Cooperative Wideband Spectrum Sensing With Multi-Bit Hard Decision in Cognitive Radio

M.A.Mehdawi, N.G.Riley, M. Ammar, A. Fanan, M. Zolfaghari

Abstract**—Cognitive radio offers an increasingly attractive solution to overcome the underutilization problem. A sensor network based cooperative wideband spectrum sensing is proposed in this paper. The purpose of the sensor network is to determine the frequencies of the sources and reduced the total sensing time using a multi-resolution sensing technique. The final result is computed by data fusion of multi-bit decisions made by each cooperating secondary user. Simulation results show improved performance in energy efficiency.**

Keywords — Coarse sensing, Cooperative spectrum sensing, Data fusion, Fine sensing, Multi bit hard combination

I. INTRODUCTION

With the incredible growth in the number of wireless systems and services, the availability of high quality wireless spectrum has become severely limited. However, actual measurements carried out in various countries [1] show that the real problem is not the spectrum scarcity but the inefficient spectrum usage. Recently, a Cognitive Radio (CR) access technology has been proposed as a promising solution for improving the efficiency of spectrum usage [2]. Spectrum sensing is the key to cognitive radio technology since it needs to detect the presence of primary users accurately and quickly to avoid interference with existing primary user. In spectrum sensing there are several possible sensing methods. One of these methods is energy detection [3]. Other methods were described briefly in [4]. Energy detection will be used here due to its simplicity and the fact that it has been thoroughly studied both in local spectrum sensing and cooperative spectrum sensing [4]. Cooperative spectrum sensing was proposed to overcome noise uncertainties, fading and shadowing in primary user signal detection and additionally can decrease sensing time [5]. In this paper, CR users/nodes are collaborated to sense usable spectrum and detect Primary User (PU) signals. A sensor network based cooperative wideband spectrum sensing is proposed using wavelet-based multi-resolution spectrum sensing methods. For cooperation of the nodes in the proposed scheme, three-bit hard combination technique is developed. Then, local detection information among users, they forward data to the data fusion center.

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The remainder of this paper is organized as follows. In Section II, the spectrum sensing techniques are briefly introduced. Section III describes the data fusion technique. Multi-resolution spectrum sensing and performance analysis of softened three bits hard combination scheme is discussed in section IV and V respectively. Our simulation model and results presented in Section VI. Finally, conclusions are made in section VII.

II. SPECTRUM SENSING TECHNIQUES

A. Non-Cooperative Spectrum Sensing Technique

There are several methods have been proposed to perform local spectrum sensing. The following section highlights three of the most relevant methods: 1) energy detection based spectrum sensing, 2)cyclostationary-based spectrum sensing, and 3) matched filtering. If the structure of the primary signal is known, the optimal detector in stationary Gaussian noise is a matched filter. However, with more primary bands being opened for opportunistic access, the implementation cost and complexity associated with this approach will increase [6]. A simpler alternative for the detection of a primary signal in noise is to employ energy detection. An energy detector simply measures the energy received on a primary band. The main drawback of the energy detector is its inability to discriminate between sources of received energy, making it susceptible to uncertainties in background noise power, especially at low signal-to noise ratio (SNR) [7]. If some features of the primary signal such as its carrier frequency or modulation type are known, more sophisticated cyclostationary feature detectors may be employed to address this issue at the cost of increased complexity.

B. Cooperative Spectrum Sensing Technique

The cooperative sensing has two stages: sensing and fusion. In sensing, secondary users collect certain measures to be used in detection techniques. In fusion, collected statistics are combined to make the sensing final decision. Cooperative sensing, where different secondary users collaborate to detect the presence of a primary users, achieves enhanced sensing accuracy by taking advantage of the spatial diversity on multiple cognitive users' networks. The diversity gain achieved through such cooperative sensing improves overall detection sensitivity, sensing performance and decrease the detection time. Cooperative can be performed in centralized or decentralized way. In decentralized way, the second users from ad-hoc network exchanging their sensing information to each other. Each secondary user then combines all the information received to reach a final decision on the channel state. On the other hand, in a centralized way, secondary users report their local decisions to fusion center which makes a global decision on the present status of the PU signal.

