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# A Fuzzy Approach to Decision Fusion in Cognitive Radio

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**Abstract**

Spectrum sensing is an important task to be carried out by a cognitive radio (CR) to locate the spectrum holes. Distributed spectrum sensing is one of the solutions to overcome the issues generated due to fading and shadowing. In this paper we propose a fuzzy based fusion rule which consider received energy and SNR of the neighboring nodes along with its own parameters to make a decision. We have used a simulation setup that models data transmission through a Rayleigh channel with AWGN. Spectrum sensing is done through energy detection. Performance of proposed fusion rule is analyzed at varying values of SNR and it is compared with fusion rules such as 'AND' and 'OR'. Fuzzy rule has shown a better performance under probability of detection and probability false alarm. But the time consumption is slightly high for the proposed method.


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*Keywords:*Cognitive Radio; Fuzzy Logic; Distributed Sensing;

## 1. Introduction

Dynamic spectrum sharing will be an essential spectrum usage policy, if we intend to add new services and

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technologies in the wireless communication scenario. At present most of the available spectrum is licensed to primary users(PU). Considering the spectrum utilization at various frequency bands, there is an opportunity to reuse the unused spectrum for the future uses. Current research is investigating different techniques of using cognitive radio (CR) to reuse locally unused spectrum to increase the total system capacity. Various methods are proposed in the literatures to sense the spectrum occupancy status of Pus. The biggest challenge related to spectrum sensing is in developing sensing techniques which are able to detect very weak primary user signals while being sufficiently fast and low cost to implement [1, 2].

Result of spectrum sensing by CRs may get affected by the low SNR at the receiver. Usually CRs operate at low power. Also the receivers may under shadowing or fading. This may lead to a wrong decision making and the CR may likely to create interference to PUs. Cooperative sensing is the approach proposed for solving such an issue. In this case CRs tries to share their sensing result with other CRs and each CR will take its decision as an aggregate of all the sensing result by an individual node.It is assumed that all the CRs will communicate its sensing result as one bit information so that the communication overhead is reduced. Each node will use a fusion rule to combine the spectrum sensing results from neighbouring nodes. This will help a CR under shadowing to make a right decision from the results of its neighbours. If more number of neighbours are under shadowing or fading, it may lead to a wrong decision also. Under these circumstances performance of a fusion rule has its importance.

Many scenarios and fusion rules are proposed in the literature. Most of the fusion rules perform well under good SNR conditions and their performance deteriorate with poor SNR. Hard fusion rules and soft fusion rules are used according to the number of sharing nodes under consideration. In this paper we propose a fuzzy based fusion rule to make a decision based on the inputs from its neighbors and its own sensing result. Main contribution of this work is that it considers the SNR level of each neighboring nodes along with a two bit spectrum sensing result. Hence there will be prominence to results of neighbors with god SNR.

The remainder of this paper is as follows. In Section 2, we briefly discuss related works in the area of spectrum sensing and fusion rules. In section 3 we present the system model for the proposed fuzzy fusion rule and the spectrum sensing through energy detection. The simulation set up and performance comparison of proposed rule with existing fusion rules are presented in Section 4. Finally Section 5 concludes.

## 2. Related Works

Cooperation is proposed in literatures to overcome the problems of fading and shadowing. Centralized sensing, distributed sensing and external sensing are the methods proposed for cooperative decision making. In all these cases decision from the single CRs or the sensors are collected and the final decision is arrived at through a fusion rule. OR, AND andK-out-of-M are some of thefusion rules used for Decision making. Equal Gain Combining and Weighted Combining are used for decision making.Square Law Combining (SLC),Maximum Ratio Combining (MRC),Selection Combining (SC) are some of the approaches proposed in [3,4] for selecting/combining the energy level of individual nodes so that it can be compared with a threshold to obtain the decision. A weighted combining fusion rule whose weights are decided based on neighbors' distance from the decision making node is proposed in [5]. They have provided its analysis on the number of neighboring nodes to be considered for decision making. Another weighted combining rule for distributed sensing, whose weights are proportional to the SNR of the respective neighbor is proposed in [6]. They have used the received signal strength (RSS) as equivalent to energy of the received signal in the simulation setup and the threshold used for energy detection is the noise Floor. In the above two cases single nodes will broadcast one bit information about its spectrum sensing to its neighbors and each node will use the same fusion rule to arrive at a decision. A Cellular automata based approach is proposed in [7] for data fusion at the central node for an external sensing scenario. A genetic algorithm-based weighted optimization strategy is also proposed for soft decision combining[8]. A fuzzy based approach is presented in [9] where they consider only the energy of the received signal as the quantity considered for data fusion.In our approach we have included the SNR of each node in the information fusion process. This will reduce the influence of neighbors under fading or shadowing, in the decision making process.

