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Performance Analysis of Improved Threshold based Adaptive Spectrum Sensing in Cognitive Radio

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Abstract

Cognitive radio (CR) is a significant technology intended to resolve the spectrum scarcity problem. CR employs dynamic spectrum access in which the transceiver intelligently detects the channels in the radio spectrum. In order to optimize the spectrum usage, an interference free efficient spectrum sensing technique is essential in CR. The existing spectrum sensing techniques shows inferior performance at low SNR as the sensing threshold remains constant throughout the spectrum. Hence an improved sensing threshold based adaptive spectrum sensing is proposed to improve the detection probability of CR for all the SNR levels.

INTRODUCTION

The huge growth of wireless devices demands for wider frequency spectrum. Since most of the frequency bands are licensed one and it is allocated in a fixed manner. In the present scenario spectrum is underutilized which leads to lack of radio resources. Cognitive radio is the suitable candidate which provides the solution for spectrum scarcity problems. It senses the radio spectrum smartly and adapts its transceiver characteristics consequently. In CR environment, users who have the licensed spectrum are called as primary users (PU) and others are known as secondary users (SU). Secondary users can be able to access the primary user's spectrum when it is underutilized.

For the effective spectrum utilization, secondary users need to sense the spectrum periodically. The key functions of CR include spectrum sensing, spectrum mobility and spectrum sharing. Among the CR functions, spectrum sensing is a vital technology to enable sharing of spectrum in an efficient manner. The secondary users need to initiate the spectrum sensing to acquire the channel for its use. The SU has to monitor the availability of PU and adapt its characteristics. CR uses certain sensing methods such as Energy detection (ED) and Cooperative detection to detect the availability of PU signal.

Energy detection is the transmitter detection approach in which the received signal energy is measured over the interval 'T'. It is compared with the sensing threshold and the decision is taken for the presence or absence of PU. Since it is a non-cooperative detection, the decision analysis is carried for a single user. The main limitation of ED is that it is not able to distinguish the noise and PU signal. Further the sensing threshold for ED is calculated using fixed noise power. Owing to the fact that the noise uncertainty in ED leads to increase the false alarm and missed detection. However the wireless channel is a time varying in nature and the fixed detection threshold does not hold good for low SNR levels.

The detection performance may be deteriorated due to multipath fading, noise uncertainty and shadowing effects. Hence a cooperative spectrum sensing is an effective method to mitigate the impact of wireless channels. It enhances the spectrum detection performance as the SUs cooperate with each other in order to detect the spectrum holes. The detection threshold estimation for the above schemes based on fixed noise power which is inefficient under varying SNR levels. Hence an improved threshold based adaptive spectrum sensing is proposed in this paper to solve the noise uncertainty. The metrics considered for performance analysis of spectrum sensing techniques are probability of detection (Pd), probability of missed detection (Pmd) and probability of false alarm (Pf).

The threshold estimation carried out in this paper is adaptive and it is performed in two ways. In the first approach, threshold calculation is based on probability of false alarm which is fixed one. Most of the spectrum sensing techniques is based on constant Pf without considering the PU's safety. To increase the protection level of PU and reduce the interference from SU, the proposed threshold estimation is a function of probability of detection. Higher protection to PU can be achieved using high detection probability. Hence an improved threshold estimation based on Pd is considered here to improve the target detection. The simulation results show that the performance of the proposed method outperforms ED and Pf based cooperative spectrum sensing.

RELATED WORK

Energy detection is the signal detection mechanism used to specify the availability of signal in the spectrum. It is the widely used spectrum sensing method as it has reasonable computational complexities, and can be implementable in both time and frequency domain. However the ED [1] requires the prior knowledge of noise power to fix the threshold. The presence or absence of PU signal is detected by comparing the energy detector output with the threshold calculated based on the fixed noise floor.

This detection approach is relatively simple and suitable for realistic. To implement ED, only the noise variance information about the single user is required. The received signal energy is given by

$$E = \frac{1}{N}\sum_{n-1}^{N} | X(n) |^2 \qquad (1)$$

where 'N' denotes the number of samples.

