Reliability factors based Fuzzy Logic Scheme for Spectrum Sensing

Tallataf Rasheed[1], Adnan Rashdi[2], Ahmad Naeem Akhtar[3]
[1]Department of Electrical Engineering, Government College University, Faisalabad Pakistan
[2,3]Department of Electrical Engineering, Millitary College of Signals, National University of Sciences and Technology (NUST)
Email: tlltfrshd@gmail.com[1], adnanrashdi@mcs.edu.pk[2], ahmadnaeem.akhtar@mcs.edu.pk[3]

***Abstract*—The accurate spectrum sensing is a fundamental requirement of dynamic spectrum access for deployment of Cognitive Radio Network (CRN). To acheive this requirement a Reliability factors based Fuzzy Logic (RFL) Scheme for Spectrum Sensing has been proposed in this paper. Cognitive Radio User (CRU) predicts the presence or absence of Primary User (PU) using energy detector and calculates the Reliability factors which are SNR of sensing node, threshold of energy detector and decision difference of each node with other nodes in a cooperative spectrum sensing environment. Then the decision of energy detector is combined with Reliability factors of sensing node using Fuzzy Logic. These Reliability Factors used in RFL Scheme describes the reliability of decision made by a CRU to improve the local spectrum sensing. This novel Fuzzy combining scheme provides the accuracy of decision made by sensor node. The simulation results have shown that the proposed technique provide better PU detection probability than existing Spectrum Sensing Techniques.**

***Index Terms*—Cognitive Radio, Spectrum Sensing, Energy Detector, Reliability Factors, Fuzzy Logic**

I. Introduction

Recent studies have shown that the radio spectrum is vastly under utilised due to static radio spectrum access policies. Whereas the demand for radio spectrum users increases proportionally to get benefit from advance wireless communication systems. The FCC's Spectrum Policy Task force has conducted the measurements and found that about 70 percent of licensed spectrum remain unutilised for a significant time in a day [1]. This have arisen to Opportunistic Spectrum Access (OSA) approach.

The basic task of OSA is to enhance the radio spectrum usability with Cognitive Radio Systems (CRS). The CRS has emerged as an advanced wireless technology to overcome the spectrum scarcity. Cognitive Radio is an advance wireless technology which sense its environment and adaptively change its mode of operation in order to enhance the service quality for CRU, without causing an interference with PUs [2]. The white spaces called unallocated portion of Spectrum can be accessed by the CRUs [3]. Therefore a CRU only finds the white spaces in radio spectrum by the process called Spectrum Sensing. Thus Spectrum Sensing is a process used by the Cognitive Radio to find the unutilised portion of the Radio Spectrum.

The most commonly used Local Spectrum Sensing Technique (LSST) is Transmitter Detection which further includes Coherent Detection and non Coherent Detection. Energy detection is a non coherent detection while Cyclostationary Feature Detection and Matched Filter detection are some commonly used types of Coherent Detection [4]. The basic key points for the appropriate selection of spectrum sensing Technique are speed of estimation, accuracy and complexity. Matched Filter and Cyclostationary Feature Detection are more accurate as they use priori knowledge of the signal for decision making and thus are more complexed as well. The less complex and more practical technique among them is Energy detection which requires no priori knowledge of the received signal. The local sensing is always unreliable under fading environment. So a Cooperative Spectrum Sensing is proposed in which different CRUs combine their local sensing decisions commonly by OR and AND combining methods in order to mitigate the effect of uncertainties [5]. The different Cooperative Sensing combining techniques are discussed in [6] which describes the Equal Gain Combining (EGC) and Maximal Ratio Combining (MRC). In [7] cluster based spectrum sensing approach is discussed which shows the advantage of reduction in reporting channels for cooperation and there by decreasing the multi path fading effects.