## 3. System Model

In this work we have considered a CR network consisting of one PU and more number of CR terminals. We assume that the PU is operating only on a particular channel and the CR terminals are trying to sense the spectrum hole in that channel. They share their sensing result among themselves and each node will make use of the fusion rule to make a final spectrum decision. We have considered that data from PU is BPSK modulated and transmitted over a channel where it gets affected by white Gaussian noise and Rayleigh fading. CR terminals act as the receiver where it checks the energy of the signal in the specified band. Energy detection method used to detect the received signal at the receiver end is shown in fig 1[10]. It is a non-coherent detection method that detects the primary signal based on the sensed energy. Due to its simplicity and no requirement on a priori knowledge of primary user signal, energy detection (ED) is the most popular sensing technique.

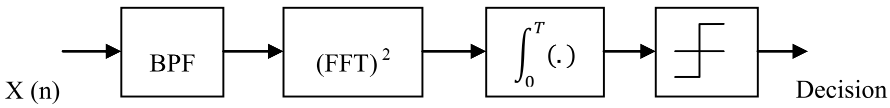


Fig.1 Energy Detector

In order to measure the energy of the received signal the output of band pass filter with bandwidth W is squared and integrated over the observation interval T. Finally the output of the integrator is compared with a threshold to detect weather the primary or licensed user is present or not. It can also be computed in frequency domain by averaging bins of a Fast Fourier Transform. In this the processing gain is proportional to FFT size N and the averaging time T. Increase in the size of FFT improves the frequency resolution which is helpful in detecting narrowband signals. Also if we reduce the averaging time it improves the SNR by reducing the noise power. It estimates the presence of the signal by comparing the energy received with a known threshold derived from the statistics of the noise.

### *3.1. Proposed Method*

Spectrum sensing part in Cognitive Radio Systems identifies the presence of the PU. A geographical area consisting of a single PU and a random number of CR terminals are considered. It is assumed that all the CR terminals are within the acceptable range from the primary user. In cooperative spectrum sensing, data from a few CR terminals are used in the final decision making process.Here in the first phase each node gives a decision on the spectrum status as Low, Medium or High. In the second phase it performs the cooperative sensing by taking the decision from neighboring nodes also. In the data fusion process for decision making, fuzzy logic is employed. Main contribution of this method is it considers the SNR at each receiver also in making a decision. Each CR terminal continuously observes the power of the signal being transmitted within a specific bandwidth and records data on the SNR value as well. For a CR to make a decision, it considers its own data on power and SNR, and power from two of the nearest neighbors. Thus a total of four inputs are considered for decision making. Model of a fuzzy fusion center is shown in fig. 2.For fuzzification of power and SNR, three membership functions are defined for both parameters. The membership functions represent three levels, LOW, MEDIUM and HIGH as shown in fig. 3. These levels are defined based on data analysis signal power and SNR, which had been made prior to simulation. However, the output is a binary parameter which denotes the presence of the PU by '1' and the absence of the PU by '0'.

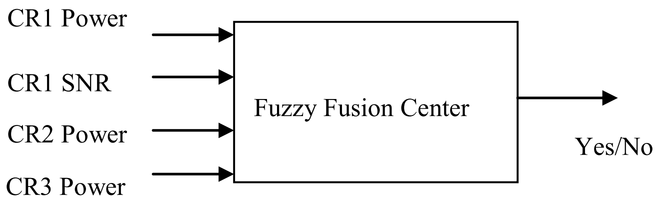


Fig.2 Fuzzy Fusion Center

The fuzzy rule base contains of IF THEN clauses which is designed in such a way that the node's own decision will get more importance than its neighbours'. For example, if the CR terminal detects high power and high SNR, then the output is 1 regardless of the data on power that has been collected from the neighbours. The rule base is defined for all the possible combination of inputs. With four inputs and three possible levels for each input, there are 81 possible combinations. A part of the rule base is shown in table -1.

