

Cooperative Spectrum Sensing in Cognitive Radio Network

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Abstract—In Cognitive Radio Network, Co-operative Spectrum Sensing (CSS) plays an important role. In CSS, each Secondary User (SU) submits their results to the Fusion Centre (FC). The FC performs the data fusion and generates a cooperative decision. It uses the hard combining technique to perform this data fusion. In hard combining OR rule, AND rule or maximum voting can be used. The OR rule is conservative, this can raise the false alarm probability. The AND rule is aggressive, this can raise the miss detection probability, and the maximum voting rule works on the majority of the SU result. In these cases, the probability of correct detection of Primary User (PU) signal reduces. To alleviate this problem, we have proposed a weighted strategy fusion decision technique for the FC in this paper. In this technique, the FC decides a weight factor for next sensing slot fusion decision, based on the present and previous spectrum sensing slots performance of the SUs. We compare the result of proposed weighted strategy fusion decision technique, with OR, AND and Maximum voting rule fusion decision techniques; where we found that the proposed technique offers better midway between aggressive AND and conservative OR than the simple Maximum voting rule.

Index Terms— Cognitive Radio, Co-operative spectrum sensing, Fusion decision, Weighted strategy.

I. INTRODUCTION

Nowadays due to globalization, the demand for data communication is rising. To meet this requirement optimize spectrum utilization is very important. Very often, the communication fails because of spectrum unavailability. To avoid such situations, Cognitive Radio Technology (CRT) plays an important role [1], [2]. In real time environment, multiple-Primary Users (PU) and multiple-Secondary Users (SU) are present. To establish a communication within such a huge network is very challenging. In such a condition to improve the performance of Cognitive Radio Network (CRN), Co-operative Spectrum Sensing (CSS) is the best solution.

In CSS, each SU performs the spectrum sensing and reports the result to the Fusion Centre (FC) [3], [14]. The FC collects the result and obtains a final decision using data fusion. In data fusion, the FC can use soft combining or hard combining techniques. In soft combining, FC considers signal from all SUs to obtain a co-operative decision. In quantized soft combining, the FC sampled the SU's signal to obtain the co-operative decision.

In hard combining, the SUs perform the spectrum sensing using Energy Detection (ED), Matched filter or Cyclostationary method [5]. Then it conducts a hypothesis test and generates the result in a one-bit decision. The one-bit could be 0 or 1 where 0 indicates hypothesis H_0 showing that the Primary User (PU) is not transmitting the

data and 1 indicates hypothesis H_1 showing that PU is transmitting the data. The SU reports this one-bit decision to the FC. The FC collects this local decision from all the SUs. It can use OR rule, AND rule or maximum voting rule to obtain final fusion decision.

In OR rule if any SU decision is one, then FC decision would be one. This approach is very conservative and often increases to Probability of false alarm (P_f). In AND rule the FC decision would be one if all SU's decision is one. This approach is very aggressive and often increases to Probability of miss detection (P_m). In the maximum voting decision, the FC takes the final decision one, if maximum SUs decision is one.

In these fusion decision techniques, FC takes the fusion decision based on the present decisions of the SUs. The FC does not consider the past performance of SUs. The SUs may present wrong decisions to obtain the benefit of the free spectrum or their result may be wrong due to mobility, noise or interference. To avoid this, we have proposed in this paper a weighted strategy fusion decision technique for FC. In this strategy, we have designed a mathematical model to estimate the present and previous sensing slot performance of each SU and estimated a test statistic for the FC.

The rest of the paper is organized as follows: Energy Detection spectrum sensing is explained in section II. The weighted strategy fusion decision technique for FC is given in section III. Results are discussed in section IV and the conclusion is drawn in section V.

II. ENERGY DETECTION SPECTRUM SENSING FOR SU

To find the present decision of each SU, we have used Energy Detection (ED) spectrum sensing and implemented it on Universal Software Radio Peripheral (USRP).