The hypothesis model for ED is as follows: The SU received signal is given by

$$y(t) = \begin{cases} n(t) & H_0 \\ s(t) + n(t) & H_1 \end{cases} \qquad (2)$$

where s(t) is the PU signal and n(t) represents the additive white Gaussian noise (AWGN). The null hypothesis 'H_0' represents the absence of licensed user and 'H_1' represents presence of licensed user. However ED is not effective, since the design is simple it is the widely used sensing scheme in CR.

The cooperative spectrum sensing in CR collects [2]the sensing information from multiple CR users and applies certain fusion rules to detect the availability of PU in the network. The CR users share the sensing information with other users and the cumulative decision is taken. It reduces the false alarm rate since the decision is derived from multiple observations rather than individual opinion at every user. The cooperative sensing can be performed using distributed and centralized approach. Centralized sensing employs Fusion Centre (FC) for making decision which combines the sensing information collected at each CR user. Distributed sensing does not depend on FC to make the decision. Each CR shares its information to the neighboring CRs, which combines its data with the received sensing information for taking the decision. In cooperative sensing [3] each user employs ED for local spectrum sensing and sends a single bit decision to FC. The presence or absence of PU signal is represented by bit '1' and '0'. The fusion rules used for cooperative detection based on AND and OR logic. The presence of PU is decided in AND rules, if all the users detected the signal and for OR rule, the presence of PU is decided if any of the user detect the signal.

PROPOSED ADAPTIVE SPECTRUM SENSING

The noise uncertainty in ED and the fixed threshold based cooperative detection introduces decision error [4]. To overcome the above

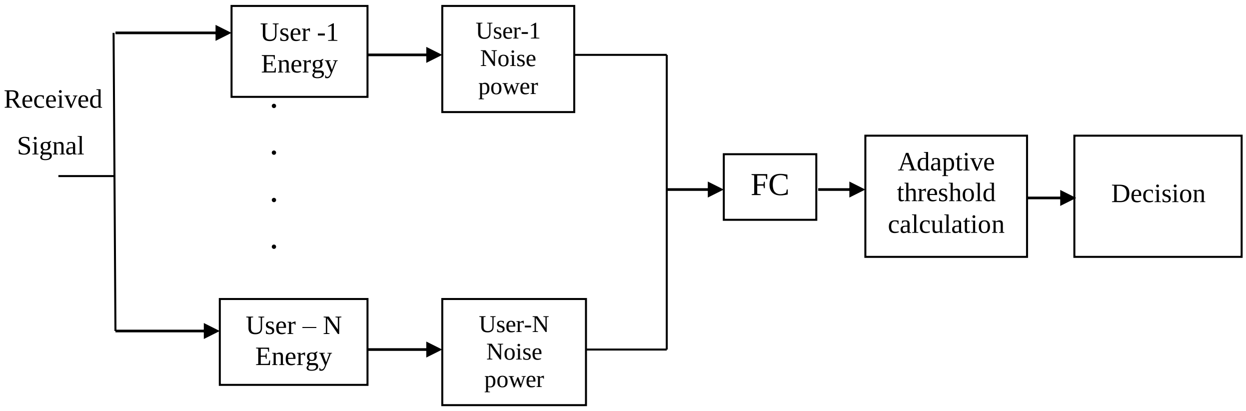

Figure 1. Block diagram of the proposed adaptive spectrum sensing

Shortcomings, threshold to be adaptive based on the noise power. An improved threshold based Adaptive spectrum sensing is proposed to improve the detection probability in all the SNR levels. The sensing threshold is calculated based on probability of false alarm and probability of detection.

The adaptive spectrum sensing is highly preferable when the secondary user does not have the sufficient SNR to detect the spectrum. In the first approach, threshold calculation is employed for the fixed probability of false alarm. The adaptive threshold based on the noise variance is given by

$$T_A = Q^{-1}\left(\frac{\sqrt{2}(1 - P_{fa})}{\sigma_n}\right) \qquad (3)$$

where P_{fa} is the probability of false alarm and σ_n is the noise variance. For the fixed 'Pfa', PU's protection against SU interference is no longer maintained [5]. Hence the improved threshold based detection is proposed.

