An Improved Energy Detection Scheme under Noisy Environment
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Abstract— Spectrum sensing is the distinct feature of cognitive radio technology that makes it significant different from other wireless technologies developed so far. This feature embed cognition to the handheld device embeds Spectrum sensing gives an idea of detecting the presence of the incumbent users in a licensed spectrum. In most of the previous works, researchers either have taken fixed threshold or adapted it based on signal to noise ratio at receiver end. In this paper, we have used channel information rather than signal to noise ratio to decide threshold of an energy detector and shown that our proposed technique improves detection probability and reduce false alarm probability over state of art techniques available so far.

Key words: Energy Detector; Channel Sensing; Adaptive Threshold; Probability of Detection; Probability of False Alarm

I. INTRODUCTION

The concept of cognitive radio is introduced by J. Mitola in 2002 to overcome the spectrum scarcity problem existing today. With the rapid development of wireless applications today, the demand for more frequency spectrum has been increased manifold today. Since, electromagnetic spectrum is natural and scarce source; it should be exploited efficiently and intelligently. So far, fixed spectrum allocation policy has been adopted worldwide in which the spectrum is auctioned to the given geographical location for stipulated time. But, the recent FCC report has revealed that this spectrum allocation policy does not work well as most of the allocated spectrum is being exploited sporadically. That is how the concept of cognitive radio technology has evolved. The technology allows unlicensed secondary user to exploit the frequency spectrum of licensed incumbent user when it is not being used by it [1]. To do so, many spectrum sharing schemes have developed so far. These schemes are broadly classified as Underlay scheme & Overlay Scheme. In Underlay spectrum sharing scheme, both licensed and unlicensed spectrum users can share the spectrum as long as the secondary user holds spectrum-sharing constraints imposed by primary user on it. Whereas, in overlay spectrum sharing scheme, secondary user is allowed to use licensed spectrum when primary user is not using it [2].

For spectrum sharing-scheme and to work efficiently it is mandatory to know the presence or absence of the primary user before exploiting spectrum opportunities. To do so, spectrum sensing capabilities are embedded to the prototype of the next generation hand held devices. Various spectrum sensing schemes have been proposed so far to make cognitive radio technology a reality. Namely, energy detection, cyclostationary detection and matched filter detection [3]. Each detection method has its own pros and cons and out of these, energy detection method is the simplest and oldest used technique. Radar is the one successful application based on energy detection method [4]. Generally, in this technique a threshold is detected for detecting the existence of the signal in the spectrum. Even though it is simpler than the match filtering and cyclostationary feature detection, it requires at least $O(1/\text{SNR}^2)$ samples for detection [5] and it has fundamental problems: (i) susceptibility to changing noise levels, (ii) cannot distinguish modulated signals, noise and interference. Therefore it cannot treat primary users, secondary users and noise in different ways, (iii) cannot detect the primary signals with very low SNR [6].

Despite these bottlenecks, energy detection can provide lower sensing period than other methods and it is applicable for wideband sensing. Hence, energy detection is the most studied technique among all sensing methods. In [7], the performance of the energy detectors is improved through cooperative sensing with multiple CRs. Significant work is reported on double threshold methods [8], [9], [10]. In most of these work, signal to noise ratio at secondary transmitter is considered to adapt sensing threshold with assumption that it has full knowledge channel state information (CSI). From a practical point of view, its never possible to have full varying in nature and thus keep changing with time and geographical location [11]. To deal with this conflict cooperative spectrum sensing schemes have also been proposed. However, they have considered that channel conditions are known beforehand. Addressing this issue, in few reports threshold adaptation techniques have been proposed for imperfect channel conditions with significant probability of detection but they requires significantly long duration for spectrum sensing and large number of energy samples. This may lead to the reduction of transmission time and thus overall throughput of the system degraded [12].

In this paper, a novel threshold adaption scheme is proposed which could determine the presence of licensed incumbent user better than conventional adaptive threshold techniques with imperfect knowledge of channel CSI. The theoretical and simulated results are presented to demonstrate the effectiveness of the proposed scheme over conventional scheme. The rest of the paper is organized as follows. In Section II analytical model for conventional energy detector with imperfect channel CSI is presented. The improved energy detection scheme and sensing threshold adaption is proposed in section III. Simulated results for both detection schemes followed by conclusion is presented in section IV and V respectively.

II. CONVENTIONAL ENERGY DETECTION SCHEME

In conventional energy detection scheme the transmitted signal power of the incumbent user is sampled over a frequency channel for fixed time duration. It is assumed that channel is following block fading model with coherence time $T_c$. The samples of energy signal are taken and...
compared with predefined threshold level to determine the presence or absence of incumbent user. Based on test statistics two hypothesis are formed namely $H_0$ and $H_1$. When aggregate energy of the sampled signal is greater than the detection threshold $\lambda$, the detector will indicate that the primary user is present and therefore hypothesis is $H_1$, otherwise, the absence of incumbent user in channel is represented by Null hypothesis $H_0$.

$$y(n) = \begin{cases} w(n) & H_0 \\ x(n) + w(n) & H_1 \end{cases}$$ (1)

The performance of energy detector is measured by two different parameters: Probability of detection ($P_d$) and probability of false alarm probability ($P_f$). $P_d$ defines the probability of detecting incumbent user signal accurately under fading. $P_f$ describes the probability of erroneously detecting the presence of primary user when actually not present. According to the central limit theorem and as long as the number of samples ($N$) is large enough, the aggregate energy signal can be approximated as a Gaussian distribution

$$\sum y^2(n) = \begin{cases} \text{Normal}(\mu_0, \sigma_0^2) & H_0 \\ \text{Normal}(\mu_1, \sigma_1^2) & H_1 \end{cases}$$ (2)