III. DATA FUSION

Data fusion performs and analyses of data from various sensors to extract final decision. There are two forms of cooperation in spectrum sensing: hard combination and soft combination. The difference between the two forms is the type of information sent to the decision maker. In soft decision strategy, each secondary reports its observation about the channel, then fusion centre combine somehow these observations to reach a global decision. In the hard decision strategy, the secondary users report their local decision (either busy or channel idle) and then the fusion centre combines these local decisions using some hard decision rule, to reach the global decision. Three hard combining decision rule used by the decision maker for a final decision, namely the AND, OR and Majority rules. Using hard combination scheme in cooperative detection reduced the communication cost at expense of loss information. Recently, Multi-bit hard combination scheme of the nodes have been proposed as solution. The main idea behind Multi Bit hard combination scheme is to divide the whole range of observed energy into several regions to assign different weights to these regions [8]. By doing this, nodes that observe higher energies in upper regions will have greater weights than nodes that observe lower energies in lower regions. Multi-bit soft hard combination way involve advantage of lower overhead, as demonstrated in hard combination approaches and greater performance gain , as demonstrated in soft combination approaches.

IV. MULTI -RESOLUTION SPECTRUM SENSING

Multi resolution spectrum sensing (MRSS) method is classified as one of the energy detection techniques. This technique senses the spectrum at two different resolutions. In such a way, Cognitive Radio avoids sensing the whole band at the maximum frequency resolution. Therefore, the sensing time is reduced and the power has been saved from unnecessary computations. Two-stage sensing techniques proposed in order to handle different situations for cognitive radio [9, 10]. Reference [9] shows two stages of energy detection suggested using Multi resolution spectrum sensing (coarse sensing and fine sensing).Reference [10] shows slightly different approach was adopted where two stage sensing was considered with energy detection for the first stage and cyclostationary detection in the second stage. MRSS techniques are classified as either wavelet-based or fast Fourier transform (FFT)-based approaches. In this paper, the wavelet-based MRSS technique was used in the proposed sensor network based cooperative wideband spectrum sensing.

V. PERFORMANCE ANALYSIS OF SOFTENED THREE BITS HARD COMBINATION SCHEME

Multi-bit hard combination scheme become an active research area. Two bit hard combination was proposed in [11]. In this paper three-bit hard combination scheme for cooperative spectrum sensing is proposed. Seven thresholds are used to divide the whole range of observed energy into eight areas. The decision node collects three-bit information from each cognitive radio after taking measurements in the energy regions of interest. Figure (1) shows the eight regions and the corresponding three-bit representations. Thresholds of the three-bit hard combination scheme are determined using the Neyman-Pearson criterion. In this criterion, while determining the threshold probability of false alarm p_{FA} is fixed to some value, the probability of detection p_D is maximized. The p_{FA} chosen to determining the threshold values in three bit hard combination scheme is $\lambda_n = \beta_n p_{FA}$ where $n = 2,..7$, and for first threshold $\lambda_1 = p_{FA}$, and coefficient β_n in figure are found by $\beta_n = (n-1)x10^{-(n-1)}$.The presence of the signal of interest is decided at the decision maker by use of the following equation.

$$\sum_{h=1}^{7} w_h N_h \geq M$$

Where M is the total number of nodes in the network, N_h is the number of observed energies falling in region h and w_h is the weight value of region h. In particular, if the weighted sum is greater than M, then the signal of interest is declared as present.

