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Enhancement in Gain for Centralized Cooperative Spectrum Sensing in Cognitive Radio Network using Improved Local Sensing

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Abstract: The parallel fusion model universalizes centralized and decentralized cooperative spectrum sensing as a three step process comprising of: local sensing, information reporting and information fusion. It is quite obvious that any amelioration in the performance quality of the constitutional steps would strengthen the overall performance of the cooperative spectrum sensing network. The performance metrics for a cooperative spectrum sensing network are the gain provided and overhead occurring (both in comparison with non cooperative scenario). An efficient cooperative sensing scheme promises a good tradeoff between both the metrics. In this work, the authors present a scheme providing improved cooperative gain for a centralized cooperative spectrum sensing network which employs hard combination at the fusion centre.

Keywords: Cognitive Radio (CR); Primary User (PU), Secondary User (SU); Cooperative Spectrum Sensing; Centralized Cooperative Spectrum Sensing; Hard combination.

I. INTRODUCTION

The concept of cooperative spectrum sensing for cognitive radio networks emerged to combat difficulties such as multipath fading, shadowing and receiver uncertainty issues which could not be resisted by the non- cooperative spectrum sensing scheme [1]. Several recent works have shown that cooperative spectrum sensing can greatly increase the detection probability for fading channels. Cooperation can be among the CRs belonging to the network or external sensors can also be used to cooperate with the network nodes. Cooperative spectrum sensing among the CRs, in literature, is classified as centralized and decentralized cooperative spectrum sensing. Cooperation for spectrum sensing can be described in the following steps:

- Stage 1 :Local Sensing
- Stage 2: Reporting of locally sensed information
- Stage 3: Information Fusion

Local spectrum sensing, as the name suggests, refers to the sensing carried out by the individual nodes by examining their respective environments. Local sensing can be carried out through any of the basic transmitter detection techniques viz. matched filter detection, cyclostationary detection, entropy-based detection or energy detection. Energy detection is the most popular and widely used method because unlike the other three techniques, it does not require any a priori knowledge of the PU signal being detected and possess lower computational complexity.

The stage followed by local sensing is the reporting where individual nodes ‘report’ the information gathered by them as a result of the local sensing carried out. The reported information can be in the form of single or multi bit decisions (as in hard and quantized combination) or in the form of raw locally sensed information (as in soft combination). In case of centralized cooperative sensing, there is a node-fusion centre reporting whereas in the decentralized scenario, node-node reporting takes place.

Information fusion refers to the amalgamation of the information collected from the nodes into a unified/global decision on the state of the PU. Information fusion takes place at the fusion centre for the centralized cooperation whereas for the decentralized scenario, it takes place within a node. Information fusion techniques are broadly classified as ‘decision’ or ‘data’ fusion and are named as hard, soft and quantized combining schemes. The centralized cooperative spectrum sensing revolves around a central unit called the 'fusion centre (FC)' which controls all the phases of cooperation. The fusion centre selects frequency band for sensing and all CR nodes are instructed to perform individual sensing for the desired band. The CR users report their sensing results to the fusion centre through the

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reporting channel .The fusion centre then combines the gathered local sensing information to form a final decision on the presence of the PU. This decision is then broadcasted to all the CR nodes belonging to the network.

II. OPTIMIZATION OF ENERGY DETECTION

Urkowitz in his work [2], models the basic energy detector which is capable of distinguishing a deterministic signal amidst prevalent white Gaussian noise. A traditional energy detector calculates the energy of the signal it is receiving, over an observation interval, which becomes the test statistic for the algorithm. The test statistic is then compared with the predefined threshold. If the value of the test statistic is greater than the threshold, PU is assumed to be present on the desired frequency band otherwise it is assumed to be absent. In [3], the authors describe a multistage enhancement for the traditional energy detection. The proposed algorithm in [3] begins with traditional energy detection proceeded by additional checks to make the detection process as foolproof as possible without much increase in complexity and overhead. At any sensing instant, the second stage includes a. evaluating the average received signal energy for a number of past sensing instances and b. the received signal energy at the immediate previous instant. The third stage check involves the energy detector cooperating with other energy detectors in the network to verify its result. The scenario in [3] can be considered as a distributed/decentralized network with no fusion centre.

In this work, we adopt the second stage of enhancement described in [3] and study its effects on a centralized network which employs hard combination scheme at the fusion centre. The aim of the proposed work thus boils down to comparing a centralized cooperative network employing hard combination at the fusion centre using traditional energy detection at every SU node ,with a, centralized cooperative network also employing hard combination at the fusion centre but using an improved version of energy detection at every SU node for local sensing.

