Comparision of Different Weight Assignment Strategy in Weighted Cooperative Spectrum Sensing

Arpita Jaitawat
Electronics and Communication Engineering Dept.
The LNM Institute of Information Technology
Jaipur, INDIA
Email: arpitajaitawat@gmail.com

Purnendu Karmakar
Electronics and Communication Engineering Dept.
The LNM Institute of Information Technology
Jaipur, INDIA
Email: purnendu.karmakar@lnmiit.ac.in

Abstract—Cooperative spectrum sensing is used to overcome limited computing power of individual nodes to correctly estimate existence of primary user in presence of multipath fading, shadowing and receiver uncertainty. However, conventional cooperative spectrum sensing is not reliable in case when users suffer different fading environment. So for such a case, new method of spectrum sensing is used and that is weighted cooperative spectrum sensing. In this paper, three different strategies of weight assignment have been discussed. In first strategy, weight assigned to all cognitive radios (CRs) is a constant value while in second case weight depends on number of CRs in system. In third case, weight assignment depends on SNR and varies with SNR. In first two cases, weight is same at each CR while in third case weight depends on SNR and changes at each CR. These three strategies have been compared and analyzed to get better result.

Keywords—Cognitive radio; Cooperative spectrum sensing; energy detection (ED); improved energy detection (IED); weights

I. INTRODUCTION

Spectrum sensing has always been a great issue of discussion. The spectrum available is limited but number of users are large in number which leads to inefficient use of spectrum. In order to avoid the issues related to spectrum sensing, a communication paradigm has been introduced and that is Cognitive Radio Networks (CRN).

Cognitive Radio Network uses a software defined architecture that detects unused licensed bands and allows unlicensed users to opportunistically use the licensed band[1][2]. In other words, it can be said that in CRN, unlicensed users sense idle spectrum and then select the best available channel, coordinate access to this channel with other unlicensed users and make this channel available to the licensed users when they need it. So, the problem of spectrum sensing can be solved by using CRN to an extend. However, when the signal is transmitted through a channel, it undergoes a number of effects like multipath fading, shadowing, interference and receiver uncertainty etc. which affects the detection process and may lead to wrong decision. Therefore, to avoid this problem cooperative mechanism can be used.

Cooperative spectrum sensing is the spectrum sensing method in which multiple CRs cooperate to perform spectrum sensing. The cooperative model consists of a Primary user (PU), secondary user (SU) and a fusion center (FC). The final decision of spectrum sensing is given by the fusion center. A number of fusion rules are used by the fusion center to compute the result. OR rule is the most common and simple rule which is most popularly used[3]. Thus, multiple node detection helps in under laying the effect of fading and provides accurate and reliable result which increases probability of detection.

Conventional cooperative spectrum sensing is not reliable in case when users suffer different fading environment. So for such a case, new aspect of sensing is used and that is weighted cooperative spectrum sensing. In this concept each CR is assigned weight depending on different criteria. Weights provide with an insight view of better PU-CR path.

In this paper, concept of weighted cooperative spectrum sensing has been introduced in which initially weights have been assigned to each CR depending on different strategies. In each round, weight depends on the presence /absence of the PU in previous round. In other words, it can be said that the presence /absence of the PU signal can be detected by the weights in each round. Two modules are included in the framework. In the first module, the signal is transmitted to CRs which individually perform spectrum sensing and provide binary decision. In the second module, instead of just providing the binary decision the sum of products of weights with binary decision is sent to the Fusion center which helps is making final decision. The best aspect of proposed work is that in each round, value of weight is increased /decreased depending on the presence/absence of the binary decision at each CR in the previous round. Also, the threshold value is updated in each round. In each round with updation in weight and threshold, the probability of detection also changes.

A. Related Work

Spectrum sensing in cognitive radio networks can be generally classified into two categories: local sensing and cooperative sensing. In local spectrum sensing, each SU independently makes a decision on channel availability based on the information collected. If there are idle channels, it
will attempt to access a selected channel otherwise it keeps sensing. As discussed earlier, a widely used technique for local sensing is energy detection. Energy detection has low computation complexity and is easy to be implemented. However, it is susceptible to multipath fading and the uncertainty of noise power[8].

In cooperative sensing, each SU independently performs local spectrum sensing and makes a binary decision (idle or occupied) for a channel. This channel is determined as idle by cooperative sensing if all SUs (or a certain number of SUs) find that it is idle. A lot of efforts have been done to improve spectrum sensing so that the system works in an efficient manner. An initiation to this is weighted cooperative spectrum sensing[8].

