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Optimization of Cooperative Spectrum Sensing Using Quantized Data Fusion Scheme for Cognitive Radio Network

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Abstract *— Cognitive Radio (CR) is used to maximize spectrum utilization. When the licensed user is not using the spectrum, at that time CR will use spectrum to communicate with other CR. Hence, spectrum sensing which is the procedure to observe primary user's existence, is important to CR. Cooperative spectrum sensing have a efficiency to detect spectrum holes in cognitive radio network (CRN) by cooperating the sensing information of multiple cognitive radio users . In cooperative spectrum sensing, combining the local observations of the secondary users and the fusion centre is the most crucial factor that determines the overall performance of cooperative sensing. Detection performance is determined by the quality of local observations and the quality of the information received by the fusion centre (FC). Therefore, the number of bits sent to fusion centre (FC), and the global decision logic affect the system performance. but the bandwidth of the control channel used for collecting the sensing information is limited, it is necessary to quantize the received signal energy information in each user In this paper, we investigate the energy detection based cooperative spectrum sensing technique and propose a quantized cooperative spectrum sensing. we obtain an optimal quantized data fusion scheme that maximizes the detection probability for a given false alarm probability through the optimization algorithm which is based on Neyman-Pearson criterion We also compare performance of conventional hard data fusion scheme like AND, OR, MAJRITY logic as well as soft data fusion scheme i.e. equal gain combiner (EGC) with proposed data fusion scheme. Simulation result shows that the performance of proposed optimized quantized data fusion scheme is better than conventional hard data fusion scheme and close to standard soft data fusion scheme i.e EGC which requited larger bandwidth and energy of reporting channel. Proposed optimal data fusion scheme require less bandwidth and energy of convention soft data fusion by just increase the overhead of 3 bit.*

Keywords*-cooperative spectrum sensing, cognitive radio, quantization, Data fusion, EGC*

I. INTRODUCTION

Inefficient usage of the radio spectrum, where a large portion of the licensed spectrum is underutilized, The Federal Communications Commission to consider opportunistic access to the licensed spectrum by SUs conditioned on no interference on the PUs or license holders [1]. In a cognitive radio network, to avoid the interference imposed on the licensed users, the SUs should be capable of identifying the presence or absence of the primary user (PU) signal. The PU signal is always subjected to deep fading effects due to propagation loss and secondary-user (SU) interference. To minimized the fading effects, we can use from the diversity gain that can be used by employing several SUs to cooperatively detect the spectrum.

Cooperation among secondary users for spectrum sensing improves the probability of detections by taking advantage of the spatial diversity obtained from the users' channel conditions each having independent shadowing and fading. This performance improvement by cooperation, called cooperative gain, relaxes also the sensitivity requirement of secondary users. Indeed, a highly accurate measurement and detection of radio signal may not be necessary and thus allow low cost implementation of the cognitive radio devices. Among the sensing techniques, energy detection is simple and practically used. In this paper, we assume that each secondary user relies on energy detection for sensing. The way the local decision is reported to the fusion centre plays a main role in cooperative schemes in general and in spectrum sensing. For instance, hard binary decision and soft decisions are the two extreme cases and were widely studied

Quantized Cooperative spectrum sensing scheme have been proposed in various literatures. In [2], a spectrum sensing technique utilizing Welch's periodogram is proposed, along with the trade-off between the sensing information and cooperative users. In [3], the sensing procedure is based on Dempster-Shafer theory. Both uniform quantization and Lloyd-max quantization techniques are considered. Also, in [4], Lloyd-max algorithm is used to minimize error for the optimal quantizer. In [5], Neyman-Pearson criterion is used. Log-likelihood is used in [4], [5] and, hence, increases the complexity for the system. In [6], the two-bit quantization scheme is proposed to maximize the probability of detection for a given false alarm. However, the optimal parameters need to be optimized.

The paper is organized as follows. We present in Section II the system model related to cooperative spectrum sensing. In Section III, we describe different data fusion scheme for cooperative spectrum sensing; several hard, soft and quantized schemes are proposed and discussed. Simulation results in section V are given to compare these fusion rules. We conclude this paper in Section VI.

