Legacy User Detection in OFDM based Cognitive Radio

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ABSTRACT

Radio transmission involves the use of part of the electromagnetic spectrum.Use of spectrum is regulated by Federal Communications Commission (FCC).Cognitive Radio (CR) provides solution to spectrum scarcity problem.The biggest challenge related to spectrum sensing is in developing sensing technique which are able to detect Primary User (PU) signals while being sufficiently fast and low cost implementation. In order to detect the presence of primary user signal with high probability, spectrum sensing is a fundamental requirement to achieve the goal of Cognitive Radio. Energy detection is one of the techniques to detect the primary users in CR. In this paper, energy detection technique is used to sense the spectrum so as to improve the detection performance of CR. The performance of energy detection may degrade at very low signal-to-noise (SNR). To overcome this, square law combining (SLC) scheme is proposed to enhance the detection probability. In particularly, the Orthogonal Frequency Division Multiplexing (OFDM) based CR receiver detect the primary user signal, where CR receiver is equipped with energy detector and SLC. Here, energy detection in OFDM based spectrum sensing in CR for single user is examined and simulation results are obtained. Significant improvement is observed in CR for primary user detection with OFDM based energy detector.

Keywords

Cognitive Radio, Energy Detection, OFDM, Spectrum Hole, Spectrum Sensing.

1. INTRODUCTION

The Electromagnetic Radio Spectrum, an expensive, limited and natural resource, is currently licensed by regulatory bodies for various applications. Presently there is a severe shortage of the spectrum for new applications and systems. A large portion of the assigned spectrum is used sporadically, leading to underutilization of a significant amount of spectrum [1]. FCC report suggests that many portion of radio spectrum are not in use for significant period of time and use of these “Spectrum Holes” can be increased significantly. Therefore, the under utilization problem can be overcome by the use of Cognitive Radio(CR) technology [2] which has built-in radio environment awareness and spectrum intelligence.

Cognitive radio [3] enables much higher spectrum efficiency. Cognitive radio transmits on a piece of spectrum found not utilized by the primary user (PU). Subsequent transmission from CR should not cause interference to primary user when PU starts using previously unused spectrum. To achieve this goal of CR, it is a fundamental requirement that the cognitive radio performs spectrum sensing from time to time to detect the presence of the PU signal. The sensing of radio environment to determine the presence of primary user is a challenging problem as the signal is attenuated by fading wireless channel. This results in low signal-to-noise ratio (SNR) condition at the CR input, and makes CR susceptible to hidden node problem, wherein CR fails to detect primary user and begins transmission, thereby causing potential interference to the primary user. To minimize the occurrence of this problem, detection technique has to achieve probability of detection close to unity for a specified probability of false alarm and a given SNR.

Many signal detection techniques has been proposed in the literature, such as matched filtering, energy detection, and cyclo-stationary feature detection [4]. The matched filter technique requires accurate prior knowledge about the primary user signal, e.g. modulation type, pulse shaping, channel equalization and timing and frequency synchronization. The sub-optimum, non-coherent energy detection technique is used only when the power spectral density of the Gaussian noise is known to the receiver. Susceptibility of threshold to changing noise statistics, inability to distinguish between PU signal and in-band interference are the major drawbacks of energy detector. The computationally complex cyclo-stationary feature detector exploits the build-in periodicity of modulated signal to perform better than energy detector in discriminating against noise.

In this work, energy detection for a signal and OFDM based energy detection technique is also considered in CR to keep the complexity of the receiver low. However, use of energy detector in CR results in poor detection performance at low SNR region, thereby causing interference to the PU signal. OFDM has been proposed here for a CR system. It has been shown that OFDM based CR equipped with energy detector scheme offer potential improvement in detection performance [5], [6].In this paper, the performance of CR is considered to receive the signal from primary user and uses SLC based energy detector to detect the presence of PU.

The rest of the paper is organized as follows: the reason for using OFDM in CR is explained in section 2.Sec.3 describes the energy detection technique. In Sec.4 the OFDM system model for cognitive radio is mentioned and provides detailed analysis of detection probabilities. The simulation results are presented in Sec. 5. Finally, Sec. 6 concludes the work.