In literature [4] a different concept of weighted has been used which uses soft combination technique for fusion. The authors in [5] have developed a distributed algorithm that the secondary users can run to sense the channel cooperatively. It is based on sequential detection algorithms which optimally use the past observations. The algorithm provides very low detection delays and also consumes little energy. Literature [6] deals with the case that the secondary users have different detection signal-to-noise ratios(SNRs) and their decisions are weighted based on the likelihood ratio test at the fusion center. The authors have also considered three different scenarios .In Scenario I, they have optimized individual secondary users thresholds together with the fusion rules threshold at the fusion center. In Scenario II, all the secondary users thresholds are constrained to be the same and we seek the optimal threshold jointly with the fusion rules threshold at the fusion center. In Scenario III, each secondary user computed its own threshold while the fusion center optimizes the fusion rules threshold based on the secondary users threshold results. This literature deals with joint optimization of sensing time and fusion scheme using weighting. In [7] the authors have implemented weighted cooperative spectrum sensing using weights of SUs decisions from their average received SNRs, integrates both their independent decisions and weights to fuse data, and makes a final sensing decision. The paper[8] presents a weighted cooperative spectrum sensing framework for infrastructure-based cognitive radio networks, to increase the spectrum sensing accuracy. To enhance the sensing ability [9] some weighted-cooperative spectrum sensing techniques have been proposed. In this paper, the authors proposed a weighted-clustering cooperative spectrum sensing algorithm based on distances for cognitive radio network. In [10] an improved form of weighted cooperative sensing is described in which weight updation depends on probability of detection at each CR. In [11] weighted clustering strategy in which weightings are used to weight the cluster-decisions before combining is used. In literature [12] distributed spectrum sensing is performed using consensus-based fusion algorithms.

The rest of the paper is organized as follows: Section II describes the system model that we have considered in simulation. Section III describes Methodology and Section IV shows the analysis of the procedure. Section V deals with the simulation results and its analysis and finally Section VI consists of conclusion carried out by proposed work simulation.

II. SYSTEM MODEL

Cooperative spectrum sensing system model consists of one PU, one Fusion center (FC) and M number of CRs (secondary user). SUs opportunistically share a licensed channel with PU for data transmission. The signal from PU is sent to CRs which individually perform spectrum sensing using different spectrum sensing techniques (e.g energy detection method). Individual results from CRs are sent to the fusion center which uses some fusion rule to give final decision.

CRs use improved energy detection and energy detection for local spectrum sensing. It is assumed that the primary signal is reasonably higher than the noise level so that it does not affect the signal. A basic hypothesis model for the local spectrum sensing takes into consideration two hypothesis, $H_0$ denote the event that the channel is idle and $H_1$ denotes the event that the channel is busy. If the channel is idle then the received signal is only noise while if the channel is busy then the received signal is PU signal and noise. A basic hypothesis model can be defined as follows[8][13]:

$$y_i = \begin{cases} n_i, & \text{if } H_0, \\ h_i s + n_i, & \text{if } H_1. \end{cases}$$

(1)

where $y_i$ is the signal received by the $i^{th}$ SU, $n_i$ is the Additive White Gaussian Noise(AWGN) at the $i^{th}$ SU, $h_i$ is the channel gain at the $i^{th}$ SU and $s$ is the signal that is transmitted by the PU. Signal contains $N$ samples during the sample period $T$ where $N=2T^*W$, $W$ is the bandwidth of band pass filter. At each individual SU spectrum sensing is performed by spectrum sensing technique. The energy of the
signal in improved energy detector method is calculated by using $p^{th}$ norm as described below[14]:

$$W_i = \sum_{n=1}^{N} |y_i(n)|^p$$  \hspace{1cm} (2)

where $p$ is a real value. If $p=2$ then it corresponds to conventional energy detector method. Now, energy at each CR is metric to threshold which decides whether the PU signal is present or absent.

$$P = \begin{cases} 1, & \text{if } W_i > \lambda \\ 0, & \text{if } W_i < \lambda \end{cases}$$  \hspace{1cm} (3)

where $\lambda$ is the threshold. If the energy value is greater than the defined threshold the signal is present and if less than the defined threshold the signal is absent. Then, the individual decision is sent to the fusion center where using fusion rule the final decision is taken.