We have assumed that the PU is transmitting a signal $x(k)$. This signal is unknown to the SU and corrupted by AWGN [4]. The observation under each hypothesis is represented as below:

$$\left. \begin{array}{l} H_1 : Y(k) = hx(k) + N(k) \quad i = 1, 2, \dots, M \\ H_0 : Y(k) = N(k) \quad k = 1, 2, \dots, K \end{array} \right\} \quad (1)$$

where, $Y(k)$ is the received signal of SU, K is number of samples, M is the number of SUs, $x(k)$ is the PU signal modeled by Gaussian distribution with μ mean and variance σ_s^2 , $N(k)$ is Gaussian noise with zero mean and variance σ_n^2 , h is the channel gain between PU and SU and is assumed to undergo Rayleigh fading, H_1 is the hypothesis that PU signal is present and the H_0 is the hypothesis that PU signal is absent. To decide whether PU is present or absent, we have taken norm of the received signal at SU

$Y = \sum_{k=1}^K Y(k)^2$, and compared it with a threshold value η . The test static for an SU can be written as:

$$\left. \begin{array}{l} H_1 : Y > \eta \\ H_0 : Y < \eta \end{array} \right\} \quad (2)$$

where, Y indicates the sum of squares of K numbers of Independent Identically Distributed (I.I.D.) Gaussian random variables with zero mean and variance σ_s^2 , hence it is called the *central Chi-square random variable* with D degrees of freedom [6], [7].

In a similar way, each SU can perform the ED spectrum sensing and generate the result H_0 or H_1 . It reports this result to the FC and the FC takes a final decision.

Many-weighted strategy for fusion decision has been proposed earlier. They differ from each other in the way they define weight. In [8] the authors have proposed an algorithm where, the global fusion center weights the spectrum sensing node according to the each node's credibility. Meanwhile, an attenuation factor is introduced to continually update the detection SU's credibility. In [9] a new linear inertia weight particle swarm optimization [LINWPSO] method was proposed. In [10] a trust-based method for CSS was proposed. Multi-bit decision adaptive CSS based on trust valuation was proposed in [11]. In [12] the authors have determined the reliability of SUs that was based on P_f and detection probability. Here, the FC selects the more reliable SU for its fusion decision. In [13] the weighted strategy was designed for FC. It was based on the past performance of each SU. In

[17] energy utility function for the SUs is determined based on the power of circuit consumption, spectrum sensing, decision reporting, and data transmission.

A. Problem statement

In [18] the weight factor was designed based on channel behavior. In [8], [18], [13] the weight factor was measured considering most recent past sensing slot performance of the SU. This is an incomplete review of SU's past performance. In most of the cases, the weight factor calculations were performed at SU, this consumes more power of SU's.

According to the literature survey in most of the research work, the weight factor is determined based on the most recent past sensing slot performance of an SU. Unlike this, to optimize the fusion decision performance of the FC, we have proposed in this paper a separate weight factor for each SU. In this, a weight factor is designed for each SU, based on its present and all past sensing slot performance of an SU. In our proposed strategy, the calculations are performed at FC rather than at SU, this reduces the SU's workload and saves its power. The FC is equipped with battery backup. This strategy could be very helpful for wired or wireless SUs. It is explained in section III.

III. WEIGHTED STRATEGY FUSION DECISION FOR FC

A. System Model

The block diagram of the CRN for the proposed weighted fusion decision is shown in Fig. 1. In this CRN, we have considered one PU and multiple SUs. Each SU performs ED spectrum sensing and reports the result either H_0 or H_1 to the FC. The FC generates a weight for each SU based on the SU's performance. It compares the weighted result with the threshold value and generates a final fusion decision. To achieve this we have divided the spectrum sensing into different time slots as shown in Fig. 2.

