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Refined Two-Step Energy Detection Methodology for Channel Sensing based on BER Calculations

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Abstract **– Spectrum sensing for Cognitive Radio (CR) determines the availability of the spectrum, from which communication parameters like modulation techniques, protocol, transmission time can be optimised for the current channel. This paper proposes a refined two-step methodology of spectrum sensing that involves both energy detection as well as the actual testing of the channel; the combined results of which are used for Primary User (PU) detection. The proposed scheme of testing has a superior Probability of Detection of a PU, as compared to conventional energy detection methods, especially in hidden and exposed node scenarios. Practical results measured using USRP boards verified the improved results obtained from simulation.**

Keywords **– Bit Error Rate, Cognitive Radio, Channel Sensing, Spectrum Decision.**

I. Introduction

Wireless Communication devices and related technology has increasedexponentially in the past few years leading to scarcity of the spectrum. Conventionally, frequencies are licensed by the government which has led to low utilisation (only 6%) of the allocated bands, mainly due to the bursty nature of data communication [1]. With the continuedoverwhelming growth of wireless services, in the near future, due to the limited number of allocated channels, the spectrum will no longer be able to cater to this traffic.

Cognitive Radio technology can provide a solution by improving the channel utilisation through opportunistically identifying the vacant periods of communication and transmitting in these slots (often referred to as white spaces or spectrum holes).

The most crucial steps in the CR communication process are spectrum sensing and the decision making function. Spectrum sensing involves the reliable detection of spectral holes which can be utilisedopportunistically by the Secondary User (SU). Additionally, once a PU starts communication, spectrum sensing should be able to detect the PU within a reasonableamount of time, so as to minimise the interference produced by the SU on the PU. The information obtained from spectrum sensing is processed by the decision making function which identifies feasible spectrum holes for SU communication. The detection process must consider any error that may occur due to the channel conditions (time-varying RF environment) as well as the fluctuations of PU activity (bursty nature of data traffic of the PU).

Spectrum sensing is generally implemented by using energy detectors which have a simple principle of operation: the energy detector calculates the energy that is received for that channel and compares it to a threshold value. If the energy is greater than the threshold, then the PU is present, else it can be considered as a spectrum hole.Energy detectors have decision making policiesthat leads to a tradeoff between the Probability of Detection (P_d) and Probability of False Alarm (P_{fa}). Furthermore, another drawback of an energy detector is the degraded performance in unknown noise levels and low Signal to Noise Ratio (SNR) conditions. Fig. 1 describes such a conventional energy detector with a sensing node (generally a SU) and multiple interfering nodes (either a PU or a SU).

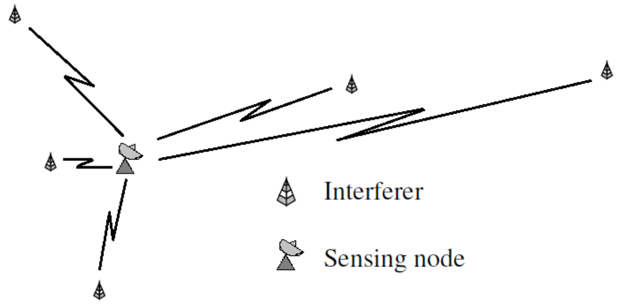

Fig.1. Conventional energy detection model where one node senses all the energies[2]

Additionally, most detectors, including the energy detectors performless efficiently in the presence of hidden and exposed node scenarios. For the case of exposed nodes, the chances of a false detection (often referred to as false alarm) increases due to energy detected being greater than a threshold, however the communication of SU is not likely to affect the communication of the PU. On the other hand, in hidden node scenarios, the energy detected will not be greater than the threshold but allowing communication of the SU will interfere with that of the PU. As a result, the decision making process will not be accurate and thus lead to crosstalk between PU and SU. This will lead to a lower utilisation of the channel than conventional allocation as PU communication is partly affected and SU communication is completely disturbed by the presence of a PU.

Parameters such ascarrier frequency, data rate, modulation technique, transmission power are all inferred by the decision making process based on the spectrum sensing results.Therefore it is of great importance that accurate spectrum sensing results are obtained. A lack of accurate results will lead to a limited performance of the CR network, irrespective of the expertise of decision making.

In recent studies, optimisation of spectrum sensing has been addressed. In [3], the energy detection method has

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been enhanced so that the energy threshold of detection will be dynamic, adapting as a function of the current environmental conditions, yielding more accurate channel sensing. In [4] an enhanced method of energy detection has been proposed which has a superior P_d because of the ability of the proposed detector to utilise the spectrum features of the PUs to differentiate each PU from the other as well as the Additive White Gaussian Noise (AWGN); however the paper addresses individual spectrum sensing and does not cover the scenarios of multiple PUs and SUs.