The vagueness of real world can be modeled by the Fuzzy Logic. It has been used to resolve many wireless communication problems since 1990. The improvement in local spectrum sensing is described in [8] by combining different Spectrum Sensing Techniques with Fuzzy Logic. A cooperative Spectrum sensing Technique based on Trust is described in [9] using Fuzzy Logic for Cognitive Radio Network (CRN). Fuzzy logic based OSA in CRN is discussed in [2]. These two approaches improve the detection probabilities at the cost of overhead which can be reduced by an accurate LSST [8].

An improved detection probabilities of Local Spectrum Sensing have been shown in this paper with proposed RFL Scheme. The energy detector is used as a LSST. The Reliability factors basically consists of SNR of sensing node, difference of single user sensing with other nodes and threshold used in Energy Detector for spectrum sensing. All these parameters are combined with Local sensing decision using Fuzzy Logic to get more reliable decision about presence or absence of PU. The effect of SNR, threshold of Energy Detector and their combined effect with P_d of single CRU have been shown by simulation on detection probability of a CRU. Finally a comparative analysis has been carried out between existing spectrum sensing techniques and our proposed technique.

This paper is organised in different sections. Related study of spectrum sensing is given in section II. The Energy Detector and Fuzzy Logic have been explained in section III and IV respectively. The Proposed Spectrum Sensing Methodology is presented in section V. The simulations analysis is carries out in section VI. The section VII presents the conclusion of the paper.

II. Related Study

Spectrum Sensing plays an important role in OSA to efficiently use the Radio Spectrum without causing an interference with a PU. There are many spectrum sensing techniques among which Transmitter Detection is mostly used which further includes Energy Detection, Matched Filter Detection and Cyclostationary Feature Detection.

An energy detector estimates the power of received PU signal and then compare it to predefined threshold value to make decision about the availability of spectrum. It cannot differentiate the noise and signal power so under low SNR it exhibit high P_{fa}. An optimal linear filter which maximizes the SNR is called Matched Filer. The sensing results through Matched Filter are taken by convolving the PU signal with time reversed version of already known signal. Then its output is compared with threshold to predict the presence or absence of PU. So a priori knowledge of received signal is required which also need dedicated receiver. Thus it is very complex technique but provide good results than Energy Detector. Commonly the communication signals have characterized patterns called cyclostationary features. In Cyclostationary Detection it exploits those periodic features by autocorrelation and mean of received PU signal and detects the spare spectrum. These features are estimated by Cyclic Autocorrelation Function. Cyclostationary Detection is suggested as more suitable Spectrum Sensing technique than Energy Detector and Matched Filter Detection but it also requires priori knowledge about signal thus more complex than Energy Detector [8].

The local spectrum sensing results are not much reliable due to fading environment . Therefore, cooperative spectrum sensing is used to avoid any wrong decision about presence or absence of PU. Cooperative Spectrum Sensing has two stages; sensing and reporting. A CRU makes its local decision in sensing stage and forward that to Fusion Center where final decision has been made using different rules, some of which have been explained in [6].

A Cluster based cooperative sensing is proposed as a bandwidth and energy efficient scheme. The number of reporting channels to the fusion center are reduced in it which results in less usage of radio spectrum. Thus it reduce the capacity as well as improves the detection performance [10]. The proposed RFL scheme is this paper gives much better results than cluster based sensing too, which have been shown by simulations.

III. Energy Detector

An energy detection is favourable in an environment when power of random AWGN is available to the CRU [11]. The energy detector is less complex and simple to implement [12]. To find the power of received signal is an elementary approach of Energy Detector. It calculates the power of received signal and compare it with the threshold set to make decision about presence or absence of PU. If energy of signal is greater than the threshold, It means PU is present otherwise spectrum is spare [13]. It works on following two hypothesis by [7].