II. COOPERATIVE SPECTRUM SENSING SYSTEM MODEL

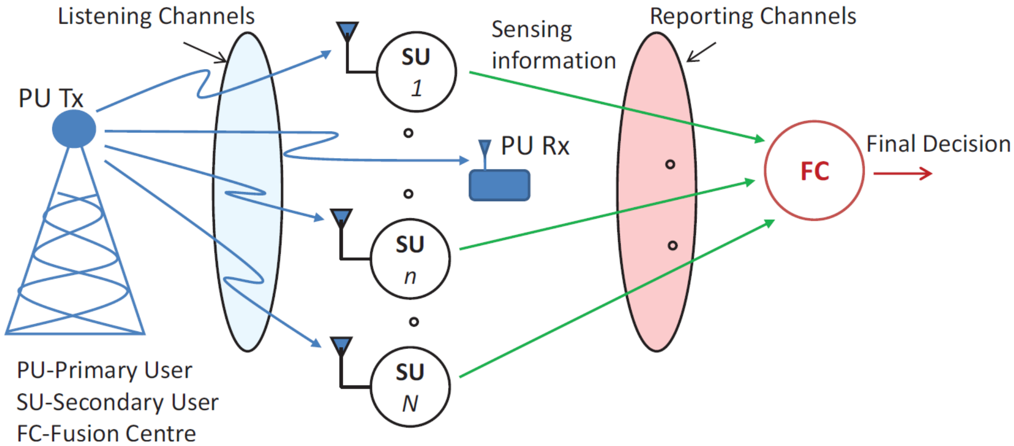

Figure 1.Cooperative spectrum sensing model of cognitive radio

Suppose there are N Secondary User (SU) and a FC in the Cognitive Radio RN, as shown in Fig.1. SUs sense their local spectrum information individually, and send their binary decisions to fusion centre, which make a final decision whether a PU is present or not. The goal of the spectrum sensing is to decide between the two hypotheses, $H0$: no signal transmitted, and $H1$: signal transmitted [7]. In this regard, there are two probabilities that are most commonly associated with spectrum sensing: probability of false alarm P_f which is the probability that a presence of a signal is detected even if it does not exist and probability of detection P_d which is the probability for a correctly detected signal. There is a trade-off between these two probabilities, high probability of detection means that the primary user is well protected whereas a high probability of false alarm reduces the achievable throughput for the cognitive radio network. In signal detection theory, the performance of a detector is often represented as a receiver operating characteristics (ROC) which is the probability of detection as a function of probability of false alarm.

$$x(t) = \begin{cases} n(t), & H_0 \\ h\ s(t) + n(t), & H_1 \end{cases} \qquad \text{……..…….. (1)}$$

In AWGN channel environment the average probability of false alarm, the average probability of detection, and the average probability of missed detection are given, respectively, by [8]

$$P_d = P\{Y > \lambda \mid H_1\} = Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \qquad \text{……..…….. (2)}$$

$$P_f = P\{Y > \lambda \mid H_0\} = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)} \qquad \text{………..….. (3)}$$

Let K denote the number of users sensing the PU. Each cognitive radio user makes its own decision regarding whether the primary user present or not, and send the binary decision (1 or 0) to fusion center (FC) for final decision. The PU is located far away from all CRs. For simplicity we have assumed that the noise, fading statistics and average SNR are the same for each cognitive radio user. We consider that the channels between Cognitive radio and FC are noiseless channel. Assuming independent decisions, the fusion problem where k out of N CR users are needed for decision can be described by binomial distribution based on Bernoulli trials. With a hard decision counting rule, the fusion center implements an n–out-of-M rule that decides on the signal present hypothesis whenever at least k out of the N CR user decisions indicate .

