An Energy Efficient Hybrid Co-operative Spectrum Sensing Technique For CRSN

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***Abstract*-Cognitive Radio Sensor Networks (CRSN) demands energy efficient and a cost effective co-operative spectrum sensing techniques which performs well in fading and shadowing environment with optimum values of sensing parameters at low computational complexities. A cluster- based co-operative network architecture, an appropriate choice for effective operation of dynamic spectrum management in CRSN is considered with hybrid spectrum sensing capability. A new energy efficient hybrid co-operative spectrum sensing technique which associates energy and Eigen value based detectors is proposed to improve the sensing efficiency and sensing reliability to enhance the performance of CRSN. All CRSN nodes are equipped with simple energy detectors and the additional task of detection using Eigen value based detectors is being assigned to a detection center. The Data fusion center is responsible for the decision making rules with an eye on the requirements of low energy consumption and low computational complexity of CRSN. Simulation results clarifies the choice for Eigen value based spectrum sensing scheme and makes a comparison between the proposed hybrid scheme and a cyclo-stationary based hybrid scheme.**

Keywords—Hybrid, cognitive Radio, Spectrum Sensing, Eigen Value Detection, Energy Efficiency.

I.INTRODUCTION

Enabling technology for ambient intelligence, wireless sensor networks (WSN) enables setting up an intelligent network capable of handling user requirements [1]–[2]. But due to the independent design and deployment of WSN for many applications in the license exempt ISM band, the frequency band is extremely crowded [3]. Critical applications like health monitoring, forest monitoring etc. requires efficient and uninterrupted communication through sensor nodes in WSN. The event driven communication nature of WSN and the need to effectively reduce the spectrum crowding in WSN together suggests the idea of cognition to the wireless sensor network, the cognitive radio sensor network (CRSN) [4]–[6]. The highlights of cognitive radio, the efficient spectrum utilization and better communication quality are well exploited in the resource constrained Wireless Sensor Networks (WSN) for many application fields.

Spectrum sensing in resource constrained, shadowing and fading environment of CRSN with receiver uncertainties is a more challenging task than conventional spectrum sensing in cognitive radio networks [7]. Co-operative spectrum sensing techniques can improve the cognitive radio network performance by enhancing spectrum efficiency and spectrum reliability by effectively combating the destructive effects present in the CRSN environment at the cost of comprises in overhead traffic, power consumption, and complexity and control channels [8]. The Cluster- based network architecture consists of local information sensing clusters distributed throughout the network. A cluster is a localized combination of event monitoring and cognitive sensors and detection centers with Eigen value based detectors are responsible for further detection and analysis. The energy efficiency comes from the basic cluster architecture and the simple energy detection schemes employed for primary sensing and also the limited number of detection centers equipped for secondary detection.

A new hybrid spectrum sensing scheme which involves simple energy detector and Eigen value based detector is proposed to enhance the performance of CRSN without any previous knowledge about the primary users and their properties [9]. All cognitive radio sensor nodes are equipped with a modified simple energy detection scheme with two appropriate energy threshold values ξ_1 and ξ_2 where ξ_1 is the lower threshold value and ξ_2 is the upper threshold value respectively. When a cognitive radio sensor node detects a signal to be in the range between ξ_1 and ξ_2, cluster head transfer this information to the detection center. Detection centers employing Eigen value based detector which does not demand any prior information about the signal or its characteristics is responsible for making a final decision on signal detection.

Eigen value based spectrum sensing relies on algorithms developed on the Eigen values of the sample co-variance matrix, determined from the received signal at the cognitive sensing node [10]. Eigen value based spectrum sensing can be mainly employed using two algorithms, based on the ratio of maximum to minimum Eigen value (MME) and based on the ratio of average signal power to the minimum Eigen value (EME). Maximum to minimum Eigen value (MME) algorithm is analyzed and applied here for the second phase of sensing in detection center and using random matrix theory (RMT) concepts, we evaluated and analyzed the detection and false alarm probabilities also [11]. The proposed hybrid spectrum sensing scheme is compared with cyclo-stationary hybrid spectrum sensing scheme which associates energy and cyclo-stationary detectors, the result shows better performance for the former hybrid scheme [12].