The threshold estimation for the second approach is the function of 'Pd'. An improved threshold for the second approach is given by

$$T_A = Q^{-1}\left(\frac{P_d}{\sqrt{2}\sigma_n}\right) \qquad (4)$$

Higher value of 'Pd' is preferable for good throughput. The threshold is calculated using inverse 'Q' function in which has the noise variance is an argument. Hence the threshold is varied in accordance with the varying noise power.

RESULTS AND DISCUSSION

The simulation was performed in MATLAB to investigate the performance of the proposed method. The number of samples 'N' considered for simulation is 500, probability of false alarm (P_{fa}) range is 0 to 1 and the number of CR users is 10. The parameters considered for simulation is listed in Table I.

Table I. Simulation Parameters

Parameters	**Value**
SNR	-10 to 20 dB
Probability of False alarm	0.1
Number of samples	500
Number of CR users	10

The performance metrics are probability of false alarm, probability of detection (P_d) and probability of missed detection. The PU is quiet in reality; 'Pfa' denotes the probability of incorrectly detecting the PU signal. 'Pd' is the probability of detecting a PU signal [6], if PU is really present. 'Pmd' represents the probability that presence of PU is omitted due to noise and channel impact.

Figure 2 shows the SNR versus threshold for cooperative spectrum sensing and the proposed improved threshold based adaptive spectrum sensing.

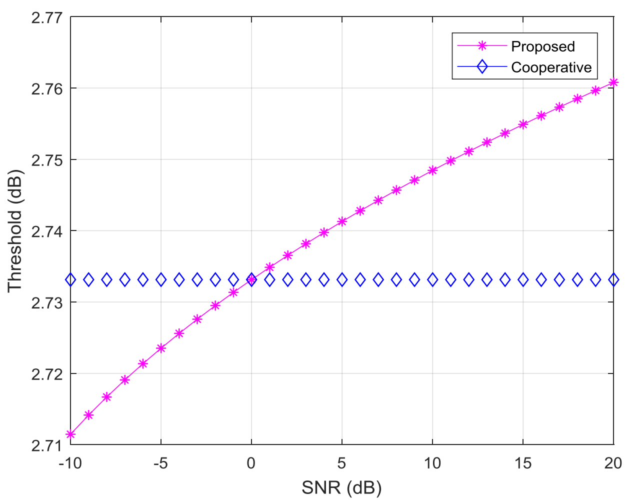

Figure 2. SNR versus Threshold for cooperative and the proposed adaptive spectrum sensing

The graph is drawn between the SNR versus the corresponding sensing threshold. The threshold value for Cooperative detection is fixed and for the proposed method the threshold is the function of SNR [7, 8]. When the SNR is increased, the corresponding threshold increases respectively. However the cooperative spectrum sensing threshold is constant irrespective of SNR.

Figure 3 and 4 depicts that the proposed adaptive spectrum sensing performance is better than existing cooperative spectrum sensing especially at low SNR [9, 10]. The proposed adaptive spectrum sensing attains higher probability of detection and lower probability of missed detection. The 'Pd' obtained for the proposed method is 0.42 and for adaptive method is 0.2 and 0.14 for cooperative spectrum sensing at SNR of 5dB. For the same SNR, the 'Pmd' obtained for the proposed method is 0.52 and for adaptive and cooperative spectrum sensing are 0.8 and 0.86 respectively.