2. OFDM BASED COGNITIVE RADIO

As aforementioned, a Cognitive Radio requires a multicarrier modulation technique, and the best suited for the same is OFDM. OFDM is a modulation scheme where a number of subcarriers are used to modulate the message. This technique helps mitigating the problems like inter carrier interference, inter symbol interference, reduction in equalizer complexity etc.

OFDM based Cognitive Radio is advantageous for the following reasons. Due to the presence of an inherent FFT block in OFDM systems, the hardware required for implementing an energy detector is minimized as the same

FFT block can be reused. The output of the FFT block gives the information about each sub band. So if certain sub bands are free, the secondary user can use OFDM to transmit in those bands while making the others null. This method called spectrum shaping helps to completely utilize the available spectrum at all times. OFDM is widely deployed in many transmission systems including MIMO based systems; it helps achieve interoperability if used in cognitive radio.

3. ENERGY DETECTION

Energy detection (ED) is a non-coherent detection method that detects the primary signal based on the sensed energy. While the matched filter and feature detection techniques require prior information about primary signals, no primary signal information is required for the energy detection technique. So, energy detection is the most popular sensing technique in cooperative sensing [7].

Energy detector block diagram is depicted in Figure. 1. Here, a Band Pass Filter (BPF) is applied to select a centre frequency and bandwidth. Then the energy of the received signal is measured by a magnitude squaring device and integrating received signal over observation time interval and receiver bandwidth. The signal is detected by comparing energy of the received signal to the threshold level. If the threshold is exceeded, it is decided that signal(s) is (are) present otherwise it is absent. Energy detectors are often used due to their simplicity and good performance.

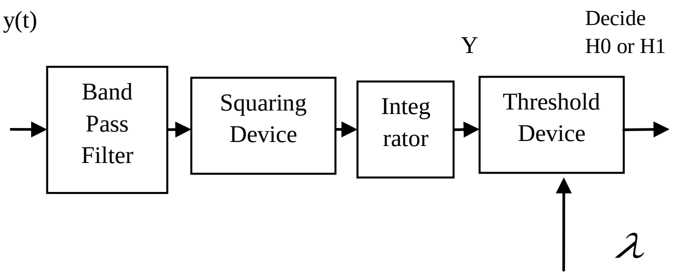

Fig 1: Block Diagram of Energy Detector

4. OFDM SYSYTEM MODEL

In this section, the detection probabilities of OFDM based cognitive radio using energy detector is derived to detect the presence of PU in a AWGN and Rayleigh fading channel. Consider PU transmitting OFDM signal with K-sub carriers on a bandwidth B. The transmission parameters, such as symbol period, carrier frequency and sub-carrier spacing of PU-OFDM signal are defined as Ti, fi and (Δf)i=1/Ti, respectively. The CR-OFDM system consists of Q number of sub-carriers with symbol period Ts, carrier frequency fs, sub-carrier spacing (Δf)s=1/Ts and occupies bandwidth W with signal to noise ratio and predefined threshold. In the following, assume fs=fi and derive the detection probabilities of PU signal on CR.

In OFDM transmission system, the symbols of user are passed though K-point IFFT block and cyclic prefix (CP) is added for eliminating inter-channel-interference (ICI). The basic block diagram of the base band OFDM system is illustrated in Figure. 2 [8].