Bapu and Suganthi [5] developed a method that does not utilise the signal characteristics but rather relies on soft and hard decision making for increasing the P_d.However, for a significant improvement of results for the proposed method, more hardware has been employed (multiple antennas). The optimisation of the conventional and basic energy detection principle isless popularly discussed and new methods such as cooperative sensing, sensing with multiple antennas and cyclostationary techniqueare being researched more widely [6]. One key downside of these methods, especially cyclostationary, is the increased computational needs required for decision making [7].

In this paper, a refined methodology of spectrum sensing has been proposed that is based on both energy detection as well as actual channel testing that will yield a more accurate analysis of the channel than conventional energy detection.

The rest of the paper is organised as follows. Section II describes the refined methodology of spectrum sensing. In Section III, we present a mathematical model for evaluating the system performances. The results obtained for the proposed system are evaluated in Section IV. We finalise the paper by summarising the achievements in Section V.

II. Proposed Spectrum Sensing Methodology

The proposed spectrum sensing methodology involves two steps for the accurate determination of PU. An assumption is that every communication node is a transceiver. The first step involves the magnitude of energy detected ($Energy_{Detected}$) by the transmitting (TX) node of the SU communication system. If $Energy_{Detected}$ is greater than a fixed threshold energy ($Energy_{Threshold}$) then a PU is detected.Those cases in which a PU is detected are not taken into consideration for the second step. The energy threshold in the proposedmethodology was set to a higher level than the energy threshold of the conventional energy detector.This is because the $Energy_{Threshold}$ is a function of P_{fa}, hence, this high threshold ensures that if a PU is detected, the chances of a False Alarm will be reduced. As a result of this, less number of false PU detections will take place and thus more cases will go to the second step, thereby giving a higher level of accuracy of channel testing. For the proposed methodology, the approach is that those cases in which a PU is not detected in the first step are not directly declared as vacant, but rather a more conclusive testing is needed, hence we proceed to the second step for such cases.

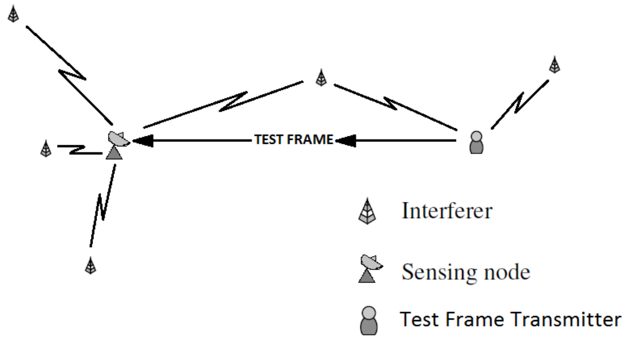

Fig.2. Proposed methodology of spectrum sensing that is able to detect the presence of a hidden node (top right interferer node)

The next step involves the transmission of a "Test Frame" (*Test Frame*) (a fixed message that is known to all users) by the receiver (RX) node of the SU to the said TX node. This allows the test frame to undergo the same channel conditions that the actual data would undergo if sent. The test frame is received by the transceiver of the TX node and evaluated for errors by comparing the received message with the original "Test Frame". The Bit Error Rate (BER) is thus obtained and this result is the main parameterby which the presence or absence of a PU is determined. If the obtained BER is greater than a certain threshold ($BER_{Threshold}$) which is determined foreach ratio of PU TX power to SU TX power (referred to as m),the inference made is the presence of another user, whichinterfered with the communication of the Test Frame. This other user can either be a PU or SU, irrespective of which (for the sensing SU), the channel is occupied and as a result, the SU cannot transmiton it. Fig. 2 describes the proposed spectrum sensing method (specifically the second step of the methodology) where the RX is transmitting a Test Packet back to the TX, in the presence of other nodes.

As the testing of the channel is carried out by actually sending data on it, a simple receiver can understand the quality of the channel without the need for complex system modeling of the channel conditions. The two-step method works on the principle that only if the TX requests the RX to send a "Test Frame" for BER analysis, then only will a test frame be sent on the requested channel. This way, not all channels will be tested but only those in which the presence/absence of a PU is uncertain. This way TX node is responsible for making the decision on which channel has to be tested as well as requesting the RX to send this Test Frame. As there will be transmission of the test frame on certain channels, these channelswill be occupied periodically, for a fractional amount of time.This is what is considered as the cost for obtaining results with greater accuracy. However, althoughactually testing of these channels is carried out, the first energythreshold test would affirm that no PU is in close proximity and thus the transmission of the test frames (at a lower power compared to normal PU transmission) would not adversely affect PU transmission. Algorithm 1explains the proposed refined spectrum sensing methodology. The result of the spectrum sensing will primarily be the channel status (referred to as *Channel Status*) as well as,from the *BER*, other parameters of communication like modulation technique, transmission time, power of TX can be deduced.