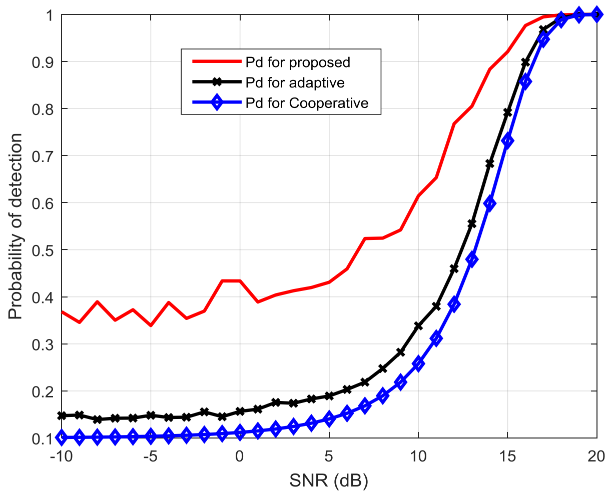

Figure 3. SNR versus probability of detection

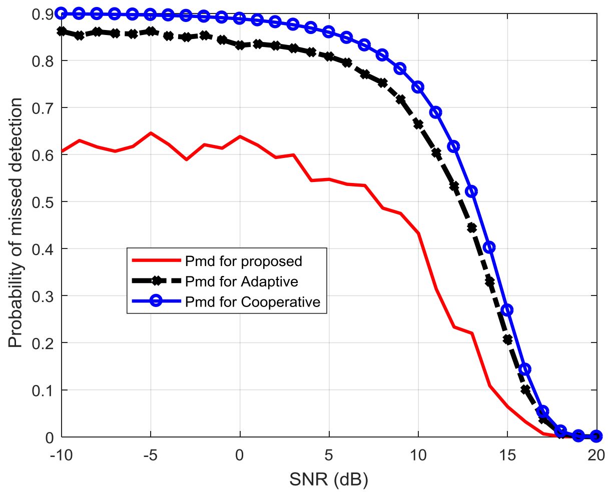

Figure 4. SNR versus probability of missed detection

Figure 5 and 6 illustrates the false alarm versus probability of detection and probability of missed detection for the spectrum sensing techniques. For the false alarm value is 0.75, probability of detection and probability missed detection measured are 0.3 and 0.65 and 0.9 for Cooperative, adaptive and the proposed method respectively. For the same Pfa the obtained 'Pmd' are 0.7, 0.35 and 0.1 respectively. It is observed that the 'Pd' and 'Pmd' performance of the proposed method outperforms the existing sensing techniques.

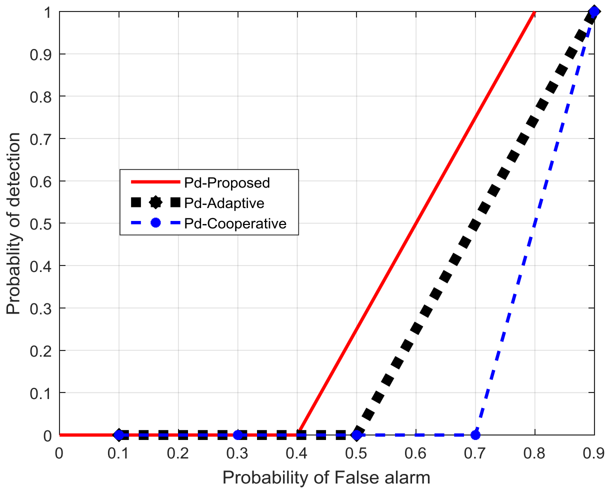

Figure 5. Probability of false alarm versus probability of detection

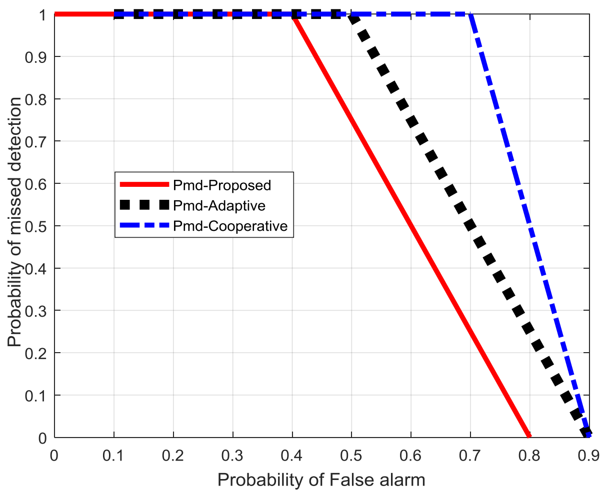

Figure 6. Probability of false alarm versus probability of missed detection

Figure 7 and 8 illustrates that the 'Pd' comparison between the proposed, adaptive and cooperative spectrum sensing techniques. The proposed adaptive spectrum sensing attains higher 'P_d' and minimum 'Pmd' for all the SNR values. For the SNR of 10dB the achieved 'Pd' values are 0.6, 0.3 and 0.2 and 'Pmd' values are 0.4, 0.7, 0.8 for the proposed, adaptive and cooperative spectrum sensing techniques respectively. Hence in both 'Pd' and 'Pmd' the proposed method outperforms the other spectrum sensing techniques.