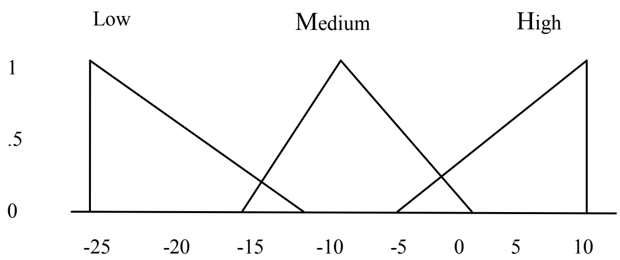


Fig.3 Membership Function [SNR]

Table 1. Fuzzy rule base

| Power CR-1 | SNR CR-1 | Power CR-2 | Power CR-3 | Output |
|---|---|---|---|---|
| Low | Low | Low | Low | No |
| Low | Low | Medium | High | No |
| Medium | Low | Medium | Low | No |
| Medium | High | High | High | Yes |
| High | Medium | Low | Medium | Yes |
| High | High | High | High | Yes |

## 4. Simulation Results

We have considered that a PU located at the center of area under consideration and 25-50 CR terminals are positioned randomly around the PU. One of the CR terminals is selected randomly and the power and SNR of that CR terminal are recorded. The powers received by the neighboring two CR terminals which lie nearest to the selected terminal are fetched by the selected CR. The four parameters, power and SNR of CR1, power of CR2 and power of CR3 are the input parameters for the fuzzy based decision making stage. For simulation we have considered similar SNR for all the nodes which are located nearby. Here each node will calculate the energy of the received signal and based on the two threshold values it decides on the output as Low, Medium, or High. This information is passed on to neighboring nodes as two bit information. Each node will take the result of two neighboring nodes, own decision and SNRto make final decision. Performance of this decision fusion method is evaluated at various SNR values and it is compared with OR- Rule, AND-Rule and single node decision.

False detection refers to the situation in which the spectrum is free (PU is not using the spectrum) but the decision made by the system indicates that the spectrum is in use by the PU. The probability of false detection was computed by running the program 100 times and counting the number of times the PU was falsely detected when it was not using the spectrum. In order to use 'AND rule' and 'OR rule' the two bit decision is converted into single bit decision by setting 'Low' as not sensed and others as sensed. Performance comparison on probability of false detection is shown in fig. 4.

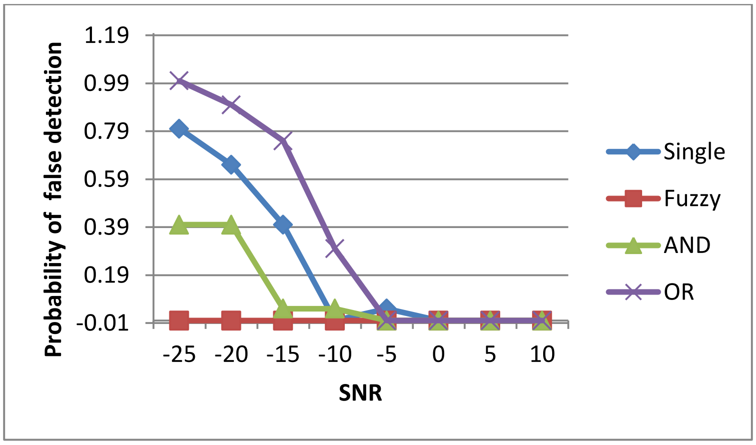


Fig.4 Probability of False Detection

The probability of false detection was observed for SNR values between -25 and 10, and the fuzzy based system returned the probability of fault detection as 0 in the given range of SNRs, which is ideal. It is found that at lower SNRs also our proposed method is giving a good result. Above results are obtained based on fixed threshold pairs for all the cases. Change in thresholds might give a change in the result. Our thresholds are chosen based on the average range of energy level received at the receiver.

Successful detection refers to the situation in which the spectrum is being used by the PU and the decision made by the CR is correct, indicating that the spectrum is in use by the PU. The probability of detection was computed the same way as that of probability of false detection and the same thresholds are been used. Performance comparison is presented in fig. 5.Even though the detection rate depends on the Rayleigh channel parameters used and the filtering