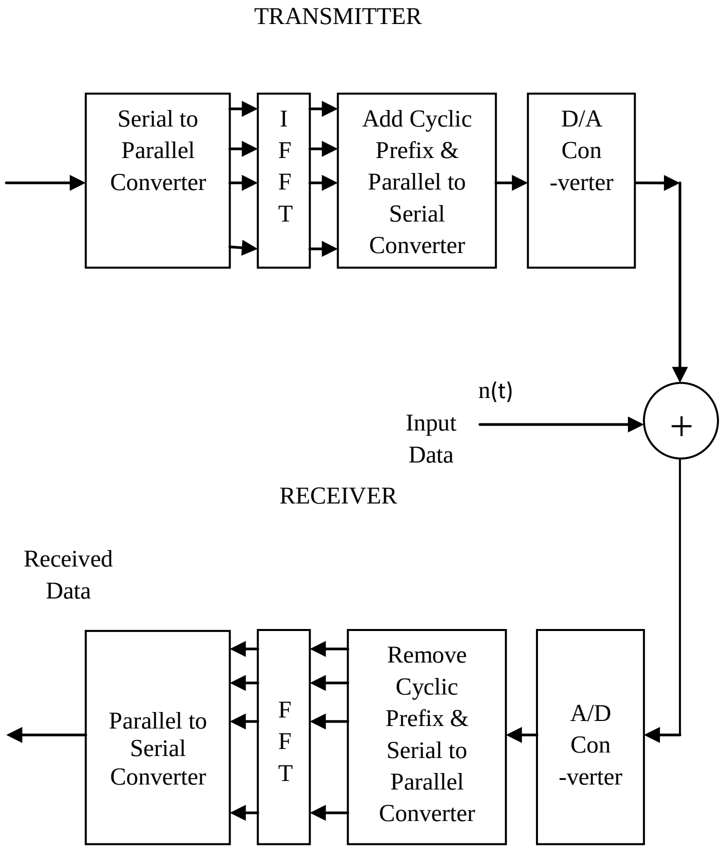

Fig 2: Block Diagram of Base band OFDM System

The digital signals are converted into analog signal and then transmitted through wireless channel. The lth transmitted PU-OFDM symbol is given by,

$$x(t - lT_i) = \sum_{k=0}^{K-1} X_{l,k} e^{\frac{j2\pi k(t-lT_i)}{T_i}} e^{j2\pi f_i (t-lT_i)} \quad (1)$$

where, Xl,k is PU symbol modulated on kth sub-carrier, generating lth PU-OFDM symbol.

The received signal on CR is converted to discrete time signal. The output of the receiver is given by,

$$s(t - nT_s) = e^{-j2\pi f_s (t-nT_{ss})} \sum_{m=0}^{L-1} h_m x(t - lT_i - mT_s) \quad (2)$$

where, h_m are coefficients of frequency selective fading channel. Substituting (1) in (2) yields

$$s = s(t - nT_s) = \sum_{m=0}^{L-1} h_m \sum_{k=0}^{K-1} X_{l,k} e^{\frac{j2\pi k(t-lT_i-mT_s)}{T_i}}$$

$$\times e^{j2\pi f(t-lT-mT)} e^{-j2\pi f_s(t-nT_s)} \quad (3)$$

At receiver side the cyclic prefix is removed to get original OFDM symbols and passed through Q-point FFT system. It is given as,

$$s(n) = \sum_{p=0}^{Q-1} s * e^{-\frac{j2\pi pq}{Q}} \qquad 0 \le q \le Q-1 \quad (4)$$

Therefore, the received signal at the CR post FFT or DFT operation can be written as

$$r(n) = s(n) + w(n) \quad (5)$$

Where, w(n) is the complex noise sequence with variance σ_w^2.

The primary objective is to determine the presence (Hypothesis H1) or absence (Hypothesis H0) of PU signal. Under these two hypotheses, received signal is denoted as[9]

H0: y (n) = w (n)

H1: y (n) = h* s (n) + w (n) (6)

where H0 is null hypothesis, H1 is presence of PU, s(n) is the transmitted signal of the primary user, h is the channel coefficient; and w(n) is additive white Gaussian noise with variance σ^2.

The energy detector forms the decision statistics (Eq) collecting N samples from the output of FFT block corresponding to qth sub-carrier. The decision statistics (Eq) will be compared with threshold calculated for a given probability of false alarm (Pf) to detect the presence of PU signal. The decision making block marks the sub-carrier as unused when the decision statistics is less than threshold value. This procedure is repeated for all the Q sub-carriers and subsequently, the number of sub-carriers free for use by CR is determined. Under H0, the normalized decision statistics is given as [10],

$$\text{Eq} = \frac{2}{\sigma_w^2} \sum_N |y(n)|^2 \quad (7)$$

Thus, Eq under H0 can be viewed as the sum of square of the 2N standard Gaussian i.i.d random variable with zero mean and unit variance. The output of the integrator Y is compared with the threshold value to detect or presence of primary user. Therefore, Eq follows a central chi-square distribution with 2N degree of freedom. The probability of false alarm is given as

$$P_f = \frac{\Gamma(N, \eta/2)}{\Gamma(N)} \quad (8)$$

where, Γ(., .) is the incomplete gamma function, is the threshold with which the decision statistics is compared to detect the presence of PU signal.