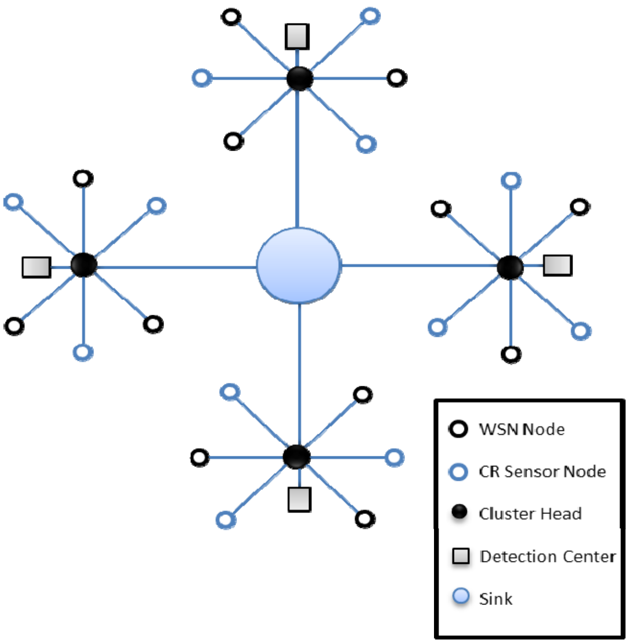

Fig. 1The Proposed Architecture of CRSN

The sections to follow are organized in this manner; section II explains the cluster based architecture of CRSNs through introducing the concept of detection centers and altogether focusing on the energy efficiency of the scheme. Section III describes the proposed hybrid spectrum sensing scheme and more about the Eigen value based spectrum sensing method. Section IV mainly focuses on the preliminary results from the comparison between the proposed method and the hybrid sensing scheme which associates cyclo-stationary detectors and simple energy detectors. The comparable performance of Eigen value based detector to cyclo stationary detector ensures the reliability of the proposed scheme within the constraints of Wireless Sensor Networks (WSN). Finally, Section V concludes with the remark that Eigen value based hybrid co-operative spectrum can be efficiently incorporated for Cognitive Radio Sensor Networks (CRSN).

II. A CLUSTER BASED ARCHITECTURE FOR CRSN WITH DETECTION CENTERS

1. Co-operative Spectrum Sensing

Cooperative spectrum sensing has been recommended as a solution to noise uncertainty, fading and shadowing problems that encountered in CRSNs. It has been identified with an inherent ability to prevent hidden terminal problems and to perform well in fading and shadowing environment with high accuracy. It offers better detection accuracy also by exploiting the diversity gain provided by associated radios. These are achievable at the cost of increased overhead traffic, power consumption due to the resulted heavy communications, increased complexity, and the need for control channels. Co-operative spectrum sensing exploits spatial correlation among the sensing data detected by different sensing nodes and allows secondary users to share data in between and thereby increasing the performance [13].

2. Cluster Based Architecture and Detection Centers

Co-operative spectrum sensing can be either centralized or distributed in architecture. Two types of sensing nodes are considered here, conventional event sensing nodes and pure cognitive sensing nodes. Conventional sensing nodes only sense the physical event to be monitored and a cognitive sensing node actually sense the spectrum and detect spectrum holes. A cluster head is assigned for each cluster and is responsible for receiving information from sensing nodes and forwarding it to the data fusion center. The design of cluster head is different from other sensing nodes and therefore it is fixed for a cluster. A cognitive sensor node is deployed with simple energy detection scheme having two threshold values ξ_1 and ξ_2. If the detected signal value is above ξ_2 the upper threshold value, the sensed spectrum is decided to be engaged and if the detected signal value is below ξ_1 the lower threshold value, the sensed spectrum is decided to be available. Cognitive sensor nodes are able to make hard decisions on a sensed spectrum on these two occasions.

Detection center is responsible for finalizing the decision on the sensed spectrum posed by an indecisive cognitive radio sensor that is when a cognitive radio sensor node detects a signal in the range between ξ_1 and ξ_2. Cluster heads analyses the signals received from the cognitive sensor nodes and if it is not a binary value it just passes these signals to the detection center. Detection centers are well equipped with advanced signal processors to support Eigen value based spectrum sensing which includes many signal processing tasks like co-variance matrix calculation, determination of Eigen values of covariance matrix, threshold value calculation etc.

Clusters assigned with one cluster head and a detection center are distributed throughout the network. Conventional sensor nodes and cognitive sensor nodes are deployed for their respective applications as conventional sensor nodes supports only event sensing and cognitive sensor nodes supports only spectrum sensing. Most of the times the detection process is carried out by the cognitive sensor node itself and assigns the task to the detection center only if it could not process.

