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Research Paper on Spectrum Sensing Error Probability in Cognitive Radio Networks

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ABSTRACT

The electromagnetic radio spectrum is a precious natural resource but with the fast development of wireless communication the increasing demand of limited spectrum ultimately cause spectrum scarcity therefore the use of this spectrum is licensed by the government. One of the most critical issue regarding wireless networks regulation agencies and researchers are thinking about is how to manage the available electromagnetic radio spectrum in a way that satisfies the needs of these growing wireless systems. Cognitive Radio has arisen as a new wireless communication paradigm aimed at solving the spectrum underutilization problems. For better Cognitive radio performance it is required to have a high probability of detection and low probability of false alarm but there is always a tradeoff between probability of false alarm and probability of miss detection We found that the performance of the cooperative spectrum sensing technique named energy detector is strongly depend on chosen decision threshold therefore the performance of the energy detector with the threshold obtained from CDR (Constant Detection Rate) and CFAR (Constant False Alarm Rate) is compared with linear combination algorithm in which threshold is obtained by linear combination of P_d and P_{fa}. Results will prove that the linear combination algorithm outperform both CDR and CFAR. The obtained numerical results are interesting and promising towards enhancing the overall performance of the spectrum sensing in cognitive radio networks simulation is done using MATLAB 2013a.

1. INTRODUCTION

The electromagnetic radio spectrum is a precious natural resource but with the fast development of wireless communication the increasing demand of limited spectrum ultimately cause spectrum scarcity therefore the use of this spectrum is licensed by the government. Practically measured Spectrum utilization between 0-6 GHz at Berkeley Wireless Research Centre (BWRC) explored in [1]. In [2], measurements shows lower frequency band is highly utilized and at higher frequency spectrum utilization is poor. This poor spectrum utilization is termed as spectrum hole. This indicates that spectrum scarcity is nothing but only a false belief.

Basically spectrum scarcity problem is due to fixed spectrum allocation policies, lack of flexibility in system, and inefficient spectrum utilization like utilization of public safety band (410-470 MHz) and unlicensed band (2.4 GHz) is only 16.6% and 1.2% respectively [3]. Some regulation authority like Federal Communications Commission (FCC) in US and Of-Com in UK found that the utilization of licensed band are varies from 15%-85% at different time and different location. Apart from these, measurement carried out at various countries shows 5-50% spectrum utilization [4]. This suggests that real problem is not spectrum scarcity but inefficient spectrum utilization. In November 2002, spectrum policy task force of USA prepared a report, aimed to improve the way in which this natural resource is managed [5]. It has found that the spectrum insufficiency is mostly caused by the fixed allocation strategy of wireless services and there always exist spectrum vacancies both in time and location. This paper also recommends certain rules and regulation to carry out efficient spectrum utilization. A possible solution to these problems has been provided if licensed spectrum is made available to unlicensed users provided there is no interference with licensed users. These spectrum opportunities can be made accessible to the unlicensed user (Secondary user), also called cognitive radio users [6].

2. PROBLEM DEFINITION

Cognitive radio (CR) is becoming an effective and capable technique to get better spectrum utilization. One of the most prominent tasks in the implementation of cognitive radios in communication networks is the spectrum sensing. Various spectrum sensing algorithms are available in the literature among which energy detection technique has been gaining popularity for primary user detection mainly because of its simplicity and low complexity.

However, its performance is adversely affected due to noise uncertainty particularly in low SNR conditions. Therefore improvement in the performance of the CR system in low signal to noise ratio conditions is the main concern. In this paper the performance of the system is studied in terms of overall probability of error while sensing operation is going on. First objective of this thesis is to analyze the tradeoff between probability of detection (P_d) and probability of false alarm (P_{fa}). This explores reliability and robustness of decision made by SS methods in under different constraints. The second objective is to improve performance of SS at low Signal to Noise Ratio (SNR). This task is very important for all CR applications, e.g. like operation in TV band where FCC put very strict requirement that CR device should be able to detect licensed TV signals at very low SNR -18dB [6] and at last performance comparison of all used detection schemes in terms of sensing error probability.

3. RESEARCH METHODOLOGY

From the following conditions we will formulate mathematical equations and then implement them into MATLAB for simulation.