$$x(t) = n(t) \quad H_0\ defining\ signal\ is\ absent \tag{1}$$

$$x(t) = s(t) + n(t) \quad H_1\ defining\ signal\ is\ present \tag{2}$$

where $s(t)$ source signal, $x(t)$ is received signal, and $n(t)$ is an AWGN. The energy of the signal (γ) is compared with threshold (τ) values as,

$$\gamma < \tau \quad for\ H_0\ signal\ is\ absent \tag{3}$$

$$\gamma > \tau \quad for\ H_1\ signal\ is\ present \tag{4}$$

The approximated formulae of P_d, P_{fa} and P_{md} can be given by [14].

$$P_{fa} = \Gamma(N, \tau/2)/\Gamma(u) \tag{5}$$

$$P_d = Q(\sqrt{2\delta}, \sqrt{\tau}) \tag{6}$$

where the δ represent the SNR, time bandwidth product is given by u, Γ (.,.) and Γ (.) are incomplete and complete gamma functions respectively. A rayleigh fading channel is more practical other than AWGN as different kinds of noises added in a signal during its path [15]. Thus Energy Detector is implemented in Rayleigh channel also to provide a more realistic environment. The average SNR δa is considered here instead of δ because of different transmission paths. The P_d is given by [14].

$$P_d = \exp^{-(\tau/2)} \sum_{k=0}^{u-2} \frac{1}{k!}(\frac{\tau}{2})^k + (\frac{1+\delta a}{\delta a})^{u-1} \\ (\exp^{-(\tau/2(1+\delta a))} - \exp^{-(\tau/2)} \sum_{k=0}^{u-2} \frac{1}{k!}(\frac{\tau \delta a}{2(1+\delta a)}) \tag{7}$$

Other Spectrum Sensing techniques provide better results than Energy Detector. A matched Filter maximizes the SNR and provide high processing gain [16] whereas Cyclostationary Feature Detection unlike Energy Detection can distinguish between noise and PU's signal [17]. But both of them require priori knowledge about received signal and dedicated receivers for every incoming signal [18]. A conventional energy detection method is used with the proposed technique to provide more practical and less complex approach for Spectrum Sensing.

IV. Fuzzy Logic

The first introduction of Fuzzy Logic from extended binary logic was given by L.A. Zadeh in [19]. It is used to model the vagueness of real world with approximate reasoning rather than exact values. The linguistic variables are used which handles the partial truth concept in it. The decision making process of Fuzzy logic can be described by following 3 steps.

1. Fuzzification: The binary Logic comprises of only two possibilities i.e. 0 and 1 whereas Fuzzy Logic consists of linguistic variables which shows as much possibilities as required to explain the inputs. In this step crisp values are converted into linguistic variables.

2. Inference Engine: The linguistic variables made in fuzzification are fed into the inference engine to apply the predefined rule base. That rule base consists of different IF-THEN rule clauses according to the requirement. The output of Fuzzy numbers is found which are the composition of IF-THEN clauses.

3. Defuzzification: The output carried out from Fuzzy Inference Engine is now converted into crisp values again which is the actual output of the system.

The above steps are described by mathematics in [20]. In CRS Fuzzy Logic is now being used into Radio Resource Management as congestion control, scheduling, radio access technology selection and power control [21]. Fuzzy Logic combine the merits of two different schemes to provide better handoff in radio and optical wireless communications system [22].

V. Proposed Spectrum Sensing Methodology

The combination of reliability factors with local sensing decision using fuzzy logic in RFL scheme is proposed for spectrum sensing. The whole process is described by a flow chart shown in Figure. 1.