III. THE PROPOSED HYBRID SPECTRUM SENSING SCHEME

Let the continuous time received signal be Xc (t) = S_c (t) + W_c (t), where S_c (t) is the detected primary signal and W_c (t) is the modeled noise signal. Noise signal is modeled to be a stationary process with zero mean and a variance of σ_η^2. The received continuous time signals are sampled and made the two simple hypothesizes for the signal detection where H0 implies that the signal does not exist; and H1 implies the signal exists.

$$H0: X(n) = W(n), \quad (1)$$

$$H1: X(n) = S(n) + W(n), \quad (2)$$

The signal samples reflect the effects of path loss, multipath fading and time dispersion. The proposed hybrid scheme incorporates Eigen value spectrum sensing along with the energy detection. The threshold values ξ_1 and ξ_2 for the energy detector depends on the noise factor and it performs well as noise factor decreases. When there is noise uncertainty, the energy detection is not an effective method due to the existence of SNR wall and/or high probability of false alarm.

Two algorithms are suggested from the literature based on the sample covariance matrix evaluated from the received signals at the sensing node [14]. The algorithms are based on the ratio of maximum to minimum Eigen value (MME) and based on the ratio of average signal power to the minimum Eigen value (EME). Since MME has a performance edge over EME, MME algorithm has been suggested for the detection.

A. Maximum-Minimum Eigen value (MME) Detection

1. The covariance matrix of the received signal samples is computed by considering N_s number of samples using the following equation

$$R_x(N_s) = 1/N_s \sum_{n=L-1}^{L-2+N_s} x(n)x^{\dagger}(n) \quad (3)$$

Where † stands for Hermitian (transpose-conjugate) operation [15].

2. The maximum and minimum eigenvalues of the matrix Rx (N_s), λmax and λmin are calculated then.

3. The final decision on signal detection is made by comparing the ratio of λmax to λmin with a threshold value γ

Decision rule: if max/ min> , signal exists; otherwise, signal does not exist.

B. Probability Parameters and Threshold Value for MME Detection

Expressions for probability of false alarm and threshold value are derived out using the random matrix theory concepts and certain distribution functions. We have listed approximated expressions for the performance parameters and threshold value by treating $R_w(N_s)$ nearly as a Wishart random matrix and using Tracy-Widom distributions for its Eigen values [16].

1. The probability of false alarm (P_{fa}) for MME detection

$$P_{fa} = 1 - F_1\left[\frac{\gamma\left(\sqrt{N_s} - \sqrt{ML}\right)^2 - \mu}{\nu}\right] \quad (4)$$

Where F_1 (t) is the Tracy-Widom distribution function and its tabled values are available.

2. The Threshold

We obtain the formulae for threshold

$$\gamma = \frac{\left(\sqrt{N_s} + \sqrt{ML}\right)^2}{\left(\sqrt{N_s} - \sqrt{ML}\right)^2} \cdot \left[1 + \frac{\left(\sqrt{N_s} + \sqrt{ML}\right)^{-2/3}}{\left(N_s ML\right)^{1/6}} . F_1^{-1}\left(1 - P_{fa}\right)\right] \quad (5)$$

L-smoothing factor, M-over sampling factor, N_s- no: of samples taken. The threshold value is not related to noise power. The threshold can be pre computed based only on N_s, L and P_{fa} [17].

3. The probability of detection (P_d)

The sample covariance matrix R_x (N_s) is no longer a Wishart matrix when there is a signal present. The distributions of its eigenvalues are unknown in this case. The approximated formulae for the probability of detection is

$$P_d = 1 - F_1 \frac{\left[\gamma N_s + \frac{N_s\left(\gamma\rho ML - \rho\right)}{\sigma_n^{\;2}} - \mu\right]}{\nu} \quad (6)$$

It can be seen that the number of samples N_s and the maximum and minimum eigenvalues of the signal Covariance matrix have an effect on P_d.