4.1 Probability of Detection and False Alarm for AWGN Channel

An approximate expression for the "probability of primary user detection" and the "probability of false detection" for the energy detection method can be described by the following equations [5],

$$P_d = P[Y > \lambda / H1] = Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) \quad (9)$$

$$P_f = P[Y > \lambda / H0] = \Gamma(m, \lambda/2) / \Gamma(m) \quad (10)$$

Where, λ is the decision threshold, is the SNR, Qm is Generalized Marcum function, Γ(., .) is the incomplete gamma function.

4.2 Probability of Detection for Rayleigh Channel

Probability density function for Rayleigh channel is,

$$f(\gamma) = \frac{1}{\bar{\gamma}} \exp(-\frac{\gamma}{\bar{\gamma}}) \quad (11)$$

Where is the average SNR.

The Probability of detection for Rayleigh Channel is obtained by averaging their probability density function over probability of detection for AWGN Channel [11],

$$P_{d,Ray} = \int_0^\infty P_d f(\gamma) d\gamma \quad (12)$$

Where, $P_{d,Ray}$ is the probability of detection for Rayleigh channel.

With eqn (5) and (7), (8) becomes,

$$P_{d,Ray} = \frac{1}{\bar{\gamma}} \int_0^\infty Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) \exp(-\frac{\gamma}{\bar{\gamma}}) d\gamma \quad (13)$$

5. SIMULATION RESULTS

Consider N sample points with false alarm probability 0.01 to 1 for single user. To show the detection performance of cognitive radio, complementary receiver operating characteristic (ROC) function is used.

In signal detection theory, the receiver operating characteristic (ROC) curve is defined as a plot of test sensitivity versus its specificity. It is an effective method of evaluating the quality or performance of diagnostic tests. To achieve the probability of detection 0.9 for Pf=0.01, SLC scheme is required.

CR senses the spectrum using energy detection equipped with SLC scheme at very low SNR for single user. For 2.5dB the performance of detection is good in AWGN channel is shown in Figure.3.

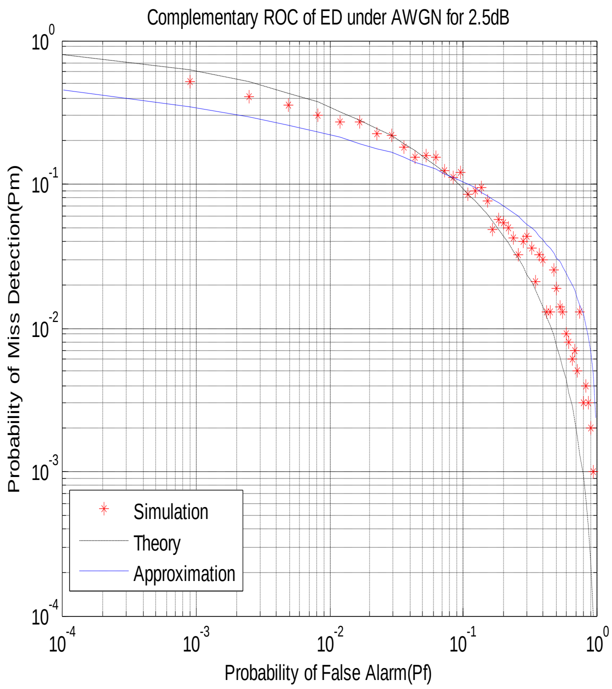

Fig 3: Complementary ROC curve of Energy Detection under AWGN for 2.5 dB SNR.

Figure. 4 illustrates the complementary ROC curves using squaring operation over different channels including AWGN and Rayleigh fading for -10 dB SNR and false alarm probability is 0.01. Comparing AWGN ROC with those corresponding to fading channel, it is observed that spectrum sensing degrades in the presence of shadowing and/or fading significantly. For example, in AWGN channel the ROC shows that Pm=0.1and Pf=0.1.However, in the case of Rayleigh fading, the ROC slightly degrades at the same Pm=0.1, respective to Pf=0.01.