The reliability factors which include the SNR of sensing node, difference of single sensing node decision with combined decision of all other nodes and threshold of Energy Detector. The SNR of sensing node is taken because wireless channels are always prone to errors due to shadowing [23]. Therefore it is calculated to check the reliability of the channel of received signal. Thus the SNR will actually tell about the channel condition of the j^{th} CRU as given in [24].

$$C_j = \delta_j \ (j = 1, 2, .., i) \tag{8}$$

The difference between the decision statistic of a single CRU and combined decision of all other CRUs is calculated to check the accuracy of decision made by a single CRU. The lesser the difference, the more accurate will be the decision of a sensing node. The local Decision statistic of a single CRU is given by Z_j(j=1,2,..,i). The local sensing difference of j^{th} CRU is given in [24].

$$D_j = |Z_j - 1/i \sum_{k=1}^{i} Z_k \ (j = 1, 2, .., i) \tag{9}$$

The selection of an appropriate threshold is very important in decision making by the Energy Detector. The weak signals with low SNR can be detected using lower values of the threshold. So lower the value of threshold, more reliable will be the results of an Energy Detector at lower SNR and provide high detection probability. The value of threshold is given by (5). All the above factors are standardized to get their consistent dimensions by [24].

$$\delta_j = (\delta_{max} - \delta_j)/(\delta_{max} - \delta_{min}) \tag{10}$$

$$D_j = (D_{max} - D_j)/(D_{max} - D_{min}) \tag{11}$$

$$\tau_j = (\tau_{max} - \tau_j)/(\tau_{max} - \tau_{min}) \tag{12}$$

where δ_{max} and δ_{min} are maximum and minimum values of SNR respectively, and the others are similar. The reliability factors are combined with the P_d of Local Sensing using Fuzzy Logic. It will provide improved detection probability than all other existing techniques of Spectrum Sensing with reduction in miss detections. All the parameters are fed as an input to the Fuzzy Logic with their membership functions in RFL scheme as,

- Antecedent 1: SNR with 3 membership functions poor, good, excellent in Figure.
- Antecedent 2: Difference with 3 membership functions low, moderate, high in Figure.
- Antecedent 3: Threshold with 2 membership functions low, high in Figure.
- Antecedent 4: P_d of Energy Detector with 3 membership functions low, medium, high in Figure.

Then final output of fuzzy logic will be the Probability of detection of our proposed scheme with 6 different membership functions which are defined as worst, very bad, bad, good, very good and best.

Table 1: Rule Base of Stage 2 for Fuzzy Combining

SNR	Difference	Threshold	P_d	output
poor	high	high	low	worst
poor	high	low	low	very bad
good	medium	high	low	bad
poor	high	low	medium	good
good	medium	low	high	very good
excellent	low	low	high	best

Table 1 describes the rule base of fuzzy logic. The sensing node with poor SNR will have chances to make wrong decision due to fading environment. Thus, the decision difference of low SNR node will be high. If the value of threshold of energy detector will be high it means its detection probability is low. By combining all these facts, the first rule base is made which shows that if SNR of sensing node is poor, difference is high, threshold is high, P_d of Energy Detector is low then the probability of presence of PU is worst. Similarly the all other rows explain the rule bases. This methodology provides better detection probability of a CRU with reliable results than existing spectrum sensing techniques. In our system model we make a local sensing decision using Energy Detector then comobine that decision probability with reliability factors using fuzzy logic in RFL scheme to get better and reliable detection probability.

VI. Simulations Analysis

The simulations of the proposed RFL scheme will be shown in this section. The performance analysis of Spectrum Sensing Techniques is based on Probability of Detection P_d, Probability of False alarm P_{fa} and Probability of miss detection P_{md}. To find the presence of PU at times when it is actually using the Spectrum is called P_d whereas P_{fa} is the false declaration of presence of PU in the spare band and P_{md} is declaring the absence of PU at the time of spectrum occupancy by it. The P_{fa} causes under utilization of spectrum while P_{md} lead to the interference with PU. Thus a CRU should exhibit both of theses probabilities as low as possible [25]. First of all the dependency of reliability of sensor node on all of its factors is shown. If SNR of sensing node increases then its decision reliability increases too which is shown in Figure. 2. It means that sensor nodes with higher SNR give more reliable decisions about presence or absence of PU.

The decision reliability of a sensing CRU is dependent on value of predefined threshold for Energy Detector. As the value of threshold increases, the detection reliability of CRU decreases because it cannot detect the weak signals at lower SNR with higher threshold. This is shown in Figure. 3.