The common receiver calculates false alarm probability and missed detection probability with the help of average probability of each CR. The false alarm probability is given by [8],

$$Q_f = \sum_{l=n}^{k} \binom{k}{l} p_f^{\,l} (1 - p_f)^{k-l} = \text{Prob}\{H_1 / H_o\} \qquad \text{………..….. (4)}$$

Also, the missed detection probability is given by;

$$Q_m = 1 - \sum_{l=n}^{k} \binom{k}{l} p_d{}^{l} (1-p_d)^{k-l} = \text{Prob}\{H_o / H_1\} \quad \text{……..…….. (5)}$$

III. DATA FUSION SCHEME

3.1 Hard Fusion Scheme.

In this data fusion scheme, each cognitive user decides on the presence or absence of the primary user and sends a one bit decision to the data fusion center. The main benifit of this method is that it needs limited bandwidth [9]. When binary decisions are reported to the common node, three rules of decision can be used, the "and", "or", and "majority rule". Cognitive user send 1 means that the signal is present, and 0 means that the signal is absent.

3.1.1 Logical AND-Rule

In this data fusion scheme, if all of the local decisions sent to the decision maker are one, the final decision made by the decision maker is one. The fusion center's decision is calculated by logic AND of the received hard decision statistics. Cooperative detection performance with this fusion rule can be evaluated by setting k=N in the probability of detection equation.

$$P_{d,AND} = P_{d,i}{}^{N} \quad \text{…..…….. (6)}$$

3.1.2 Logical OR-Rule

In this data fusion scheme, if any one of the local decisions sent to the decision maker is a logical one, the final decision made by the decision maker is one. Cooperative detection performance with this fusion rule can be evaluated by setting k=1 in the probability of detection equation.

$$P_{d,OR} = 1 - \left(1 - P_{d,i}\right)^{N} \quad \text{……..….. (7)}$$

3.1.3 Logical MAJORITY -Rule

In this data fusion scheme, if half or more of the local decisions sent to the decision maker are the final decision made by the decision maker is one. Cooperative detection performance with this fusion rule can be evaluated by setting $k = N/2$ in the probability of detection equation.

$$P_{d,MAJ} = \sum_{l=\lfloor N/2 \rfloor}^{N} \binom{N}{l} P_{d,i}{}^{l} \left(1 - P_{d,i}\right)^{N-l} \quad \text{……..…... (8)}$$

3.2 Soft Fusion Scheme.

In soft data fusion scheme, CR users forward the entire sensing result to the fusion centre without performing any local decision and the decision is made by combining these results at the fusion centre by using appropriate combining rules such as equal gain combining (EGC), maximal ratio combining (MRC) and selection combining (SC). Soft combination provides better performance than hard combination, but it requires a larger bandwidth for the control channel for reporting [10]. It also generates more overhead than the hard combination scheme [9].

3.2.1 Equal gain combining (EGC)

Equal gain combining (EGC) is one of the simplest linear soft combining schemes. In this method the estimated energy in each node is sent to the centre fusion where they will be added together. Then this summation is compared to a threshold to decide on the existence or absence of the PU and a decision statistic is given by [11].

$$E = \sum_{k=1}^{K} E_k \quad \text{……......... (9)}$$

3.3 Quantized data fusion

In this data fusion scheme, we try to realize a tradeoff between the overhead and the detection performance. Instead of one bit hard combining, where there is only one threshold dividing the whole range of the detected energy into two regions, a better detection performance can be obtained if we increase the number of threshold to get more regions of observed energy. In [9], a two-bit hard combining scheme is proposed in order to divide the whole range of the detected energy into four regions. The presence of the signal of interest is decided at the FC by using the following equation

$$\sum_{i=0}^{3} w_i n_i \geq L \quad \text{…......…….. (10)}$$

Where L is the threshold and it is equal to the weight of the upper region, n_i is the number of observed energies falling in region i and w_i is the weight value of region i with $w_0=0$ $w_1= 1$, $w_2= 2$ and $w_3= 4$

In this paper, we extend the scheme of [9] to a three-bit combining scheme. In the three-bit scheme, seven threshold λ1, λ2… and λ7, divide the whole range of the statistic into 8 regions, Each CR user forwards 3 bit of information to point out the region of the observed energy. Nodes that observe higher energies in upper regions will forward a higher value than nodes observing lower energies in lower regions. The three-bits combining scheme is performed in following steps.