We have considered the m number of sensing slots. In one slot, each SU performs the ED spectrum sensing for N number of times and reports the result to the FC. At the FC, to decide the weight factors for each SU for next sensing slot, we measure the performance of the each SU in the present and previous sensing slot. The performance measurement for one SU is explained below:

Let, D_i be the local decision of i^{th} SU, D_{FC} the decision of FC, then the Probability of correct decision (P_d^i) for i^{th} SU can be given by,

$$P_d^i = P(D_i = H_1 | D_{FC} = H_1) + P(D_i = H_0 | D_{FC} = H_0) \quad (3)$$

Similarly, the P_f for i^{th} SU can be given by,

$$P_f^i = P(D_i = H_0 | D_{FC} = H_1) \quad (4)$$

Let, m be a present spectrum sensing slot for SU_i , $D_{x,y}^{i,j}$ represent a decision for SU_i in m^{th} slot where, x indicates the D_i decision, y indicates the D_{FC} decision and j is 1 to N . Both decisions could be either H_0 or H_1 .

Thus, there are four possibilities of the final decisions: $D_{1,1}^{i,j}$; $D_{1,0}^{i,j}$; $D_{0,1}^{i,j}$; $D_{0,0}^{i,j}$. These decisions are measured using (5) and (6):

$$\left. \begin{aligned} D_{1,1}^{i,j} &= \begin{cases} 1 & \text{if } D_i = H_1 \text{ and } D_{FC} = H_1 \\ 0 & \text{else} \end{cases} \\ D_{1,0}^{i,j} &= \begin{cases} 1 & \text{if } D_i = H_1 \text{ and } D_{FC} = H_0 \\ 0 & \text{else} \end{cases} \\ D_{0,1}^{i,j} &= \begin{cases} 1 & \text{if } D_i = H_0 \text{ and } D_{FC} = H_1 \\ 0 & \text{else} \end{cases} \\ D_{0,0}^{i,j} &= \begin{cases} 1 & \text{if } D_i = H_0 \text{ and } D_{FC} = H_0 \\ 0 & \text{else} \end{cases} \end{aligned} \right\} \quad (5)$$