A. System Model

The spectrum sensing problem is modelled in the form of a binary hypothesis represented as :

$$y(k) = \begin{cases} n(k) & : \quad H0 \\ n(k) + p(k) & : \quad H1 \end{cases}$$

Here y (k) represents the detected signal, n (k) represents noise and p (k) refers to the PU signal and H1 and H0 represent the presence and absence of the PU, respectively.

In the practical scenario, it is possible that at any sensing instant, there is a sudden drop in the received signal energy due to the environmental conditions (such as the introduction of a sudden noisy burst) and in such a case, because of low received signal energy, the traditional energy detector would assume the PU to be absent even if it is present in reality. Thus the adopted improvisation in energy detection avoids misdetections due to the instantaneous energy drops, rendering a better detection performance.

B. Test Statistics

Unlike traditional energy detection, the optimized energy detection involves three test statistics instead of one. At any sensing instant ‘i’, the first test statistic (Ei(y)) is the measured received signal energy observed over an observation interval and the second statistic is the average instantaneous energy for past 'M' sensing instants . For any sensing instant ‘i’ the instantaneous energy of the immediate past sensing instant i.e. (i-1)th instant is also calculated if the need arises. The following equations give the mathematical expressions for the test statistics

$$E\mathbf{i}(y) = \frac{1}{L}\Sigma\,|y(k)|^2 \qquad \text{for } k=0\ldots(L-1)$$

$$Eavg = \frac{1}{M}\Sigma\,E\mathbf{j} \qquad \text{where } j = (i-M)\ldots..i$$

C. Design And Performance Parameters

The design parameters of an energy detector are the characteristics that are input to its design process. In practice, the energy detector is designed for a target probability of false alarm which sets the decision threshold. The target probability of false alarm and the threshold modify for the enhanced energy detection .Considering the target probability of false alarm for traditional energy detector as Pf trd , the target false alarm probability for the improved energy detection can be approximated by the following relation

$$\mathbf{Pf}\ \ en = 2\,Pf\,trd - (Pf\,trd)^2$$

The corresponding threshold becomes

$$\boldsymbol{\lambda}\,en = \sigma^2\left[\sqrt{\frac{2}{N}}\,Q^{-1}(\,\mathbf{Pf}\,en) + 1\right]$$

The probability of detection represents the detection capability of a detector and hence it becomes the primary performance parameter. The probability of detection for enhanced energy detector is given mathematically in terms of detection probability for the traditional energy detector(Pd) as

$\mathbf{Pd}\ en = Pd+\{(1- Pd).(Q[(\boldsymbol{\lambda}\ en - \mu\ avg)/ \sigma\ avg]).(Pd\ )\}$

where μ avg and σ avg are average mean and variance of Eavg.

Algorithm for optimized energy detection

```
Input :  y(k), L
Output: H0 or H1
Design parameters: Pf , $\lambda$
Performance metric: Pd
 At every sensing instant 'i'
do
compute  $\mathbf{E_i}$
compute  $\mathbf{E_{avg}}$
 if
    $\mathbf{E_i} > \boldsymbol{\lambda}$
     Decide H1
  Else
        If
          $\mathbf{E_{avg}} > \boldsymbol{\lambda}$ then
             If
                 $\mathbf{E_{(i-1)}} > \boldsymbol{\lambda}$ then
          Decide H1
Else
          Decide H0
End if
End if
End if
```

III. SIMULATION RESULTS AND DISCUSSION

We consider a homogeneous cooperative spectrum sensing for a centralized network consisting of a cognitive base station (fusion centre) and a number of nodes collaborating in a non fading (AWGN) environment with perfect reporting and sensing channels. The network assumed employs the optimized energy detection described in section II, at every node, for local sensing and adopts hard combination for information fusion at the fusion centre. The simulations are done in MATLAB version R2013a for SNR= -14 db, L=1000 and 20 SU nodes. Fig 1. depicts the transmitted PU signal, channel noise and the received PU signal by all the energy detectors belonging to the network. It is assumed that the transmitted PU signal and the channel noise are independent random normal variables and thus their addition (which is the received PU signal at every node) is also a random normal variable.

