Spectrum Sensing in Cognitive Radios for Efficient Utilization of Resources

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Abstract— The last decade has witnessed a growing demand for wireless radio spectrum due to the rapid deployment of new wireless devices and applications. Spectrum is a precious resource and thus underutilization of a large part of allocated spectrum is not acceptable. Cognitive Radio(CR) is proposed as a promising solution for increasing spectrum utilization. We conduct simulations to validate and evaluate our proposed scheme.

Key words: Cognitive Radio (CR), Probability of false alarm(Pfa)

I. INTRODUCTION

With rapid growth in the wireless devices and applications, the usage of spectrum resources plays a vital role in the current wireless scenarios. In particular most of the allocated spectrum to the licensed users is idle, results in demand of allocation of spectrum to users called spectrum scarcity. The underutilization of spectrum in wireless communication can be solved in a better way by using the technology called cognitive radio. Recent studies by the FCC, Spectrum Policy Task Force have reported vast temporal and geographic variations in the usage of allocated spectrum with utilization ranging from 15 to 85%. The large portions of the spectrum are unused as illustrated in Figure 1. Cognitive radios can change its transmitter parameters based on interaction with environment in which it operates. It consists of four main functional blocks such as spectrum sensing, spectrum management, spectrum sharing and spectrum mobility.

![Fig.1: Spectrum Utilization](image)

Spectrum sensing aims to determine availability of spectrum and the presence of the licensed users. Spectrum management is to predict how long the spectrum holes are likely to remain available for use to cognitive radio users. Spectrum sharing is to distribute the spectrum holes fairly among the secondary users. Spectrum mobility is to control seamless communication requirements during the transition to better spectrum [1].

There have been several sensing algorithms including the cyclostationary detection, the matched filtering and the energy detection. For example, cyclostationary detection requires the knowledge of cyclic frequencies of the primary users, and matched filtering needs to know the waveforms and channels of the primary users. On the other hand, energy detection does not need any information of the signal to be detected and is robust to unknown dispersive channel.[2] However, energy detection relies on the knowledge of accurate noise power, and inaccurate estimation of the noise power leads to SNR value and high probability of false alarm. Thus energy detection is vulnerable to the noise uncertainty.

II. PROPOSED COGNITIVE RADIO

The cognitive radio and dynamic spectrum access represent two complementary developments that is expected to refashion the world of wireless communication in future. In order to investigate the roles of knowledge representation and reasoning technologies in this domain, an experimental cognitive radio simulation environment is developed. The main specific benefit of full CR is that it would allow systems to use their spectrum sensing capabilities to optimize their access to and use of the spectrum. The objectives of spectrum sensing are: 1) CR users should not cause harmful interference to primary users (PUs) by either switching to an available band or limiting its interference with PUs at an acceptable level and, 2) CR users should efficiently identify and exploit the spectrum holes for required throughput and Quality-of-Service (QoS). Decision regarding use of the band in spectrum sensing is made by comparing the detection statistic to a threshold value, \( \lambda \). Mathematically, the detection is a test of the following two hypothesis:

A. Hypothesis 1 (H_0):

The input \( y(t) \) is noise alone:

\[
y(t) = n(t)
\]

\[
E[n(t)] = 0
\]

Noise spectral density= \( N_{02} \) (two–sided)

Noise Bandwidth=\( W \) cycles per second

B. Hypothesis 2 (H_1):

The input \( y(t) \) is signal plus noise:

\[
y(t) = n(t) + s(t)
\]

\[
E[n(t) + s(t)] = s(t)
\]

The received signal \( r(t) \) takes the form

\[
r(t) = h s(t) + n(t)
\]

Where, \( h = 0 \) or \( 1 \) under the hypothesis \( H_0 \) or \( H_1 \) respectively. \( r(t) \) is the received sample signal (or whitespace sample) to be analysed at each instant \( t \). \( n(t) \) is additive noise (having zero-mean and variance \( \sigma^2 \)). The
received signal is first pre-filtered by an ideal bandpass filter with transfer function \( H(f) \) to limit the average noise power and normalize the noise variance, as:

\[
H(f) = \begin{cases} 
\frac{2}{\sqrt{N_{01}}} & |f - f_c| \leq W, \\
0 & |f - f_c| > W 
\end{cases} \tag{3.4}
\]

The correctness of sensing signal availability is defined using quality parameters. This feature make up the performance metrics; among which are the probability of detection \((P_d)\), false alarm probability \((P_f)\) and probability of missed detection \((P_m)\). \(P_d\) specifies that a detector makes a correct detection that a channel is occupied, hence it is an indicator of the level of interference protection provided to the primary user. A large \(P_d\) denotes exact sensing; thus a small chance of interference. An SU misses the chance to exploit a free spectrum when a false alarm event occurs. \(P_f\) should be kept as low as possible in order to prevent underutilization of transmission opportunities. This is an important measure in the study of a spectrum sensing technique.

To quantify and depict receiver performance, the receiver operating characteristics (ROC) curves is used. These graphs show relative trade-offs between detection probability and false alarm rates, (i.e. \(P_d\) versus \(P_f\)), thus allowing the determination of an optimal threshold.