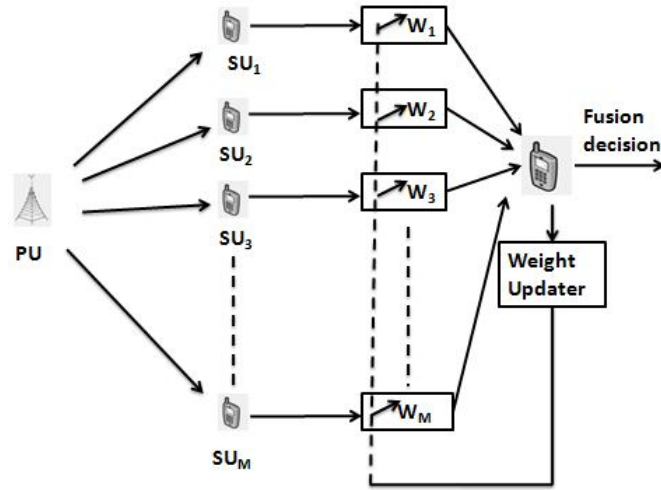


Fig. 1. Block diagram of the CRN

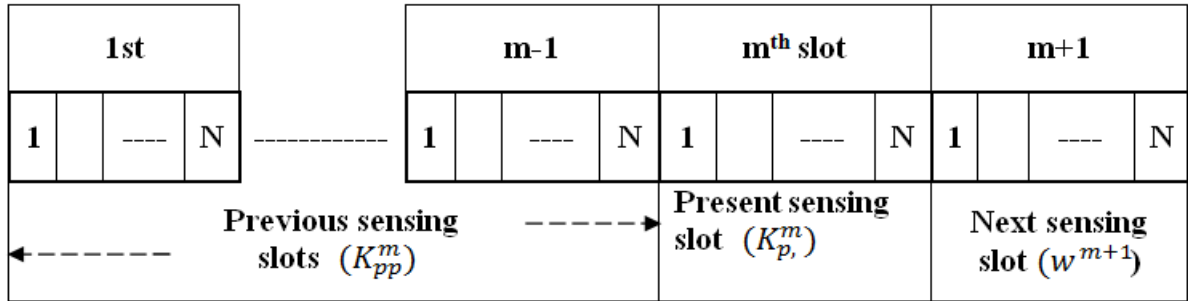


Fig. 2. Spectrum sensing slots for Sus

$$\left. \begin{aligned}
 D_{1,1}^i &= \sum_{j=1}^N D_{1,1}^{i,j} \\
 D_{1,0}^i &= \sum_{j=1}^N D_{1,0}^{i,j} \\
 D_{0,1}^i &= \sum_{j=1}^N D_{0,1}^{i,j} \\
 D_{0,0}^i &= \sum_{j=1}^N D_{0,0}^{i,j}
 \end{aligned} \right\} \quad (6)$$

Based on these measurements the P_d^i and the P_f^i are calculated using (7).

$$\left. \begin{aligned}
 P_d^i &= \frac{D_{1,1}^i + D_{0,0}^i}{N} \\
 P_f^i &= \frac{D_{0,1}^i}{N}
 \end{aligned} \right\} \quad (7)$$

Using these parameters, we have introduced a performance parameter $K_{p,i}^m$ for SU_i in m^{th} slot, it is given in (8).

$$K_{p,i}^m = P_d^i \times (1 - P_f^i) \quad (8)$$

The value of $K_{p,i}^m$ is only dependent on the performance of SU_i in the present spectrum sensing slot. It does not include the past performance of SU_i . In order to include the past performance of the SU_i , we have introduced a new parameter named past performance parameter $K_{pp,i}^m$. It is an average of performance parameter in all past sensing slots of the SU_i , which is a unique quality of the proposed technique. It is given in (9).

$$K_{pp,i}^m = \frac{K_{p,i}^{m-1} + K_{p,i}^{m-2} + \dots + K_{p,i}^1}{m-1} \quad (9)$$

To design a weight factor for next sensing slot for SU_i (W_i^{m+1}), we have combined the present and past performance parameters as shown in (10).

$$W_i^{m+1} = K_{pp,i}^m + K_{p,i}^m \quad (10)$$

The FC generates a fusion decision, where it adds the weighted result of each SUs and compares it with a threshold value λ . An SU whose weighted decision is greater than λ , can be considered in fusion decision else not. Hence, FC obtained high performance, reliable SUs to take its final fusion decision. To achieve this, the test statistics for the FC can be written as:

$$D_{FC} = \begin{cases} H_0, \sum_{i=1}^M W_i D_i < \lambda \\ H_1, \sum_{i=1}^M W_i D_i \geq \lambda \end{cases} \quad (11)$$

The threshold value λ can be given as $\lambda = \frac{\sum_{i=1}^M W_i}{\alpha}$ where α is the strictness parameter. For better performance of

the system, we limit the value of α between 2 and $\sum_{i=1}^M W_i$, so the limit of λ is from 1 to $\frac{\sum_{i=1}^M W_i}{2}$. If α is maximum, then λ tends to 1, this reduces the strictness, and even single SU can change its decision from H_0 to H_1 . If α is minimum, λ tends to maximum, which is the most strict scenario, where SU cannot change hypothesis very easily. For optimal results, there should be a proper tradeoff between α and λ values.

The FC compares the SU_i decision with the optimum λ and obtains the optimum fusion decision using (11). The proposed algorithm for weighted strategy is as follows:

- 1) Fix the period N .
- 2) Initialize the weights $W_i = 2$ for all CRN.
- 3) Fix the value of α and calculate the threshold (λ).
- 4) Calculate the final decision using (11).
- 5) Calculate $D_{1,1}^{i,j}$; $D_{1,0}^{i,j}$; $D_{0,1}^{i,j}$; $D_{0,0}^{i,j}$ for each CRN and for each final decision within period N using (5).
- 6) Calculate $D_{1,1}^i$; $D_{1,0}^i$; $D_{0,1}^i$; $D_{0,0}^i$ after the end of 1st period using (6).
- 7) Calculate the probability of correct decision and the probability of false alarm using (7).
- 8) Calculate the performance parameter K_p^m using (8).