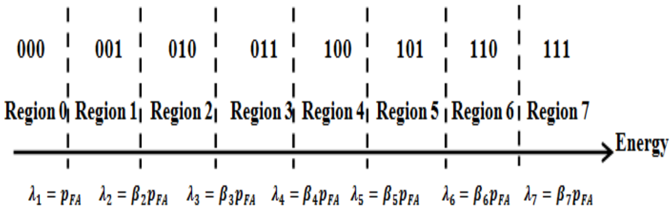


Fig. 1. Energy Regions of Softened Three Bits Hard Combination

VI. SIMULATION MODEL OF PROPOSED ALGORITHM

The proposed two-stage with three-bit cooperative wideband spectrum sensing using the wavelet-based MRSS scheme is shown in Figure (2). The implementation of determination of seven thresholds, coarse resolution sensing and fine resolution sensing are carried out using MATLAB programming language represented by the following steps: Seven thresholds are determined by the decision maker. Determines three-bit information value after coarse sensing and sends the data to the decision node. The occupied spectrum bands are determined by the decision maker and select the CR nodes with strong three-bit hard combination, which apply fine resolution spectrum sensing on these spectrum Bands. The CR nodes that apply fine resolution spectrum sensing, determine the primary transmitted frequency bands. The report is sent to the decision maker again to determine the occupied, vacant and weak channels.

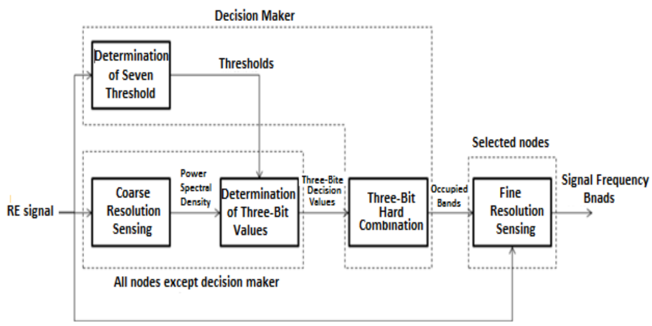


Fig. 2. Simulation Block Diagram of the Cooperative Wideband Spectrum Sensing of the Proposed Scheme

VII. SIMULATION RESULTS

In the following subsections detection percentage is used as a detection performance measure.

A. Coarse and Fine Resolution Sensing Results for a Node

Figure (3) shows the result of seven thresholds that divide the whole range of observed coarse resolution sensing band between (430 MHz -530 MHz). Two peak values at 441 MHz and 461 MHz correspond to the two transmitters whose specifications are given during simulation with different power value. Also shows the energy into eight regions. The observed energies at 441 MHz, 461 MHz are in regions 7 and 1 respectively. With this information, it can be deduced that Node will send a three-bit local observation value of "111" for 441 MHz and "001" for 461MHz. Since the observed energies at other frequencies are in Region 0, no information will be sent to the decision maker for these frequencies. If we assume that after the coarse resolution sensing stage that the node sensing the highest energy between 440 MHz and 445 MHz band, the decision maker will demand from Node a fine resolution sensing of 440 to 445 MHz band.

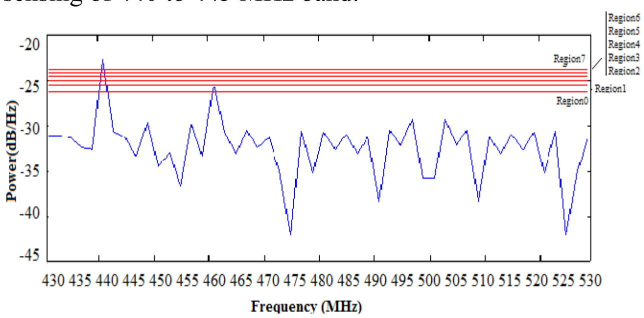


Fig. 3. Result of Coarse Sensing of 430-530 MHz Band

B. Effects of PSDs Averaged and SNR

Figures(4-a)&(4-b)shows the plot of detection percentage versus number of PSDs averaged and SNR for different SNR values and PSDs averaged respectively when there are ten nodes participating in the cooperative wideband spectrum sensing. Both figures indicate that when the SNR and PSD averaged are increased, the detection percentage performance improved. In Figure (4-a), for a particular SNR value, when more PSDs are averaged, a higher detection percentage is obtained. This result is consistent with the discussion in [12], which mentions the need for longer detection time to detect weak signals in energy detectors. When the number of PSDs averaged is increased, it takes more time to decide the presence of the signal of interest.

