi\beta t}\right] \quad (5)$$

Where, $E[.]$ is expectation operation, $*$ denotes complex conjugation, β is cyclic frequency.

Generally, feature detector can distinguish noise from the PU signals and can be used for detecting weak signals at a very low SNR region, where the energy detection and matched filtering detection are not applicable.

The block diagram of the Cyclostationary feature detection is shown the fig. 6 [8].

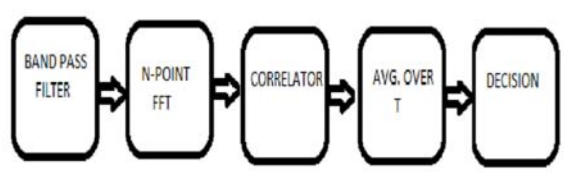

Fig. 6 Cyclostationary feature detection technique

IV. SIMULATION RESULTS

Till now, we have gone through the various Signal processing techniques for detecting the PU whether it is present or not.

Where the detection probability (Pd) is given by the Eq. (03). In our simulation we have number of samples = 20, Probability of False Alarm = 0.01, FFT size = 64, Number of Sub-carriers = 52 with Rayleigh fading channel. Since, the Threshold is inversely proportional to the number of samples, more number of samples causes the poor Detection of PU. Hence, we have kept number of samples = 20. The lower the false alarm probability, the larger the capacity of the secondary user due to more chances to access to vacant spectrum [09]. Hence, we have kept Pf = 0:01. Fig. 7, Fig. 8 and Fig. 9 are the simulation results obtained for Energy detection, Wavelet based detection and the Cyclostationary feature detection techniques.

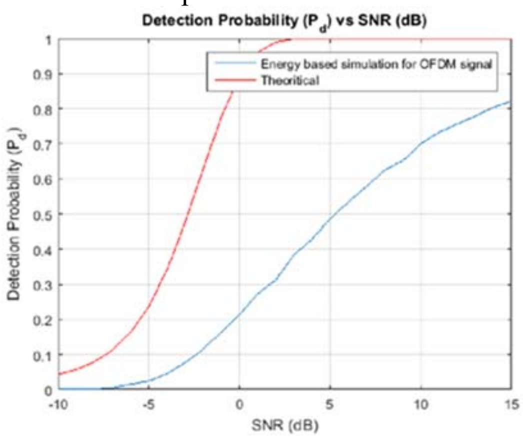

Fig. 7 Simulation of Energy detection for QPSK modulated transmitted signal over Rayleigh fading channel

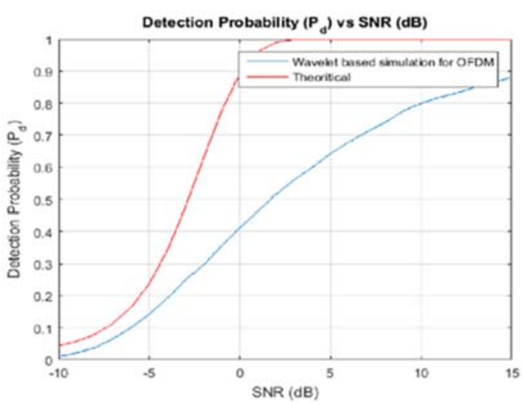

Fig. 8 Simulation of Wavelet based detection QPSK modulated transmitted signal over Rayleigh fading channel

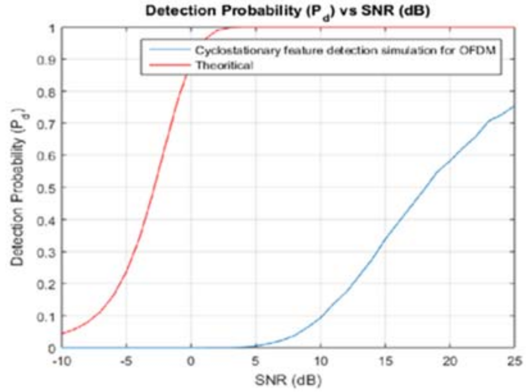

Fig. 9 Simulation of Cyclostationary feature detection for QPSK modulated transmitted signal over Rayleigh fading channel

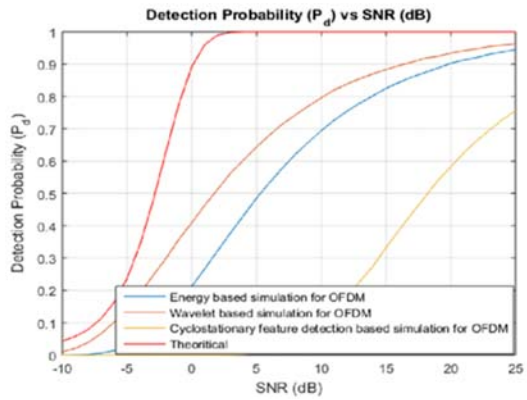

Fig. 10 Comparative result of Energy detection, Wavelet based detection and Cyclostationary feature detection for QPSK modulated transmitted signal over Rayleigh fading channel

V. CONCLUSIONS

Cognitive Radio can play a major role in today's Radio environment to improve the utilization efficiency of radio spectrum. We are using cooperative spectrum sensing with different fusion rule (ED) & Wavelet based spectrum sensing technique is used to get the best utilization of underutilized spectrum. Energy based detection signal processing technique is easy to implement and requires no prior information about the PU signal. However, the uncertainty of noise power imposes fundamental limitations on the performance of the energy detector. At low SNR value, the Energy detector cannot distinguish the PU signal from the noise and other interference signals, which may lead to a high false-alarm probability (Pf). There are many reasons which gives better performance for detecting the white spectrum holes in the radio spectrum for the Wavelet based spectrum sensing technique compared to Energy detection based and Cyclostationary feature detection spectrum sensing e.g. The Order of Wavelet used, Scaling parameter, Dilation parameter etc. Cyclostationary feature detection technique gives poor detection of white spectrum hole as compared to Energy detection technique and Wavelet based detection technique for Multi-Carrier (OFDM) QPSK modulated transmitted signal over Rayleigh fading channel.

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