Algorithm 1: Refined Spectrum Sensing

Require: P_{fa}, *m*, $Energy_{Detected}$, *Test Frame*
$Energy_{Threshold} <= P_{fa}$
BER_Threshold<= m
if $Energy_{Detected} > Energy_{Threshold}$
Channel Status <= PU Present
else
// TX requests RX to send Test_Frame
BER<= Test Frame
if *BER* $> BER_{Threshold}$
Channel Status <= PU Present
Else
Channel Status <= PU Absent
End if
End if
Return*Channel Status*

In situations where the PU is a hidden node, the PU is closer to the RX node with respect to the TX node. In such cases the hidden node will interfere with the transmission of the test frame, thereby degrading the BER, leading to a greater chance of detection of a hidden node than by using simple energy detection.For the case of exposed nodes, if the initial energy detected is less that the energy threshold, then BER testing will reveal if this exposed node is actually close enough to cause interference to the communication link that is to be established. As a result, any node will only be detected if it is actually causing PU and SU interference, without the need for considering the transmitting power and location.

III. Mathematical Modeling

For the system modeling, we have considered the channel noise model as AWGN. Different values of P_{fa} have been considered from which the energy threshold has been obtained for that specific value, by using (1), where Γ denotes the Gamma function [8][9].

$$P_{fa} = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)} \qquad (1)$$

In (1)λ is the power (energy detected per unit time) threshold and$u$ is the time-bandwidth product which is assumed to be constant for the entire mathematical modeling; thus resolving to a direct relation between P_{fa} and λ. Therefore, for a given value of P_{fa} the corresponding power threshold is obtained using (1).

The SNR value γ is the ratio of PU power to noise present. From the calculated power threshold value λalong with observed γ, theP_d is deducedusing(2), where Q_u denotes the Marcum Q-function [10].

$$P_d = Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \qquad (2)$$

If there is a detection of the PU (or even another SU), the proposed methodology will not proceed to the next step as the channel is not available for utilisation. Otherwise, in cases where any user is not detected, the proposed methodology will proceed to the next step that involves BER testing by sending the Test Frame.From the second step, the *BER*is obtained and on the basis of this parameter, the presence or absence of a user is determined. The SNR obtained in this step is the ratio of SU power to the sum of PU power and AWGN which is denoted byγ_{BER}. Equation (3) is used for the relation between Bit Error Rate, energy of symbol,E_{symbol} and the noise power spectral density for AWGN. $N_o$is twice the noise power spectral density for AWGN. It isconsidered that the Test Frame is transmitted using 8-PSK modulation [11].

$$Bit\ Error\ Rate_{8-PSK} = 2Q(\sqrt{2\gamma_{Symbol}} \sin\frac{\pi}{8}) \qquad (3)$$

γ_{Symbol} is the ratio of the E_{Symbol} to N_o, which can be related to SNR, used in the second step, by using (4) (for 8-PSK).

$$\gamma_{Symbol} = \frac{E_{symbol}}{N_o}$$

$$\therefore \ \gamma_{Symbol} = \frac{\gamma_{BER}}{2} \qquad (4)$$

Thus from the *BER* obtained from thesecond step of sensing, $\gamma_{BER}$is calculated, which is replaced in (2) so as to obtain (5).

$$P_{d_{BER}} = Q_u(\sqrt{2\gamma_{BER}}, \sqrt{\lambda}) \qquad (5)$$

$P_{d_{BER}}$ is the probability of detection for the cases that entered the second step of detection. So although this probability of detection might be substantially higher, this will not be the overall detection probability as we have to take into account the number of cases that go into the second step compared to the overall number of cases that were tested. This is given by (6), where *x* is the number of cases that underwent the second step of channel testing and *y* is the total number of cases considered.

$$P_{d_{overall}} = \frac{x\,(P_{d_{BER}}) + (y-x)\,P_d}{y} \qquad (6)$$

$P_{d_{overall}}$ is the resultant probability of detection for the proposed two-step methodology of spectrum sensing.

IV. Results

For the proposed scheme, MATLAB has been employed for simulating the two-step spectrum sensing methodology using the mathematical modeling presented in the previous section. It is considered that the PU transmits at a power that is double that of the SU (i.e. *m*=2). Fig. 3 shows the simulation results of spectrum sensing.