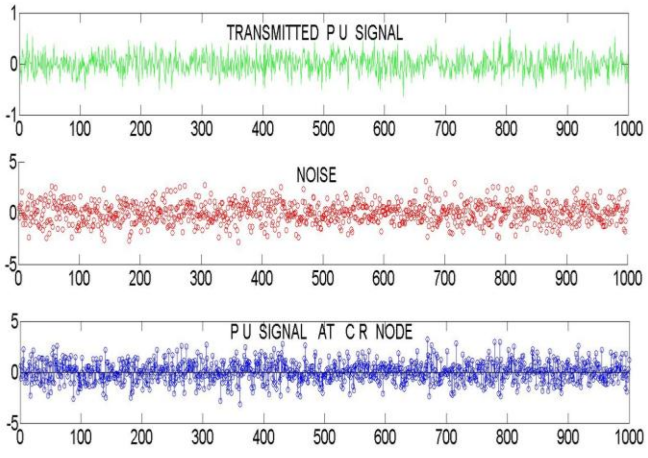

Fig1. Signal waveform for transmitted PU signal, Noise, Received PU Signal

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Fig 2. illustrates the simulation performance comparison for the traditional and the optimized energy detector. It is evident from the performance analysis that at any given value of the false alarm probability, the enhanced energy detector provides higher probability of detection as compared to the traditional energy detector. Thus if each SU node employs the optimized energy detection algorithm better local sensing results can be obtained. Fig 3. depicts the effects of improvised local sensing on the hard combination rules viz. AND , OR and MAJORITY rule through the respective ROC plots. The implications of analysing Fig 3., reassert the fact that OR rule outperforms the MAJORITY and AND rules for an AWGN environment [4] . It is also clearly evident that the hard combination preceded by local sensing done through the optimized energy detector at the SU nodes, provides better performance than hard combination preceded by local sensing done through the conventional energy detector.

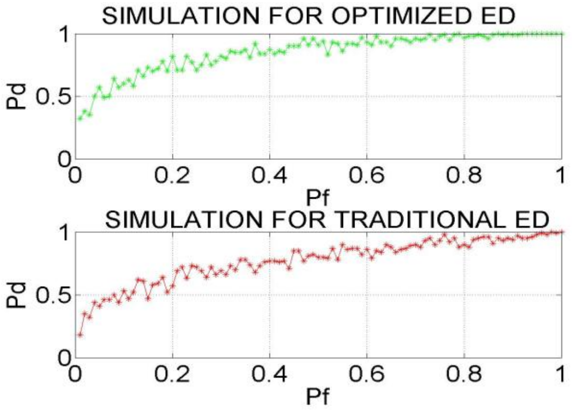

Fig2. Simulation for traditional and optimized energy detection

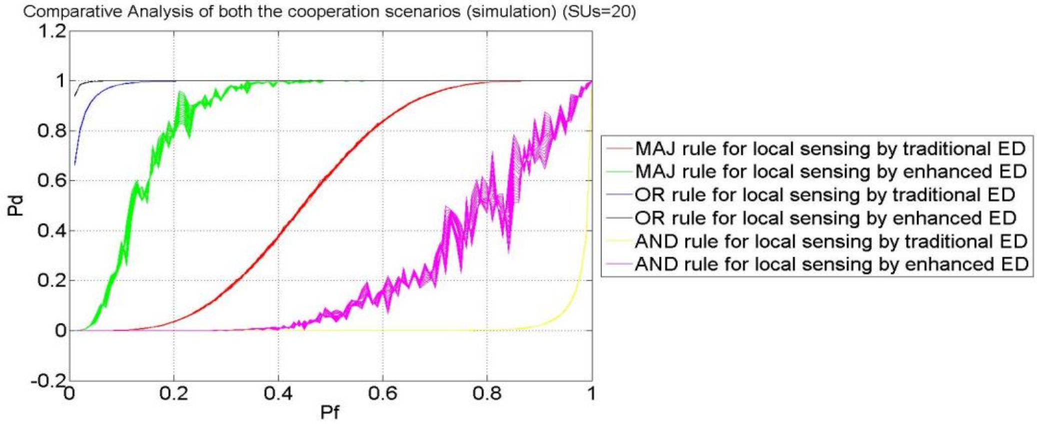

Fig3 ROC Curve for hard combination for cooperative sensing using traditional and optimized ED based local sensing

IV. CONCLUSION

In this paper, the effects of quality improvement in local sensing on the overall gain of a homogeneous centralized cooperative spectrum sensing scenario have been investigated. The proposed scheme adopting optimized energy detection at every node , provides enhancement in sensing gain without much increase in algorithmic and implementation complexity .

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