### III. METHODOLOGY

This section deals with basic idea of spectrum sensing opted in proposed work. Basic steps carried to perform spectrum sensing in cooperative system are described as follows:

1) The signal from the PU is transmitted through the channel to M number of CRs. The channel considered is a Rayleigh fading channel and noise is AWGN noise.

2) At each CR, spectrum sensing is performed individually using a spectrum sensing technique. The spectrum sensing technique which we have considered is energy detector and improved energy detector method.

3) Now, the sum of the product of weight with the result of individual binary detection at each individual CR is forwarded to the fusion center.

4) The fusion center applies some fusion rule and thus provides the final result about the presence/absence of the signal.

The basic flow chart that shows how the whole process of spectrum sensing is carried out is shown in Figure 2.

### IV. ANALYSIS

#### A. Weight Initialization

Initially, weights are assigned to each CR depending on different conditions to view which CR is performing better. Weights can be initialized depending on different strategies. The different strategies are described below:

1) **Constant Weight**: In this the weight assigned to all CRs is same and it is a constant value.

$$w_i(1) = c$$  \hspace{1cm} (4)

where $c$ is a constant real value 0 and 1.

2) **Depending on Number of CRs**: Weight can be initialized depending on number of CRs in the cooperative system. Thus, as the number of CRs increases, weight assigned to each CR decreases. Weight assigned to all CRs is same and that is equivalent to:

$$w_i(1) = \frac{1}{M}$$  \hspace{1cm} (5)

where $M$ denotes number of CR in system.

3) **Depending on SNR**: A much practical way of weight initialization is depending on SNR. Lower the value of SNR better is the performance and so higher is the value of weight for such CR.

$$w_i(1) = \frac{\text{SNR}(i)}{\sum_{i=1}^{M} \text{SNR}(i)}$$  \hspace{1cm} (6)

SNR(i) is signal to noise ratio at $i^{th}$ CR.

#### B. Weight assignment in succeeding rounds

In this paper, it is considered that threshold and weight are updated at each CR in each round. Weight assigned to each individual CR depends upon the spectrum sensing result of each individual CR of previous round. In the same way, threshold is also updated depending on the presence/absence of the signal of previous round. The threshold for $k+1^{th}$ round is updated as follows:

$$\lambda_i(k+1) = \begin{cases} \lambda_i(k), & \text{if } P_i(k) = 1 \\ \lambda_i(k) - 1, & \text{if } P_i(k) = 0 \end{cases}$$  \hspace{1cm} (7)

The following steps are followed for the updation of weight at each CR in each round:
1) Firstly, the correct detection \(a(k)\) and miss detection \(b(k)\) is counted in the previous round at CRs.

2) Then, value \(\Delta w\) is determined by which the weight is increased or decreased

\[
\Delta w = \begin{cases} 
\frac{\text{lcm}(a(k), b(k))/m}{M/m}, & \text{if } a(k) \neq 0 \text{ and } b(k) \neq 0 \\
0, & \text{otherwise}
\end{cases} \quad (8)
\]

where \(a(k)\) and \(b(k)\) denote the correct detection and miss detection in \(k^{th}\) round, \(M\) denotes the number of secondary users (CRs). The value of \(m\) can be any value but since \(\Delta w\) should be very small so we have considered the value of \(m\) as 100. Lcm of \(a(k)\) and \(b(k)\) is considered to maintain a ratio between the amount of increase and decrease in weight.

3) Finally, the weight is updated by following rule:

\[
w_i(k+1) = \begin{cases} 
w_i(k) + \Delta w, & \text{if } P_i(k) = 1 \\
w_i(k) - \Delta w, & \text{if } P_i(k) = 0
\end{cases} \quad (9)
\]

Thus, in each round the weight and threshold is updated for each CR depending on its spectrum sensing result in the previous round. If the CR has made a correct decision in the previous round then the value of threshold remains the same and the weight at that particular CR increases. But if the CR has made a miss detection in the previous round then its threshold and weight are decreased. Weight at \(i^{th}\) CR for each round should lie between 0 and 1 i.e.

\[
0 < w_i(k) < 1 \quad (10)
\]

If updated weight at \(i^{th}\) CR for \(k + 1^{th}\) round does not satisfy the condition following rule is applied:

\[
w_i(k+1) = \begin{cases} 
1, & \text{if } w_i(k+1) > 1 \\
0, & \text{if } w_i(k+1) < 0
\end{cases} \quad (11)
\]

Thus by the change in weight, we can make an idea whether the secondary user is making correct decision or not in each round. Also, by decrement in threshold the probability of detection at CR increases thereby increasing the probability of detection of the system.