From Fig. 3 it can be seen that the $P_{d_{overall}}$ curve significantly outperforms the $P_d$in regions of low and moderate SNR values. With the increase in SNR, fewer cases proceed to the second step and the nature of the $P_{d_{overall}}$ curve is influenced more by the first step curve of P_d than the second step curve of $P_{d_{BER}}$. In high SNR regions, a high value of power is detected from PU (or another SU) and so fewer cases will proceed to the second

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step of testing thus leading to $P_{d_{overall}}$ curve effectively taking the trajectory of the P_d curve. Thus, for the proposed scheme, over the entire range of SNR values, the performance of $P_{d_{overall}}$ exceeds (in most cases, by a considerable amount) the P_d that is obtained from a single step of energy detection.

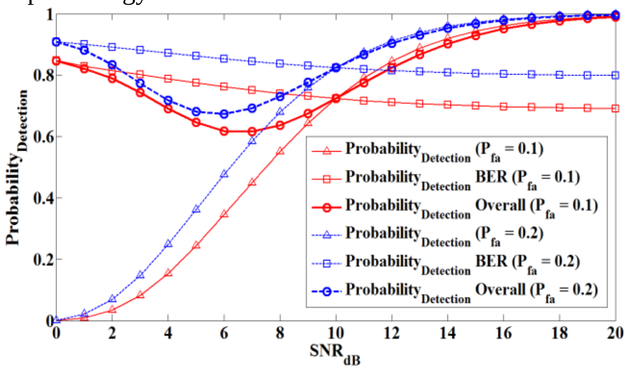

Fig.3. The Plot of Probability of detection at various stages of detection against SNR (dB) for two values of P_{fa}

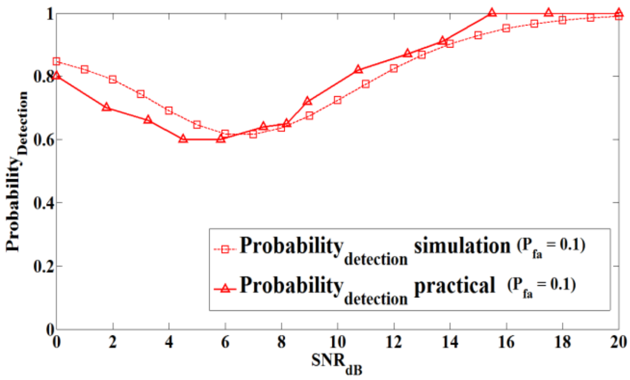

Fig.4. The plot of overall probability of detection of simulation and practical observations for $P_{fa} = 0.1$

For practically verifying the proposed scheme, National Instruments' Universal Software Radio Peripheral (USRP) 2922 Boards were used. We considered a pair of SUs and a single PU. Throughout the experimentation, the bandwidth was considered to be 400 kHz and 2.0 GHz was the sample channel for testing.The practical results shown in Fig. 4 and Fig. 5concurred with the simulation results, thus validating the enhanced performance of the proposed scheme.

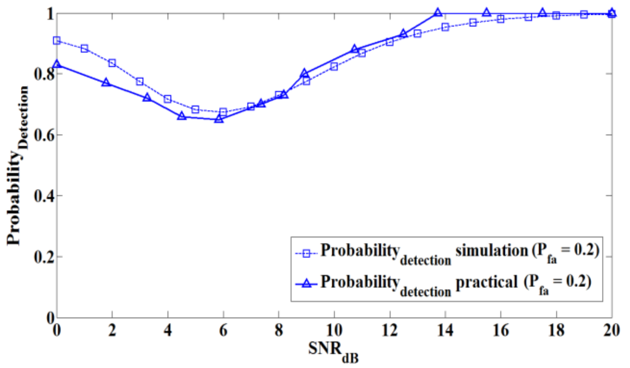

Fig.5. The plot of overall probability of detection of simulation and practical observations for $P_{fa} = 0.2$

V. Conclusion and Future Work

This paper proposed a two-steprefined methodology of spectrum sensing that has a performance significantly better than other conventional energy detector methods. The proposed scheme has been validated for AWGN channel under varying SNR values for different energy thresholds using both simulation as well as practical results. For low SNR regions of up to 6dB, on average, the proposed scheme has a P_d more than twice that of conventional energy detectors (for proposed scheme average P_d is 0.65 against conventional average P_d of 0.3). For future work, we wish to study the performance of a CR system that employs the proposed sensing methodology. More specifically, the impact of second step channel testingwhen the PU is actually present. Furthermore, we wish to consider evaluating the proposed method for different channel models over a range of frequencies.

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