The output of the integrator denoted by \(Y\) will act as the test statistic to test the two hypothesis or \(H_0\) and \(H_1\). According to the sampling theorem, the noise process can be expressed as:

\[
n(t) = \sum_{i=-\infty}^{\infty} n_i \text{sinc}(2Wt - i) \tag{3.5}
\]

Where \(\text{sinc}(x) = \frac{\sin(\pi x)}{\pi x}\) and \(n_i = n(\frac{i}{2W})\). One can easily check that \(n_i = N(0, N_{01}W)\), for all \(i\). Using the fact that

\[
\int_{-\infty}^{\infty} \text{sinc}(2Wt - i) \text{sinc}(2Wt - k) \, dt = \begin{cases} 
\frac{1}{2W} & i = k \\
0 & i \neq k 
\end{cases} \tag{3.6}
\]

Equation 3.5 can be written as:

\[
\int_{-\infty}^{\infty} n^2(t) \, dt = \frac{1}{2W} \sum_{i=-\infty}^{\infty} n_i^2 \tag{3.7}
\]

Over the time interval \((0, T)\), \(n(t)\) the noise energy can be approximated by a finite sum of \(2TW\) terms as:

\[
n(t) = \sum_{i=1}^{2TW} n_i \text{sinc}(2Wt - i), \quad 0 < t < T \tag{3.8}
\]

Similarly, the energy in a sample of duration \(T\) is approximated by \(2TW\) terms of the right-hand side:

\[
\int_{0}^{T} n^2(t) \, dt = \frac{1}{2W} \sum_{i=1}^{2u} n_i^2 \tag{3.9}
\]

Where, \(u = TW\). It is assumed that \(T\) and \(W\) are chosen to restrict \(u\) to integer values. Thus,

\[
n_i^2 = \frac{n_i}{\sqrt{N_{01}W}} \tag{3.10}
\]

Where \(N_{01}\)-one-sided noise power spectral density, and the test of decision statistic \(Y\) can be written as

\[
Y = \sum_{i=1}^{2u} n_i^2 \tag{3.11}
\]

\(Y\) can be viewed as the sum of the squares of \(2u\) standard Gaussian variates with zero mean and unit variance. Therefore, \(Y\) follow a central Chi-square \((\chi^2)\) distribution with \(2u\) degrees of freedom. The same approach is applied when the signal \(s(t)\) is present with the replacement of each \(n_i\) by \(n_i + s_i\), where \(s_i = s(\frac{i}{2W})\). The decision statistic \(Y\) in this case will have a noncentral \(\chi^2\) distribution with \(2u\) degrees of freedom and a non-centrality parameter \(2\lambda\). Following the short-hand notations mentioned in the beginning of this section, the decision statistic can be described as:

\[
Y = \left\{ \begin{array}{ll}
\frac{\chi^2_{2\lambda}}{\chi^2_{2\lambda}(2\gamma)} & H_0 \\
\frac{\chi^2_{2\lambda} + (2\gamma)}{\chi^2_{2\lambda}(2\gamma)} & H_1
\end{array} \right. \tag{3.12}
\]

The probability density function (PDF) of \(Y\) can then be written as:

\[
f_Y(y) = \left\{ \begin{array}{ll}
\frac{1}{2^u \Gamma(u)} y^{u-1} e^{-\frac{y}{2}} & H_0 \\
\frac{1}{2^u \Gamma(u)} y^{u-1} e^{-\frac{y}{2}} \frac{\Gamma(u) - \Gamma(u - \frac{1}{2})}{\Gamma(u - \frac{1}{2})} & H_1
\end{array} \right. \tag{3.13}
\]

Where, \(\Gamma(.)\) is the gamma function. The probability of detection and false alarm can be generally computed by:

\[
P_d = P(Y > \lambda | H_1) \tag{3.14}
\]

\[
P_f = P(Y > \lambda | H_0) \tag{3.15}
\]

Where, \(\lambda\) is the final threshold of the local detector to decide whether there is a primary user present. Combining equations 3.12 to 3.15 to have:

\[
P_f = \frac{\frac{\Gamma(u - \frac{1}{2})}{\Gamma(u)}}{\frac{\Gamma(u) - \Gamma(u - \frac{1}{2})}{\Gamma(u - \frac{1}{2})}} \tag{3.16}
\]

And,

\[
P_d = Q_u(\sqrt{2\gamma}, \sqrt{2\lambda}) \tag{3.17}
\]

Where, \(\gamma = \frac{\sigma^2}{2\sigma^2_0}\) denotes the signal to noise ratio and \(Q_u\) is the generalized Marcum’s Q function.

### III. Simulations & Results

We investigated the performance of an energy detector applied to a secondary user for spectrum sensing. All simulations in this work is executed on MATLAB. Monte Carlo(MC) method, which is a stochastic technique forms the basis of these simulations. Receiver operating characteristics (ROC) curves is used to compare different
scenarios described. ROC has been widely used in the signal detection theory due to the fact that it is an ideal technique to quantify the tradeoff between the probability of detection (Pd) and the probability of false alarm (Pfa).

From Fig. 2 it is evaluated that when the SNR is between 18db to 25db, a high probability of detection is observed.

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Table 1: Detection probability changes based on SNR & u

From Table 1, it is observed that probability of detection decreases when time bandwidth factor (u) increases.

From Fig. 4 it can be seen that the detection probability is increasing, when Pfa is increasing and it also shows that when SNR increases, the detection probability also increases.

Fig. 4: Probability of detection vs Probability of false alarm

IV. CONCLUSION

In this paper, we study the performance of energy detection algorithm for spectrum sensing in cognitive radio by drawing the curves between probabilities of false alarm vs. probability of detection, SNR vs. probability of detection and the performance of dynamic threshold on spectrum detection techniques. It is observed that cognitive radio is a paradigm for new wireless communications to meet the
required standards. It is also found that by increasing the number of sample points, the detection performance is much better even at lower SNR values.

V. FUTURE SCOPE

In future, the concept of energy detection based spectrum sensing in cognitive radios can be implemented on real signals e.g. cognitive radio over fibre techniques (CRoF). As we know that the detection performance can be improved by using dynamic threshold based spectrum detection algorithm in cognitive radio systems. So in future, the dynamic threshold can be used.

REFERENCES