1. Define a quantization threshold λi (i=1 . . . 7) for each region according to the maximal received energy of the signal.
2. Each user makes a local decision by comparing the received energy with the thresholds predefined in 1, and sends 3-bits information to the Fusion centre.
3. The Fusion centre sums the local decisions with weights w_i (i=0.., 7)

The final decision is made by comparing this sum with a threshold L.

$$\sum_{k=1}^{K} w_{i,k} \geq L \quad \text{……...….. (11)}$$

IV. OPTIMIZATION PROBLEMS AND SOLUTION

Main aim of spectrum sensing is to decide between two hypotheses that the channel state is empty (H_0) or is actively used (H_1), the most suitable optimality criterion is Neyman–Pearson optimality that maximizes the P_d Subject to P_f constraint. Different threshold values change the quantization and the corresponding decision hence proposed quantized cooperative spectrum sensing and global decision logic are optimized by optimizing the threshold.

Optimization problem: Maximize P_d
Subject to P_f < path loss exponent α

The algorithm for finding the solution to the given problem formulation is as follows

Algorithm: Threshold Optimization Algorithm for cooperative spectrum sensing

1. **Input:** Given *N*, *m*, *SNR Weight* vector, and path loss exponent α
2. Initialized the Maximum detection probability Pd , Threshold value, Increment of Threshold
3. **While** Increment > precision **do**
   i. Find P_f for this Threshold
   ii. Evaluate $\mathbf{P_d}$ for a given P_f
   iii. **If** ($\mathbf{P_d}$ > evaluated $\mathbf{P_d}$) **then**
      1. Increase Threshold
      2. Evaluated $\mathbf{P_d}$ = $\mathbf{P_d}$
   iv. **else**
      1. Decrease Threshold
      2. Decrease Increment
      3. Increase Threshold
   v. end if

   vi. **If** ($\mathbf{P_d}$ > Maximum detection probability $\mathbf{P_d}$) **then**
      1. Maximum detection probability $\mathbf{P_d}$ = $\mathbf{P_d}$
      2. Optimized Threshold = Threshold
   vii. end if
4. **end while**

In the above algorithms, the thresholds are optimized that finds the optimum thresholds for the proposed quantized cooperative spectrum sensing in terms of P_d with given P_f .

V. SIMULATION RESULT

We analyze the performance of quantized cooperative spectrum sensing under AWGN. We calculate the maximum P_d for a given P_f constraint. For comparison, we show in Fig. 2 the ROC curves for the different data fusion rules under AWGN channel. As from the simulation result figure indicates, all data fusions method outperform the single node sensing, the performance of proposed quantized cooperative spectrum is almost close to EGC based soft combining scheme which required larger overhead as compared the proposed scheme.