9) Calculate the past performance parameter $K_{pp,i}^m$ using equation (9).

10) Calculate the new weights W_i^{m+1} using (10).

11) Go to step three.

B. Merits/demerits of the proposed technique

- 1) Due to weighing factor introduced in fusion decision, the present and the past performance of each SU is considered in this technique. This prevents the SUs from performing any malfunctioning with its result and improves the fairness of the system.
- 2) Better Probability of Detection (P_d) at FC and more reliable fusion decision is obtained as compared to OR, AND and Maximum voting rule.
- 3) Only one value of $K_{pp,i}^m$ is needed to be stored at each SU for each spectrum sensing slot, this does not consume more memory space.
- 4) At FC the value of $K_{pp,i}^m$ for each spectrum sensing slot is needed to be stored for each SU, this requires more memory space at FC.

IV. RESULT

A. SU Spectrum Sensing Result

We have implemented the ED spectrum sensing on Universal Software Radio Peripheral (USRP) [15], [16]. During experimentation, we have considered the CRN with one PU and two SUs. For the PU signal transmission, QPSK signal was generated in Labview using PN sequence order 9. To reduce the Inter Symbol Interference (ISI) and bandwidth of the QPSK signal, Root Raised Cosine (RRC) filter was used. To improve the Bit Error Rate (BER) performance of the trans-receiver the Root Raised Cosine (RRC) filter used with the filter length 6 and a roll off factor 0.5. The carrier frequency of PU and SU was tuned to 2.5 GHz, IQ rate (channel bandwidth) was 200 KHz, channel gain was 10 dBm, the distance between PU and SU was varied from 1m to 4m and data rate was 70kbps. With these specifications, both the SUs have performed the successful ED spectrum sensing. The test-bed of USRP is shown in Fig. 3.

The result of ED spectrum sensing is shown in Fig. 4 (a) and (b). In Fig. 4(a), the spectrum sensing result is 0, which shows that PU is present. In Fig. 4(b) the spectrum sensing result is 1, indicating that PU is absent.



Fig. 3. USRP test-bed for Energy detection spectrum sensing

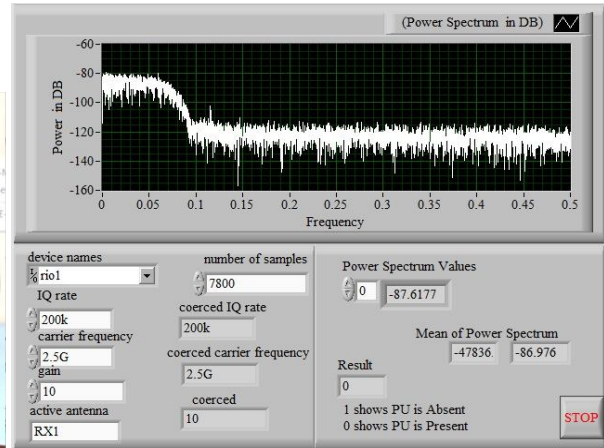


Fig. 4 (a). The PU signal detected as present at the SU

This is the result of one SU. In a huge CRN, many SUs are present. The sensing result of SU's may affect due to their mobility, unreliability or noise introduced in PU's signal. This causes incorrect spectrum prediction. To improve the CRN's P_d reliable co-operative decision is needed. To achieve this, we have proposed the weighted strategy for FC to obtain accurate fusion decision. We have compared our proposed technique's result with the traditional OR, AND and Maximum voting rule.