The effect of decision reliability of RFL scheme on detection probability of sensor node is shown in Figure. 4. The higher the reliability of CRU, the more will be its detection probability.

Different Spectrum Sensing Techniques have been implemented to make a comparative analysis with our proposed scheme. The improved detection probability of the proposed RFL scheme is shown in Figure. 5.

Different Factors on which Probability of detection P_d is dependent are SNR, threshold and Probability of false alarm P_{fa}. When SNR of CRU increases, P_d increases too as shown in Figure. 6. Thus a signal can be easily detected by an Energy Detector at higher SNR. It is also shown that the RFL scheme provides better results of P_d at even lower SNR than all other existing spectrum sensing techniques.

Similarly decrease in P_d causes due to increase in threshold values because in this way a CRU only detect the strong signals with higher value of SNR. The effect of threshold on P_d and comparative analysis of existing Spectrum Sensing Techniques is shown in Figure. 7.

The comparison of the proposed RFL scheme with single node sensing, Cooperative spectrum sensing with different combining rules and cluster based spectrum sensing have been described. On the basis of different matrices e.g. improvement in P_d at very low SNR values and at high threshold is shown in RFL scheme. Hence it is proved by simulation analysis that RFL scheme will provide better detection probability, less false alarms and lower miss detections of a PU. Therefore a CRU can utilise the spectrum efficiently without causing an interference with PU which is a main objective of Spectrum Sensing in CRN.

VII. Conclusion and Future Work

In the literature different transmitter detection techniques are given for Spectrum Sensing. The detection probabilities over fading channels may also be improved by Cooperation among CRUs but it causes an additional overhead. So to provide better cooperation with lower overhead, the need to improve the local sensing has emerged. Thus new Reliability factors based Fuzzy Logic Scheme for Local Spectrum Sensing is proposed in this paper. An Energy Detector is used as a transmitter detection technique and its results have been improved by reliability factors using Fuzzy Logic. This scheme provide better results of different matrices for spectrum sensing. However, this scheme requires hardware implementation, though this hardware complexity can be sacrificed over an accurate prediction of detection probability with reduced false alarm and miss detections.

In this paper the Local Spectrum Sensing is improved. In future the researchers may find a way to use this scheme with Cooperative Spectrum Sensing, to further improve the results with low overhead because of an improved local sensing usage. The cluster based Sensing also improve the results with less bandwidth usage than Cooperative sensing by using improved local sensing scheme.