Sensing Error Probability Pe with Constant False Alarm Rate: Sensing error probability is the key metric on which performance of the energy detector depends and it should minimize as much as possible. In spectrum sensing, it is important to minimize theP_{fa} to access more spectrum opportunity and lower miss detection probability is desired to provide protection to the licensed user. In this section, we investigate the probability of error as a function of threshold determined by keeping false alarm rate constant (CFAR) with the assumption that noise is fully known. In such case threshold is obtained from equation is given by [8]:

$$\lambda_{fa} = \mathrm{erfcinv}(2P_{fa}) * \sigma_0 + \mu_0)$$

Pe with Constant Detection Rate: In this section, we investigate the probability of error as a function of threshold determined by keeping detection rate constant (CDR) with the assumption that noise is fully known. In such case threshold is obtained from equation is given by [9]:

$$\lambda_d = \mathrm{erfcinv}(2P_d) * \sigma_1 + \mu_1$$

Threshold obtained from equation (39) is denoted as λ_d.

Pe under noise uncertainty: Practically there may be several reasons of noise in the received signal. This noise may be caused by independent sources such as interferences due to unintended emissions from transmitters and thermally generated noise, etc. However the noise power may varies over time and location, which results into noise uncertainty [10].

$$P_d = \frac{1}{2}\mathrm{erfc}\left(\frac{\lambda_d - N\sigma_n^2(\frac{1}{a}+\gamma)}{\sqrt{4N}\sigma_n^2(\frac{1}{a}+\gamma)}\right)$$

$$P_{fa} = \frac{1}{2}\mathrm{erfc}(\frac{\lambda_{fa} - Na\sigma_n^2}{\sqrt{4N}a\sigma_n^2})$$

Where, σ_n^2 is the nominal noise power and noise uncertainty is known to be exist within the range $\sigma^2 \in (\sigma_{min}^2, \sigma_{max}^2)$, where σ^2 is the estimated noise power, ($\sigma_{min}^2 = \sigma_n^2 / a$) is the lower limit of the noise uncertainty, ($\sigma_{max}^2 = a\sigma_n^2$) represent the upper limit of the noise uncertainty, ($a \geq 1$) denotes the noise uncertainty factor.

Linear combination algorithm: An alternative and efficient method of setting of the decision threshold is to merge the Pd and Pfa linearly. Let $P(\lambda)$ denote the collective performance of CFAR and CDR criteria [11-13]. Thus, we have

$$P_d = \frac{1}{2}\left(\frac{\lambda_{lcm} - \mu_1}{\sigma_1}\right)$$

$$P_{fa} = \frac{1}{2}\left(\frac{\lambda_{lcm} - \mu_0}{\sigma_0}\right)$$

Where,

$$\lambda_{lcm} = \frac{1 + \sqrt{1 + \frac{4(2\sigma_n^2 + \sigma_s^2)}{N\sigma_s^2}\ln\left(\frac{(\sigma_n^2+\sigma_s^2)}{\sigma_n^2}\right)}}{\frac{2\sigma_n^2+\sigma_s^2}{\sigma_n^2((\sigma_n^2+\sigma_s^2))}}$$

4. SIMULATION SETUP AND RESULTS

Results are simulated by computer simulation in Matlab2013a and are arranged as follow:

P_d and P_{fa} tradeoff analysis: First two figures 1.1 and 1.2 show the tradeoff between Pd and Pfa and these results also illustrate that the performance of the ED start degrading below a critical value of SNR.
Sensing Error Probability (Pe): Figure 1.1 to 1.6 shows the analysis of Pe for both certain and uncertain noise and also includes analysis of Pe with different value of threshold.

Simulation Model Parameters

For simulation purpose some values of parameters used in this paper are assumed. These are, targeted value of P_d is taken 0.9 - 0.95 for CDR scheme and targeted value of $P_{fa}$is taken as 0.01 for CFAR scheme. SNR range is taken from -20 db to 0 dB. For certain noise, noise power is assumed to be completely known (σ_n^2=1).

Simulation Results

Results are generated by computer simulation in Matlab2013a. Figure 1 illustrate that energy detector with the decision threshold (λ_f) obtained from CFAR criteria, works well in high SNR conditions but as the value of SNR decrease probability of detection decrease dramatically but when the decision threshold is λ_d then Pd meet the targeted value.

Traditional energy detector calculates the threshold by targeting the P_{fa}which doesn't require knowledge of SNR therefore when SNR is below the particular SNR value, performance of the energy detector deteriorates. If the SNR of the channel is more than critical value than there are two options, if it is mandate to cause the least interference with the primary user than λ_{fa} can be chosen as decision threshold. But, if high throughput is required from the secondary network than λ_d can be chosen as decision threshold.

For constant false alarm scheme targeted Pfa is set to 0.01 and for constant detection scheme Pd is set to 0.9 i.e Pm=0.1 and the range of the SNR is taken from (-25, 0) dB.