Fig. 5 shows the graph of the P_d of individual SU versus the P_d of fusion decision at FC. It can be clearly noted from the graph that, in OR rule the P_d of fusion decision approaches one, even if individual SU's P_d is near to 0.3. In AND rule the P_d of fusion decision approaches one when the SU's P_d is above 0.9. In Maximum Voting, the P_d of fusion decision increases above 0, when individual SU's P_d crosses 0.5 and P_d of fusion decision approaches one, when individual SU's P_d crosses 0.8. When this is compared with proposed weighted strategy, the P_d of fusion decision increases above 0 when individual SU's P_d crosses 0.2 and

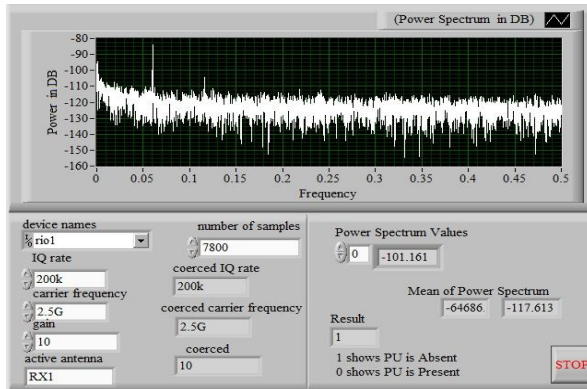


Fig. 4 (b). The PU signal is detected as absent at the SU

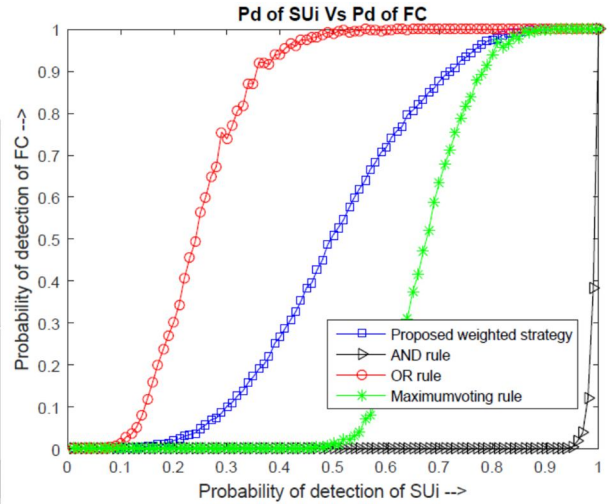


Fig. 5. Probability of detection of an SU Vs probability of detection of an FC

P_d of fusion decision approaches 1 when individual SU's P_d crosses 0.8. Thus, we can easily conclude that the proposed weighted strategy gives better performance.

In [8] Accumulated Credibility-based Weighted CSS algorithm was proposed and in [12] reliability based CCS algorithm was proposed. In both the papers, P_d versus SNR simulation was performed and for lower SNR from -16 dB the proposed algorithm gave higher P_d of 0.9 and above. In these cases, if individual SU P_d is higher, then overall FC's P_d would be high. In our proposed technique the FC approaches the P_d variation range 0 to 1, when individual SU's P_d is in the range of 0.2 to 0.8. In [13], [18] the weight factor has decided based on limited sensing slots performance of the SU's. In our proposed technique we have considered the previous all sensing slots performance of the SU. Hence, it gives more reliable spectrum sensing fusion decision result as compared to other techniques.

V. CONCLUSION

In a huge number of SU's Cognitive Radio Network, the SUs may present wrong probability of detection (P_d) to grab the free spectrum. The P_d of SU's can be affected because of its mobility, remote location, noise or interference introduced in PU signals, etc. In such a case, the SU's performance reduces. This affects the fusion decision of Fusion Centre (FC). To avoid this and improve the reliability of co-operative decision taken at FC, we have proposed in this paper a weighted strategy fusion decision technique. In this technique, we have divided the spectrum sensing into different time slots. Then we have designed a weight factor for next time slot fusion decision, based on present and previous spectrum sensing time slots performance of an SU. This gives a more reliable result of co-operative decision with higher P_d as it offers a better mid-way between aggressive AND and conservative OR than simple maximum voting.

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