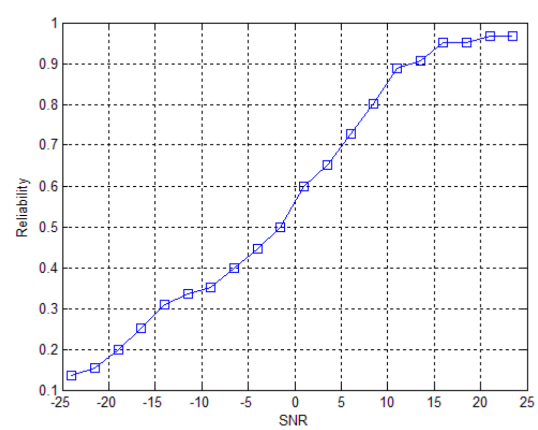

Fig. 2. Reliability of Sensing node with SNR

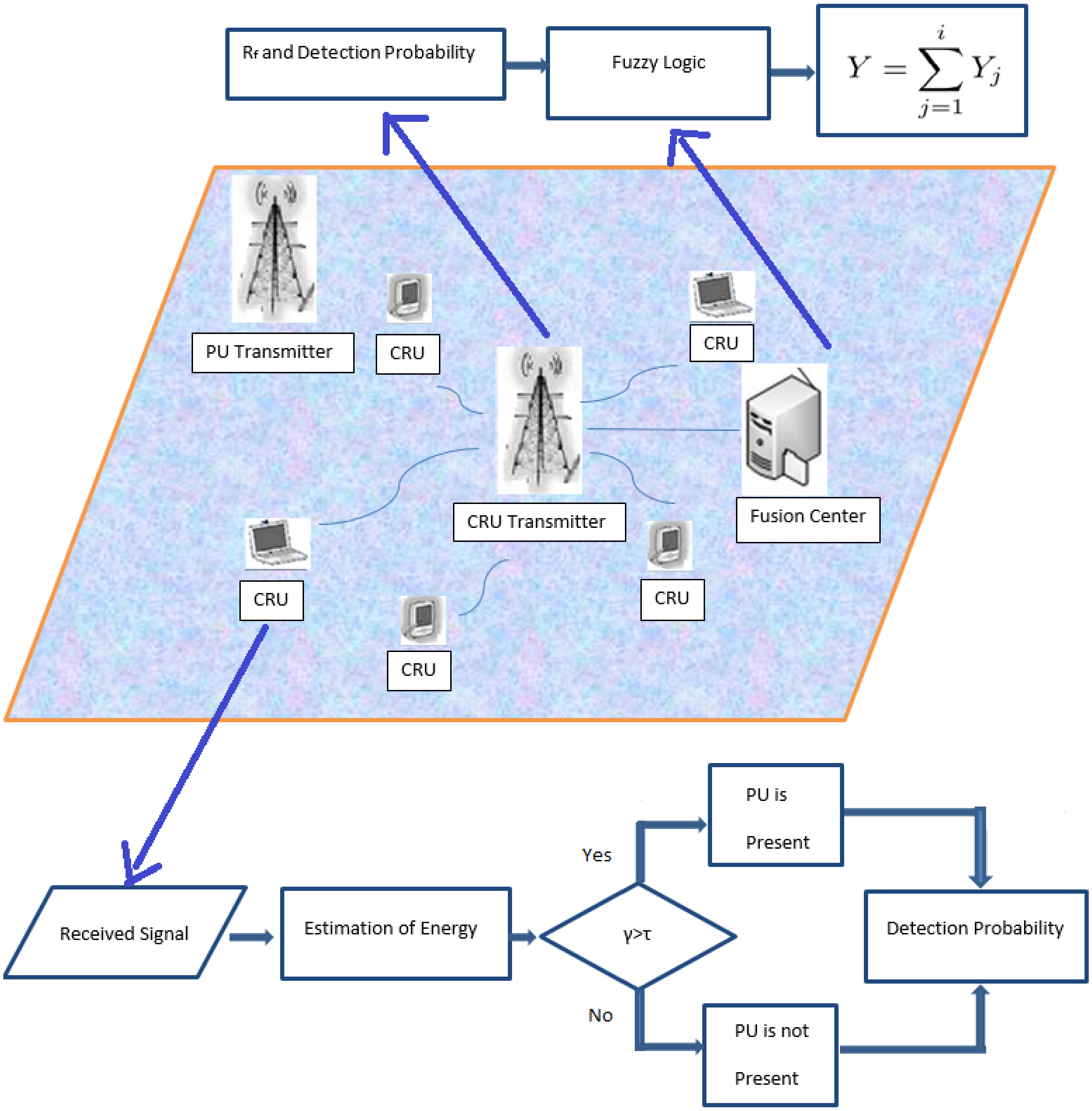

Fig. 1. Proposed RFL Scheme for Spectrum Sensing

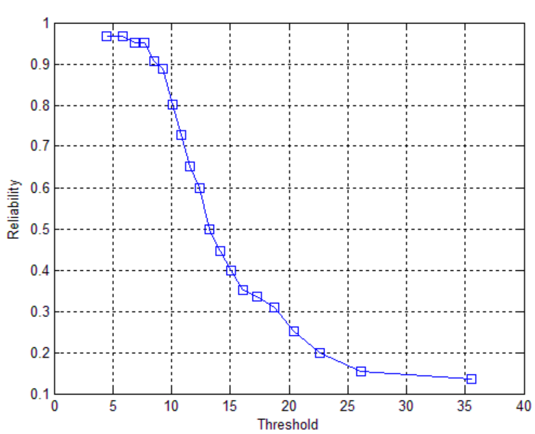

Fig. 3. Reliability of Sensing node with Threshold

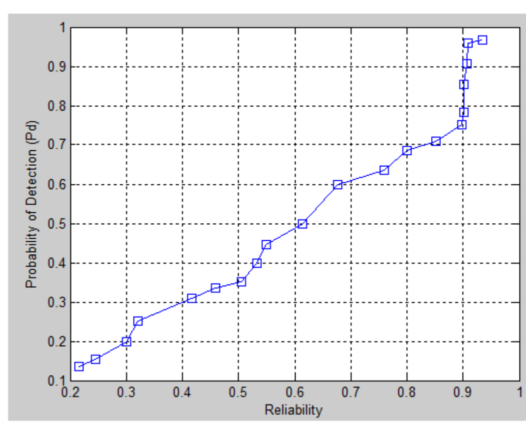

Fig. 4. P_d with Reliability of Sensing node