C. Effects of Number of Nodes and Number of Transmitters

Figure (5-a) depicts the effect of numbers of nodes cooperating on detection percentage at various SNR values. As seen in Figure (5-a), a maximum detection percentage is obtained when there are more nodes participating in the cooperative wideband spectrum sensing. Also indicates that the non-smooth effect of the nodes and the applied decision criterion disappears when the SNR is higher. Figure (5-b) shows the performance of the proposed scheme on the detection of the signal emitted by Transmitter 3(assumed transmitter) for the following scenarios: Only Transmitter 3 is present, transmitter 1 and transmitter 3 are present and transmitter 1, Transmitter 2 and Transmitter 3 are present. As shown in Figure, when other transmitters are present in the medium, percentage of detecting the signal emitted by Transmitter 3 decreases. This is an expected result since the signals of Transmitter 1 and Transmitter 2 contribute to the channel noise while the signal of Transmitter 3 is being detected.

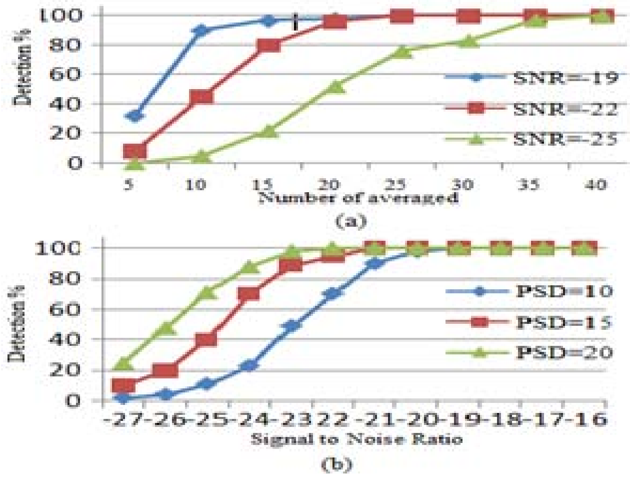


Fig.4. (a) -Detection versus Number of PSDs Averaged for three different SNR Values, (b) Detection versus SNR for three different Numbers of PSDs Averaged.

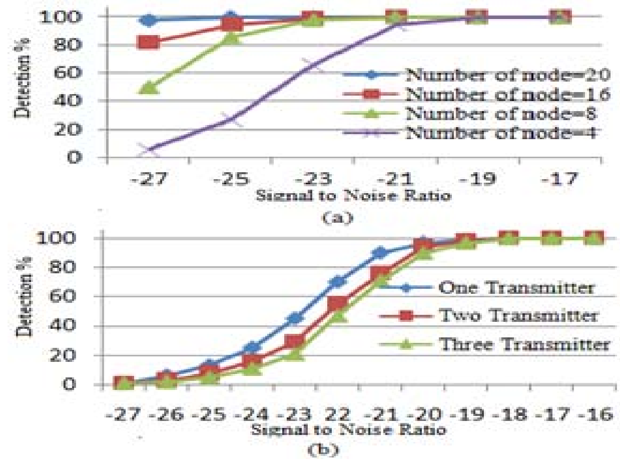
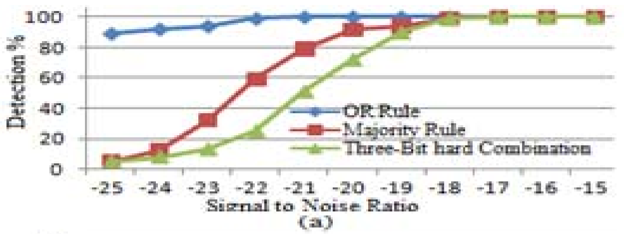


Fig.5. (a)-Detection versus SNR for four different Number of Nodes values, (b)-Detection of Transmitter3 versus SNR for three different scenarios.