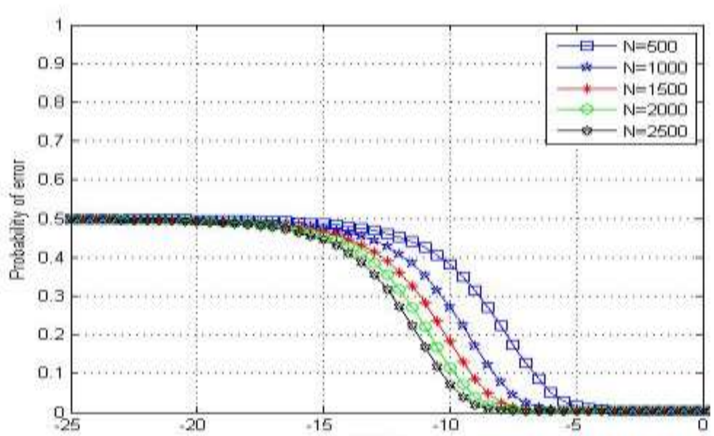

Fig. 1: Sensing error probability according to average SNR with constant false alarm rate scheme.

The probability that primary user is present is taken to 0.5 and the probability of primary user is absent is taken to 0.5. Figure 1 shows the variation in sensing error probability with respect to average SNR with different values of N. It is obvious that at low SNR, as the value of N increase the value of Pe decrease dramatically.

The performance of the constant detection scheme is also verified for noise uncertainty. Figure 2 illustrate that, as the noise uncertainty factor (a) increase, probability of error increase accordingly. The uncertainty factor varied from 1 to 1.2. It is clear from the figure 1.6 that constant detection rate scheme also perform better for uncertain noise. In noise uncertainty sensing probability error reduced by 0.5 for a given range of SNR (-25,5) dB. It is clear from figure 1.2that when the uncertainty factor (a) is 1.1, the value of sensing probability error reduce to 0.1 at a SNR value of -2.5 dB for constant false alarm scheme.

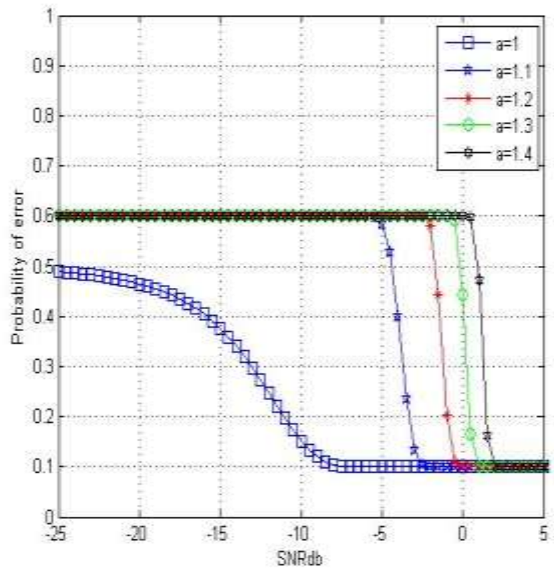

Fig. 2: Pe according to average SNR with different values of noise uncertainty factor for CFAR scheme

CONCLUSION AND FUTURE SCOPE

In this paper performance of the energy detector at low SNR is analyzed and it is shown that the performance of the energy detector degrade at low SNR. For better performance it is required to have a high probability of detection and low probability of false alarm but there is always a tradeoff between probability of false alarm and probability of miss detection i.e. if energy detector getting high Pd at low SNR than for the same SNR P_{fa} is also high due to which overall probability of error remains high. The motivation behind work was to minimize the overall probability of error for both certain and uncertain noise cases, which we have achieved successfully.

It can be concluded now that the performance of the energy detector is strongly depend on chosen decision threshold therefore the performance of the energy detector with the threshold obtained from CDR and CFAR is compared with linear combination algorithm in which threshold is obtained by linear combination of Pd and Pfa. Results prove that the linear combination algorithm outperform both CDR and CFAR and the obtained numerical results are interesting and promising towards enhancing the overall performance of the spectrum sensing in cognitive radio networks.

This work analyze the sensing error probability and explore some situations that really helpful in real time scenarios. This work can further be used in order to obtain batter probability of error. This work can be extended in two ways:

1. One can improve the performance if it is possible to enhance the SNR of the channel. If the SNR of the channel is enhanced than it will simultaneously improve the Pd and Pfa which will definitely reduce the sensing error probability (Pe).

2. A system should be developed that dynamically choose the threshold based upon the usability of the spectrum band that is under scan.

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