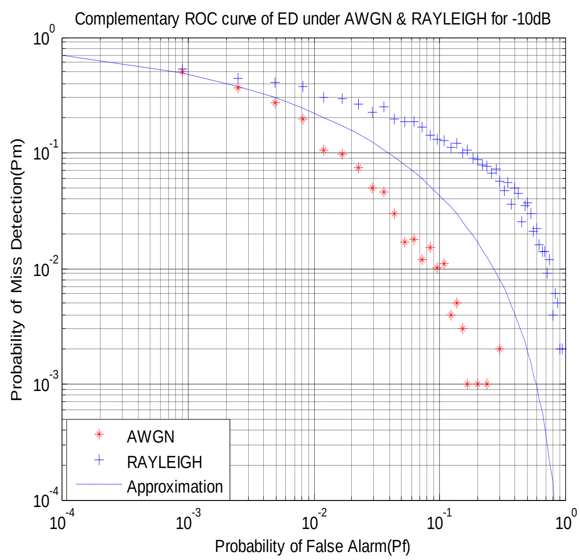

Fig 4: Complementary ROC curve of Energy Detection under AWGN and Rayleigh for -10 dB SNR.

5.1 Simulation Results for OFDM Based CR

Consider CR-OFDM system consists of Q=128 sub carriers of symbol period Ts=2.5μs and carrier frequency fs = 3.1 GHz equipped with energy detector for single user.

Figure.5 shows that the probability of detection increases for very low SNR.OFDM based CR equipped with energy detector achieves maximum detection for single user. It shows that the probability of detection is almost 100% for SNR=-5dB with 5% of false alarm probability.

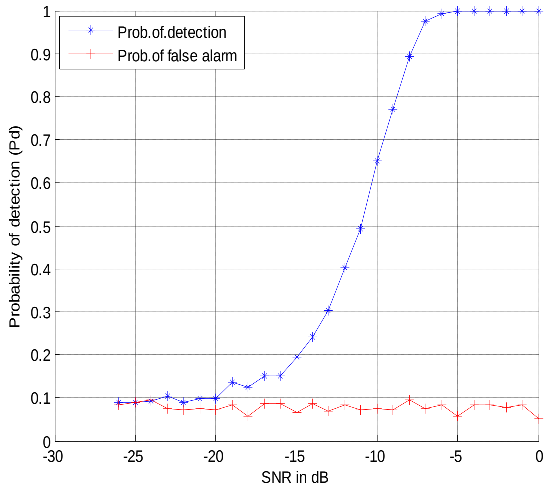

Fig 5: Probability of Detection vs SNR

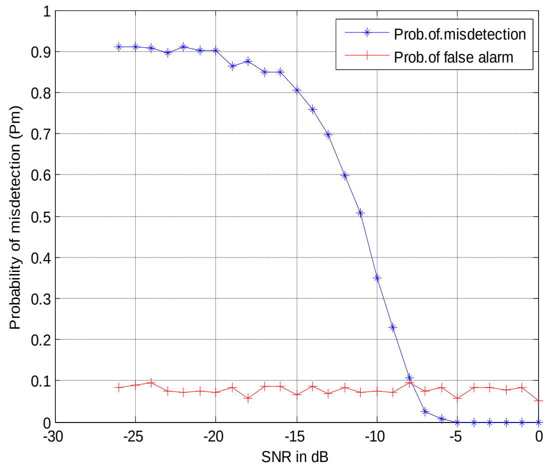

Fig 6: Probability of Missed detection vs SNR

In Figure.6 the missed detection decreases for low SNR. It shows the missed detection is almost 0% for -5 dB SNR with 5% of false alarm probability. The detection probability also increases by considering high number of OFDM samples (N) for forming decision statistics. However, considering high number of samples increases the sensing time, where sensing time is directly proportional to N.

6. CONCLUSION

In this paper, the performance of energy detector was evaluated over AWGN and Rayleigh fading channel. Here, CR is equipped with SLC based energy detection to detect the primary user signal. The SLC based energy detector provides high detection probabilities even at low to moderate SNRs. Also OFDM based Cognitive radio with energy detector is implemented by which high detection probability is achieved and the missed detection decreases with increasing SNR is analyzed. Thus Energy detection has the advantage of low implementation and computational complexities. And also it does not require prior information about primary signal. As in the case of OFDM signal sensing using energy detection which is chosen for decision statistics,if number of OFDM symbol is increased so that the performance increases, but at the expense of increased sensing time.

To avoid this, multiple user and multiple antennas will be used in OFDM based CR, to improve the performance of sensing method and time. Moreover, spatial correlation among users and antennas may be considered for further better sensing.

7. ACKNOWLEDGMENTS

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