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Cooperative Spectrum Sensing using Energy Detection in Mobile and Static Environment

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Abstract. Cognitive radios are proposed to be the technology that will alleviate the problem of spectrum scarcity by using the underutilized radio frequency opportunistically on non-interfering basis. For this purpose the cognitive radio user must be able detect the available spectrum opportunity reliably and efficiently. In this paper, we consider the problem of spectrum sensing in Rayleigh fading environment for opportunistic access using energy detection in cognitive radio. We present the simulation results for cooperating cognitive radios (CR) in mobile and static environment in order to determine performance gain in terms of probability of detection, SNR, mobility and number of CR users. The target performance level is set by taking the requirements mentioned in IEEE 802.22 WRAN standard. It is found that the mobility adds spatial diversity to the CR systems and hence improves the sensing performance.

Keywords: Cognitive radio, spectrum sensing, IEEE 802.22, probability of false alarm, probability of detection.

1. Introduction

Entire spectrum bands are already been allocated to different services, most often requiring licenses for operation, a fundamental problem facing future wireless systems is to find suitable carrier frequencies and bandwidths to meet the predicted demand for future services. However, studies by the FCCs reported vast temporal and geographic variations in the usage of allocated spectrum with utilization ranging from 15% to 85% [1]. This has forced researchers to explore new technologies to efficiently utilize this underutilized spectrum. One of such technologies that are actively under research to increase the capacity of wireless system is cognitive radio which aims at improving the utilization of crowded otherwise underutilized spectrum in time, frequency and space. The first and foremost requirement of cognitive radio (CR) for capitalizing the unused spectrum is to efficiently detect the availability of spectrum hole or white spaces, where there is no active primary user (PU).

Since cognitive radio user have low priority in the licensed band, they must detect the spectrum hole efficiently to avoid interfering with primary user and exploit the spectrum holes to increase the data rate and increase the spectrum efficiency. For this purpose many signal detection techniques can be used in spectrum sensing ranging from feature detection [2] to energy level measurements [3]. The energy detection approach is optimal for detecting any unknown deterministic signal [4] and widely investigated as it is fast and offers low complexity. However, performance of the energy detector is susceptible to uncertainty in noise power [5]. Many factors in practice such as multipath fading, shadowing, and the receiver uncertainty problem may significantly reduce the detection performance in spectrum sensing. This is the reason why cooperative spectrum sensing (CSS) [6] is an attractive and effective approach to combat multipath fading and

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shadowing and mitigate the receiver uncertainty problem by exploiting spatial diversity. Another way to exploit spatial diversity is via exploiting mobility of CR. Since RF signal are essentially uncorrelated over spatial displacements of the receiver of about λ/2, results in significant spatial diversity.

IEEE 802.22 [7], recently, they adopted an amendment for the operation of mobile device so as to include the mobility aspect in wireless regional area network (WRAN) [8]. Several paper have focussed on determining the performance of the cooperative spectrum sensing using energy detection in terms of probability of detection, required SNR, decision fusion rules, threshold and number of user. But the effect of mobility in cooperative environment has not received much attention. Recently, impact of user mobility on the performance of spectrum sensing has been presented in [9]. In this paper we analyse the performance of energy detection of mobile and static CR system under OR fusion rule to determine the performance gain achieved in each scenario and compare those performance gain. This paper is organized as follows, Section 2 gives the review of channel sensing hypothesis and energy detector followed by cooperative sensing in Section 3. Section 4 provides the simulation results and discussions. The conclusions are drawn in Section 5.

2. Spectrum Sensing in Fading Channels

Cooperative sensing starts with spectrum sensing performed individually at each CR. Typically, local sensing for primary signal detection is formulated as a binary hypothesis problem as follows:

$$x_i(t) = \begin{cases} n_i(t), H_0 \\ h_i(t).s_i(t) + n_i(t), H_1 \end{cases} \tag{1}$$

where $x_i(t)$ denotes the received signal at the CR user, $s_i(t)$ is the transmitted PU signal, $h_i(t)$ is the channel gain of the sensing channel, $n_i(t)$ is the zero-mean additive white Gaussian noise (AWGN), H_0 and H_1 denote the hypothesis of the absence and the presence, respectively, of the PU signal in the frequency band of interest. For the evaluation of the detection performance, the probabilities of detection P_d and false alarm P_f are defined as [3],

$$\begin{aligned} P_d &= P\{decision = H_1 \mid H_1\} = P\{Y > \lambda \mid H_1\} \\ P_f &= P\{decision = H_1 \mid H_0\} = P\{Y > \lambda \mid H_0\} \end{aligned} \tag{2}$$

where Y is the decision statistic and λ is the decision threshold. The value of λ is set depending on the requirements of detection performance. Probability of false alarm, P_f is the probability of a CR user declaring that a PU is present when the spectrum is actually free. Probability of detection, P_d is the probability of a CR user declaring that a PU is present when the spectrum is indeed occupied by the PU. A miss in the detection will cause the interference with the PU and a false alarm will reduce the spectral efficiency. In the energy detection approach the radio frequency energy in the channel is measured in a fixed bandwidth W over an observation time window T to determine whether the channel is occupied or not. The average probability of false alarm, the average probability of detection, over AWGN channels [4] is given as:

$$P_f = \frac{\Gamma(u, \frac{\lambda}{2})}{\Gamma(u)} \tag{3}$$

$$P_d = Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \tag{4}$$

where $\Gamma\ (.,.)$ is the incomplete gamma function and $Q_u(a, b)$ is the generalized Marcum Q-function, u represents the time-bandwidth product and γ represents the SNR. In case of Rayleigh fading, average probability of detection may be derived by averaging (4) over fading statistics, which gives [6]:

$$P_d = \int_x Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) f_\gamma(x)dx \tag{5}$$

where $f_\gamma(x)$ is the probability distribution function (PDF) of SNR under fading.