Table 2 gives the comparison chart for the spectrum sensing techniques. From the chart the performance of the proposed method is superior in both 'Pd' & 'Pmd' for all the SNR levels and 'Pfa'.

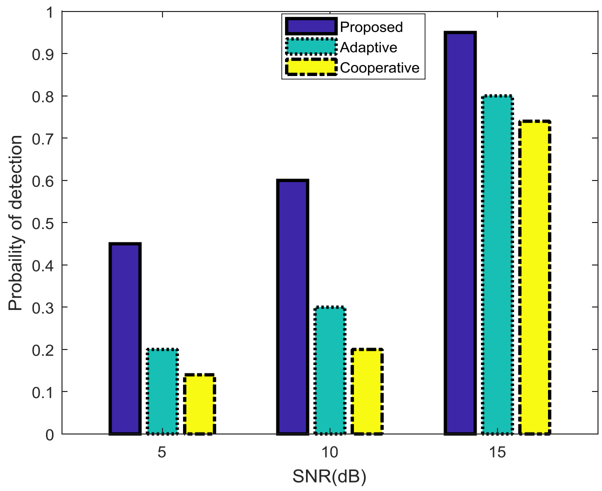

Figure 7. Comparison of probability of detection

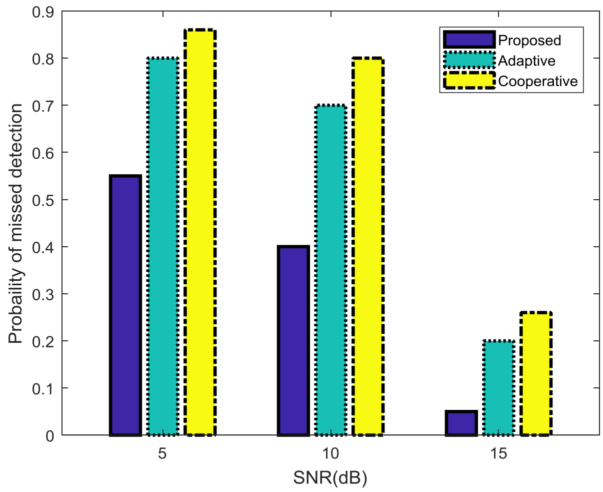

Figure 8. Comparison of probability of missed detection

Table 2. Comparison Chart

Parameters	Proposed Adaptive spectrum sensing		Adaptive spectrum sensing		Cooperative spectrum sensing	
	P_d	P_{md}	P_d	P_{md}	P_d	P_{md}
SNR=5dB	0.42	0.58	0.2	0.8	0.14	0.86
SNR=15dB	0.95	0.05	0.8	0.2	0.74	0.26
Pfa=0.75	0.9	0.1	0.65	0.35	0.3	0.7
Pfa=0.80	1	0	0.75	0.25	0.5	0.5

CONCLUSION

The performance analysis of various spectrum sensing techniques is carried out in this paper. Cooperative sensing solves the detection probability for low SNR levels. However the cooperative sensing uses fixed noise power for threshold calculation. The adaptive spectrum sensing method based on false alarm probability reduces the protection level of PU. The detection probability based threshold calculation in the proposed adaptive spectrum sensing produces better performance in both low and high SNR levels. The simulation results show that the proposed method offers high detection probability irrespective of the false alarm probability. Hence the proposed method can be the better choice to solve the spectrum scarcity problems in the future generation wireless networks. The future envisions will be the real time implementation of the proposed adaptive spectrum sensing using GNU radio based RTL-SDR. The work can be extended to detect the presence of TV white spaces in the radio spectrum. The proposed spectrum sensing will be applied to 5G communications, for better energy and spectrum allocation.

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