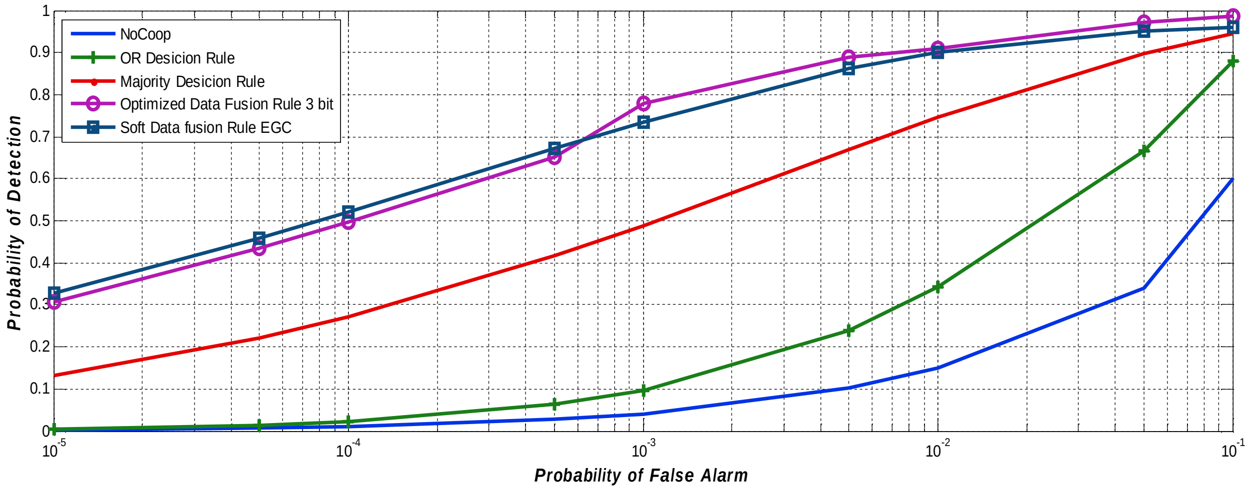

Figure 2.ROC curves of different data fusion scheme under AWGN channel

we also analyze the effect of number of cognitive users on P_d for a given P_f as shown in the figure 2**.** Increase in the number of nodes results in higher P_d. The performance of proposed scheme for given number of cognitive radio is close to EGC based soft data fusion scheme, proposed scheme outperfom the convention hard data fusion scheme.

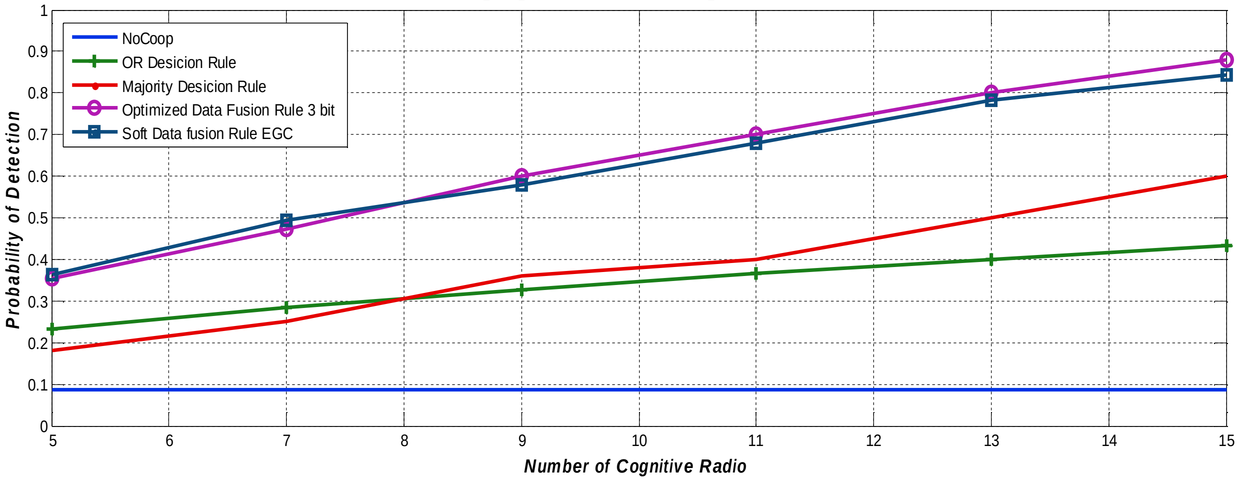

Figure 3.Cognitive radio versus P_d curves of different data fusion scheme

VI. CONCLUSION & FUTURE WORK

In this paper, we investigate the effect of data fusion scheme on performance of cooperative spectrum sensing. We proposed a quantized cooperative spectrum sensing and optimized quantization parameter i.e threshold value. The performance of optimized scheme is outperform the hard data fusion scheme and is very close to EGC based soft data fusion scheme, which is upper bound of data fusion scheme. Out proposed method have a less overhead, complexity and bandwidth as compared to other data fusion scheme. In practical application, we can select an appropriate data fusion scheme and rule according to the requirement of detection performance and the requirement of the available bandwidth for the reporting channel.

The future work of this paper is the development of adaptive SNR weight vector, improvement of throughput, sensing time, and developing an optimal sensing framework.

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