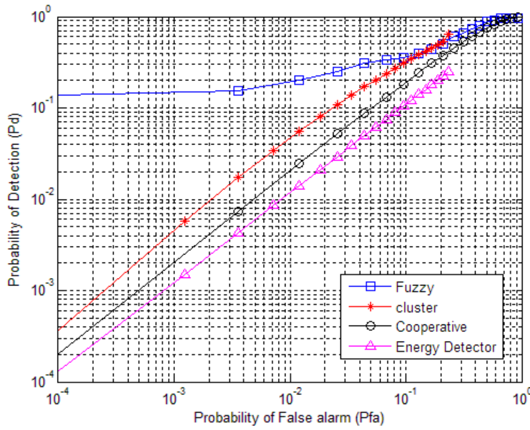

Fig. 5. Comparison of different Spectrum Sensing Techniques in terms of P_d and P_{fa}

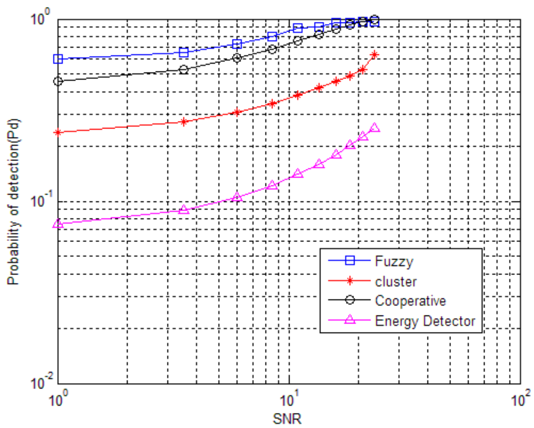

Fig. 6. P_d with SNR

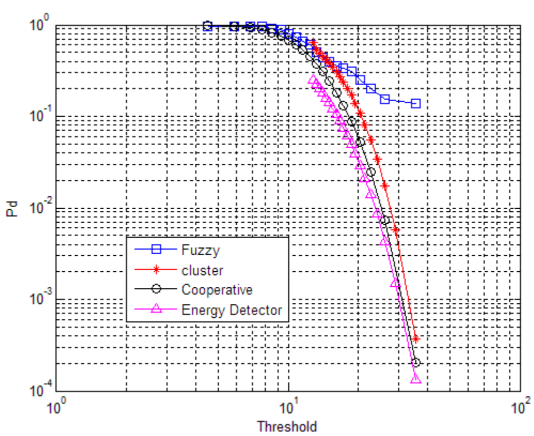

Fig. 7. P_d with Threshold

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