D. Compare Three-Bit Hard Combination with traditional Hard Combination.

Figure (6-a) shows the detection percentage versus SNR, for three combination schemes. It shows that when the SNR is between –26 dB and –19 dB, the traditional hard combination schemes have a better detection percentage than the proposed three-bit hard combination scheme. In particular, the traditional hard combination scheme using logical-OR rule is fairly superior to the other two schemes for SNR <-18 dB. This is due to the fact that for declaring the presence of the signal of interest, only one node sensing energy above the threshold is enough. The disadvantage of this fact can be seen when false alarm performances are compared. Figure (6-b) shows the false alarm performances of the three combination schemes. In particular, the y-axis denotes the percentage of the scanned frequencies in coarse resolution sensing that contributes to false alarm for more than 50% of the simulation. It can be seen from Figure 8-b that the proposed three-bit hard combination scheme presents robust false alarm performance compared to the two traditional hard combination schemes. For example, with the traditional hard combination scheme using logical-OR rule, at SNR = 10 dB, 61% of the scanned frequencies in coarse resolution sensing will be sent to the fine resolution sensing block redundantly. When the results of Figure (6-a) and Figure (6-b) are analyzed, the following conclusions can be made. The higher percentage of the scanned frequencies in coarse resolution sensing that contribute to false alarms means that some of the nodes will apply fine resolution sensing unnecessarily. This is a waste of scarce battery energy for redundant computations and communications between the node and the decision maker. The detection performance of the three-bit hard combination scheme can easily be improved by increasing the number of PSDs averaged. Increasing the number of PSDs averaged requires more computations, but the cost of these excess computations is less than the cost of the communication overload, which requires more battery power in wireless sensor networks.



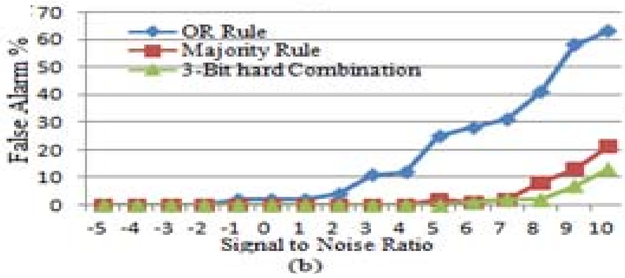


Fig. 6. (a) -Detection versus SNR for three different combination schemes, (b)-False Alarm versus SNR for three different combination schemes.

VII. CONCLUSION

Effective spectrum sensing is a precondition for CRs. To achieve higher sensing efficiency, cooperative sensing is the most beneficial strategy. In cooperative spectrum sensing, it is critical to know how to fuse the data to make a global decision about the presence or absence of primary users. In this paper, we proposed a scheme that aims to improve the cooperative spectrum sensing scheme in cooperative radio networks. In the proposed solution, the significant results obtained stem from the fact that it senses a wide spectrum band in an energy efficient manner whilst providing resilience to fading, shadowing, and noise. Energy efficiency comes from the usage of MRSS and the proposed three-bit hard combination scheme. In particular, redundant exhaustive sensing on empty bands is avoided with MRSS, and less overhead in collaboration with respect to the soft combination is provided by three-bit hard combination. The result show that the detection performance improved as SNR, PSD averaged and Number of Nodes are increased. The algorithm performances of three-bit hard combination scheme proposed is superior to the traditional hard combination schemes such as AND, OR and Majority rules in false alarm reduction. In addition, the detection performance of the three bit hard combination scheme can be improved with little additional cost by increasing the number of averaged PSDs. For future work there are several ideas from this paper. Simulation models can be improved and multipath fading effects could be added and their effects on the performance of the proposed scheme could be investigated. Instead of generating the RF signals in MATLAB, actual transmitted signals could be collected in the field.

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