C. Local spectrum sensing at each CR

The signal from the primary user is transmitted through Rayleigh channel to the CR (secondary user). The signal at CR goes through different spectrum sensing techniques and gives the final decision. Two issues need to be addressed for CR to make a decision on the channel status. First, what is the optimal threshold to be used by CR and second, how to assign an appropriate weight to each CR to minimize total error probability. The optimal value of threshold is decided by the value of the energy calculated at each CR that provides the least probability of error at the output[15]. The whole analysis is carried out in rounds. The basic idea of our weight assignment is that initially weight assigned to each CR depends on different strategies. Now, in each succeeding round, the weight increases or decreases depending on spectrum sensing result at each individual CR in the previous round.

The weight at each CR is normalized to satisfy the condition that weight at \(i^{th}\) CR for \(k^{th}\) round should lie between 0 and 1. With assigned weight at each CR, output signal at each CR is \(w_i P_t\). The input to the fusion centre is

\[
Y = \sum_{i=1}^{M} w_i(k) P_i(k) \quad (12)
\]

Now this sum at the fusion center is compared with \(\alpha\). Since the value of sum lies between 0 and 1 thus value of \(\alpha\) can be any real number between 0 and 1. For proposed system the value of \(\alpha\) considered is 0.5. The sum is metric to \(\alpha\) as shown below:

\[
PU = \begin{cases} 
H_0, & \text{if } Y < \alpha \\
H_1, & \text{if } Y > \alpha
\end{cases} \quad (13)
\]

If value of sum is greater than \(\alpha\) then the fusion center gives final decision that PU signal is present \((H_1)\) else the primary user signal is absent \((H_0)\). Hence this is how the proposed weighted cooperative spectrum sensing system is working.

V. SIMULATION RESULT AND ANALYSIS

In this section, we have evaluated the performance of our proposed weighted cooperative spectrum system. The simulation has been carried out for different weight assignment strategies in various rounds for low SNR region. The channel between PU-CR link is a Rayleigh fading channel which includes path loss. Also, it has been assumed that the PU signal is a binary signal and is always present. Number of CRs considered for simulation is 10. Different results have been discussed in this section.

A. Simulation using Energy Detection Method

The whole process of simulation has been carried out in ten rounds and in each round, threshold and weight have...
been updated depending on the previous round results. Thus, average of the Probability of detection of all ten rounds is being calculated for a particular value of SNR. In this section we discuss how the average probability of detection varies with increase in the value of SNR(dB) for different number of secondary users in each round.

The simulation result in Figure 3 shows that average probability of detection (Pd) increases with increase in SNR. The weight assignment depending on number of SNR provides much better probability of detection than other two strategies. By Figure 4, it can be concluded that with updation in threshold and weight in each round the probability of detection(Pd) increases. In other words, it can be said that because of updation in threshold in each round the detection rate at each CR increases and because of that the weight assigned to CR increases. This in turn leads to increase in the probability of detection in each round.

B. Simulation using Improved Energy Detection Method

Energy Detector Method is the most commonly used spectrum sensing technique. An improved form of Energy detector method is the Improved Energy Detector Method. In this section, simulation using improved energy detection method has been discussed.

In case of IED method, value of p considered for simulation is 3.5 because it gives the least value of total error rate [15]. By simulation it can be concluded that IED method provides much better result than energy detection method. As it can be concluded from result, when weight depends on SNR, the result is better than when weight is same in case of IED method as compared to ED method. So, IED method is much better than ED method.

VI. CONCLUSION

In this paper we have proposed a new framework of cooperative spectrum sensing in form of weighted cooperative spectrum sensing. Weight assignment depends on different strategies. The proposed framework provides increase in the detection rate with updation in threshold and weight in each round. It can be concluded that weight assignment depending on number of CRs provides a good detection rate as compared to other two strategies. The value of threshold is determined by the energy value of CRs which provides the least total error probability. Local spectrum sensing using ED method and IED method is considered. Thus, it can be concluded that proposed system provides better results using
IED method and the Probability of detection increases with increase in rounds. Also, weight assignment depending on number of CRs provides good probability of detection (Pd).

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