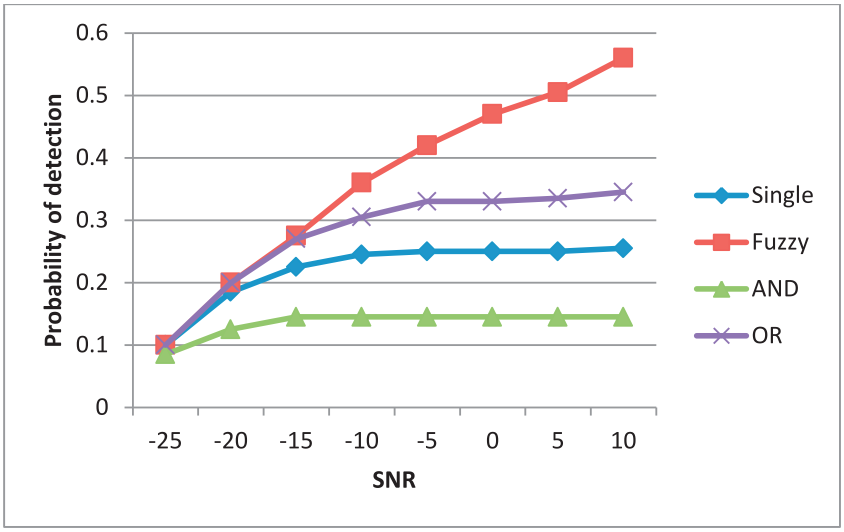


Fig.5 Probability of detection

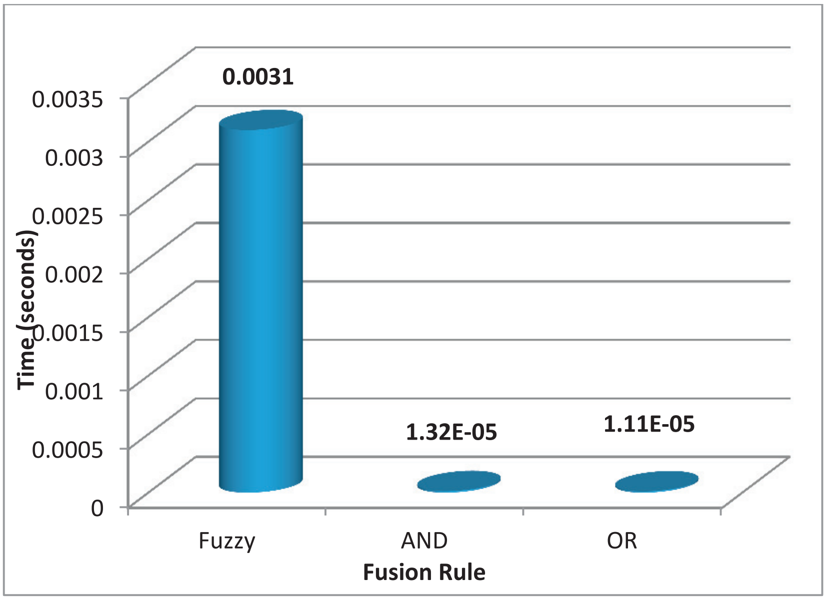


Fig.6 Time taken to perform decision fusion

process, relative performance of fuzzy based method is giving a better detection rate. In both the cases the performance of our proposed fuzzy based approach is better. Conversion of two bit decision to one bit decision for the implementation of 'AND rule' and 'OR rule' are suppose to help either probability of false detection or probability of detection. And it is seen that the proposed fuzzy based approach is giving a better result compared to other cases. This is because of the fuzzy nature in the decision making that gives a favorable outcome. Effect of SNR is also contributed in giving a better result. Overall performance can be even improved with the choice of an optimum threshold. A comparison on the time taken for data fusion is analyzed in fig.6. It shows that the performance of fuzzy rule consumes more time compared to other rules. This is because of the size of the rule base, which is to be evaluated for tacking a decision.

## 5. Conclusion

We have proposed a modified fuzzy approach for decision making in co-operative sensing. We have done a simulation set up to model and AWGN channel with Rayleigh fading. BPSK modulated bit stream is transmitted through the channel and at the receiver energy detector is used to sense the status of the spectrum. We have included the SNR of the receiver in making a decision fusion at the CR. It was found that the performance of our fuzzy based approach is giving a better performance compared to other methods considered. However, the system has its disadvantages. Due to its wide range of possibilities the computation time for a fuzzy decision is high compared to other systems. Furthermore, increase in number of inputs will increase the number of rule base exponentially, which is a cumbersome task to the system designer. As a future work, we can include more neighboring nodes in the decision making process. This will further increase the probability of detection. Also other weighing parameters such as distance can be included so that the inputs from far away nodes will have less effect on the decision making process.

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