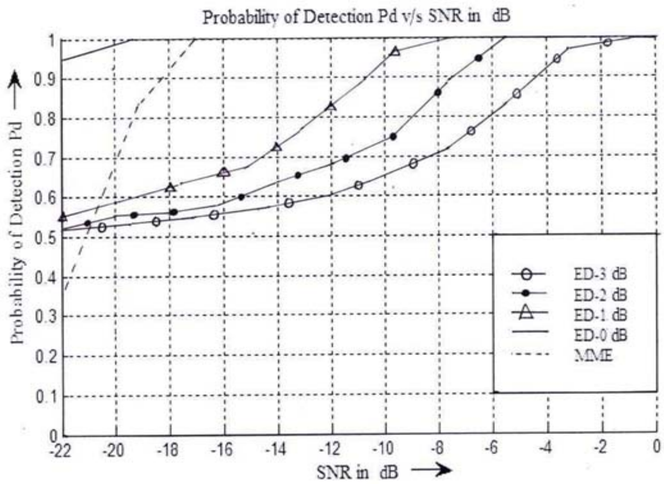

Fig. 2 Probability of Detection P_d V/S SNR

IV. SIMULATION RESULTS AND DISCUSSIONS

When the noise uncertainty is more the energy detector is not in a position to make a decision on the signal being detected and it consults Eigen value based detector. The Spectrum sensing parameters such as the probability of detection and the probability of false alarm are simulated with different SNR values and compared together for both Eigen value based method and the energy detection method. The performance comparison between energy detector and Eigen value based detector for various values of signal to noise ratio (SNR) shows the sharp degrading performance of energy detector with decreasing SNR values (fig-2). Where ED-XDB means the energy detection with noise uncertainty bound being -xdB. Energy detector with no uncertainties about the noise gives out the best result.

Comparison is also made between the performance of the hybrid spectrum sensing scheme which incorporates hybrid cyclostationary /energy detector and the proposed hybrid spectrum sensing scheme, it shows nearly better performance from the later scheme and is energy efficient too (fig 3-4). The comparable performance of Eigen value based detector to cyclostationary detector and the fact that Eigen value based method does not require any pre knowledge of the signal or its properties put ahead the proposed hybrid spectrum sensing scheme among all other hybrid spectrum sensing schemes for CRSNs.

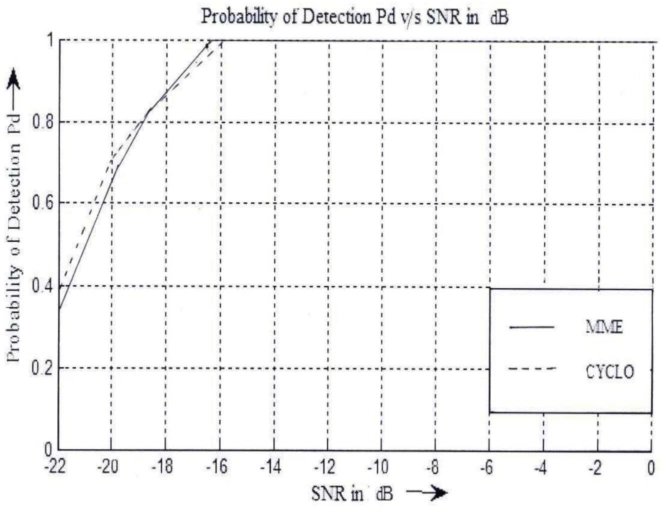

Fig. 3 Probability of Detection P_d for the Hybrid Schemes.

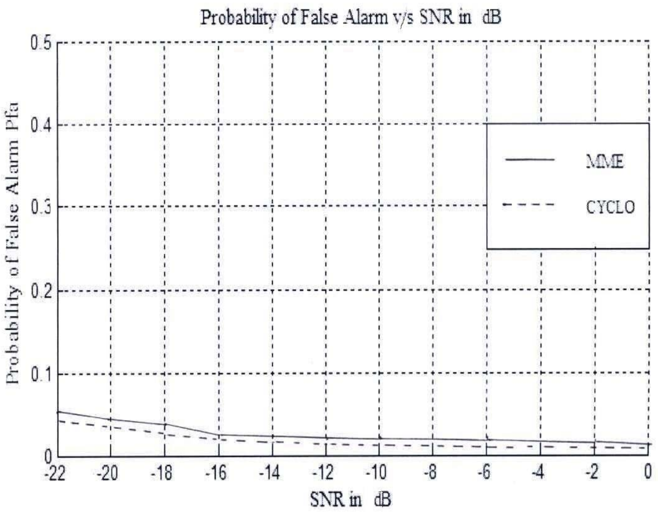

Fig. 4 Probability of False Alarm P_{fa} Comparison for the Hybrid Schemes.

V. CONCLUSION

The design of an appropriate spectrum sensing scheme for CRSN is a challenge within the constraints of wireless sensor nodes. Energy efficient and a cost effective co-operative spectrum sensing technique which performs well in fading and shadowing environment is to be developed. A cluster-based co-operative network architecture with the concept of detection centre is introduced which actually helps to reduce the power consumption and in turn increase the energy efficiency. A hybrid co-operative detection scheme which associates Eigen value based spectrum sensing with an energy detector has been proposed and it can be implemented for various signal detection application without knowledge of the signal, channel and noise power. Simulation results clarify the choice for this proposed scheme over cyclostationary /energy detection hybrid scheme.

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