Based on these test statistics, $P_d$ and $P_f$ may be given by (3) and (4) respectively.

$$P_d = 0.5 \operatorname{erfc} \left[ \frac{Th - \mu_1}{\sqrt{2\sigma_1}} \right]$$ (3)

$$P_f = 0.5 \operatorname{erfc} \left[ \frac{Th - \mu_0}{\sqrt{2\sigma_0}} \right]$$ (4)

Where, $\gamma$ is average signal to noise ratio of received signal and $Th$ is sensing threshold based on assumption that full channel CSI is known to the secondary transmitter beforehand can be calculated as $Th$

$$\frac{-\left(\sigma_0^2\mu_1 - \sigma_1^2\mu_0\right) + \left(\sigma_0^2\mu_1 - \sigma_1^2\mu_0\right) - \left(\sigma_0^2 - \sigma_1^2\right)}{\left(\sigma_0^2\mu_1 - \sigma_1^2\mu_0\right) - 2\sigma_0^2\sigma_1^2\ln(\gamma)} = \sqrt{\left(\frac{\sigma_0^2 - \sigma_1^2}{\sigma_0^2}\right)}$$ (5)

A. Conventional ED under with partial CSI

Since, it wireless channel is time varying in nature, its difficult to predict it accurately. Thus, the conventional detection scheme with fixed threshold leads to the erroneous response for given $P_d$ and $P_f$. If we define $\beta$ as a CSI parameter to indicate channel conditions such as $\beta \propto \frac{1}{\beta_{ps}}$ where $\beta_{ps}$ is gain between primary transmitter and secondary transmitter. Thus, higher the value channel CSI ,weaker is the channel. When partial CSI information is available, the noise variance is modified accordingly to adapt threshold accordingly.

$$\sum y^2(n) = \begin{cases} \text{Normal}(\beta N\sigma_n^2, \beta^2 2N\sigma_n^4) & H_0 \\ \text{Normal}(N\sigma_n^2(\gamma + \beta^{-1}), 2N\sigma_n^4(\gamma + \beta^{-1})^2) & H_1 \end{cases}$$ (6)

The sensing threshold can be calculated by substituting modified test statistics from (6) into (5).

III. PROPOSED DETECTION SCHEME WITH PARTIAL CSI

Under fading channel conditions, it is very important to choose a suitable detection threshold as it deteriorate the detection performance severely if not chosen properly. In this paper, we have present a dynamic optimal threshold algorithm to combat the effect of improper channel CSI. According to the channel inversion method if the channel CSI factor is $\beta$, we adapt the threshold value to the minimum value such as $Th_{min} = \frac{Th}{\beta}$ and to maximum value such as $Th_{max} = \beta Th$. Therefore, when channel CSI is high (Deep Fading) accordingly the threshold will be lower down by an amount of $\beta$ and when channel CSI is low (Low fading) accordingly the threshold will be enhanced by an amount of $\beta$. The (3) and (4) will be modified as

$$P_d = 0.5 \operatorname{erfc} \left[ \frac{Th/\beta - \mu_1}{\sqrt{2\sigma_1}} \right]$$ (7)

$$P_f = 0.5 \operatorname{erfc} \left[ \frac{\beta Th - \mu_0}{\sqrt{2\sigma_0}} \right]$$ (8)

IV. NUMERICAL RESULTS & DISCUSSIONS

In this section, simulated results are presented to validate the theoretical results. The results are simulated in MATLAB environment. Fig.1 shows that under similar channel conditions proposed scheme has higher probability of detection than conventional scheme even in low SNR region. With an increase in SNR to secondary channel it improves further and achieve 100 % detection of incumbent user in shared channel with improper information of channel CSI. Here, we have assumed channel CSI equals to 1.3 and number of samples equals to 30.

Probability of false alarm with channel CSI equals to 1.5 is shown in fig.2. It is clear from the graph that our proposed algorithm is performing better than conventional and it reduces $P_f$ from 0.33 to 0.02 at SNR equals to 0 dB.

![Fig.1: $P_d$ verses SNR(dB)](image-url)

Figure 3 shows the number of samples requirement energy detector for $P_d$ equals to 0.9 and $P_f$ equals to 0.1. It is observed that proposed detection algorithm requires significantly less numbers of samples over conventional technique. As it can be observed from fig.3 at SNR equals to 0 dB, number of samples required are 23 for conventional scheme whereas for our proposed scheme it requires only 9 samples for same probability of detection and false alarm.

Figure 4 is showing the comparison of the required value of threshold for conventional scheme as well as proposed scheme. It is observed that for conventional scheme with full CSI knowledge, threshold value is very less whereas for the same scheme with partial CSI knowledge, threshold increases significantly. As it may be seen that for our proposed schemes, threshold value is neither too high nor too low to discriminate incumbent signal user from background noise.

V. CONCLUSION
In this paper, a novel sensing threshold adaption scheme is proposed in which sensing threshold is selected based on channel sensing information. It is shown that for proposed scheme the probability of detection increase significantly and probability of false alarm decreases significantly over conventional scheme. Moreover, the number of samples required to sense the presence of incumbent primary user are also significantly less over conventional scheme.

REFERENCES