3. Cooperative Spectrum Sensing Under Mobile CR

There are three different methods for cooperative spectrum sensing which are centralized, distributed and relay assisted sensing. In this paper we use centralized cooperative spectrum sensing as it is adopted in IEEE 802.22. In centralized cooperative sensing the decision on the availability of free spectrum is taken by fusion of the sensing result of individual CR users at the fusion centre or secondary base station (BS). As shown in Fig. 1, three CR users sense for the transmission by primary base station and send their final sensing results to the fusion centre. To minimize the transmission overhead of the sensing data, each CR user will transmit one-bit binary decision to the secondary BS for final decision on the sensed channel. In this paper, we will use OR fusion rule because given a targeted probability of detection P_d the individual secondary users threshold can be easily derived and the sensing performance can be evaluated [10]. In OR fusion rule, when at least 1 out of k secondary users detect the primary users, the final decision declares a primary user is present. The Q_d and Q_f of the final decision are therefore, respectively:

$$\begin{aligned} Q_d &= 1-(1-P_d)^n \\ Q_f &= 1-(1-P_f)^n \end{aligned} \tag{6}$$

where n is the number of cooperating nodes in spectrum sensing, Q_d is the probability of detection and Q_f is the probability of false alarm in cooperative scenario. At the common receiver, all 1-bit decisions are fused together according to following logic rule:

$$Z = \begin{cases} \sum_{i=1}^{n} D \geq 1, H_1 \\ 0, H_0 \end{cases} \tag{7}$$

where Z is the final combined decision at the fusion centre and the D_i is the individual decision from the sensing nodes.

The main idea of cooperative sensing is to enhance the sensing performance by exploiting the spatial diversity in the observations of spatially located CR users. By cooperation, CR users can share their sensing information for making a combined decision more accurate than the individual decisions. Fig. 2 shows how the performance degradation due to multipath fading and shadowing can be overcome by cooperative sensing such that the receiver's sensitivity can be approximately set to the same level of nominal path-loss without increasing the implementation cost of CR devices [11].

Similar to the cooperative spectrum sensing mobility in CR provides spatial diversity as it moves from one place to another place. Motion of CR causes small-scale fading, resulting in variations of up to ±5dB. In situations where the signal normally does not have enough power to be detected by the receiver, fading can be advantageous, as it can cause a temporary increase in signal power. This typically happens when an obstacle creates a favourable geometry by producing one or more multipath components whose path length is shorter than the path length of previously existing components. With multiple static sensors, their spatial signal diversities are limited to their geographical area, whereas a single mobile sensor can fully exploit spatial signal diversity as it keeps moving around.

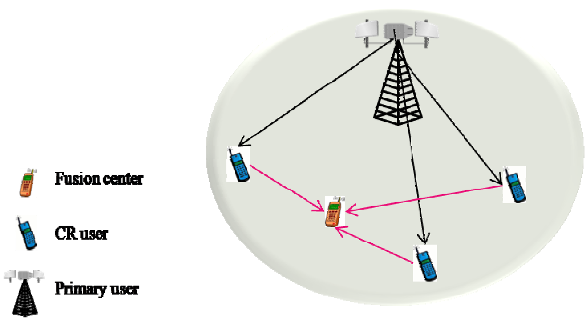


Fig. 1 Cognitive cooperative communication scenario consisting of CR users, primary user and fusion centre.

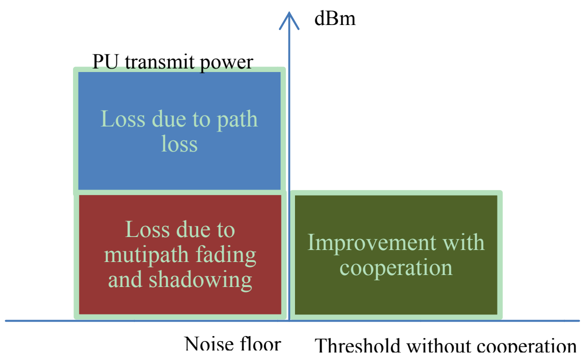


Fig. 2 Improvement due to cooperation to compensate path loss, multipath fading and shadowing.

4. Results and Discussions

We consider a scenario in which a group of n CR is moving with speed of V m/s and makes a decision on the presence of PU signal in a certain bandwidth W. We further assume that the primary signal undergoes independent and identically distributed (i.i.d) fading. In order to minimize the communication overhead, users may only share their final 1-bit (hard) decisions which is combined based on OR rule. The target probability of detection is P_d = 0.9 whereas the P_f is varied ranging from 0.0001 to 0.1. Time-bandwidth product, u, is set to 5 and the average SNR at each cooperating node is set 10 dB until mentioned otherwise.

Fig. 3 shows the advantage of cooperative communication over the single user case in AWGN and Rayleigh environment as the number of cooperating user increases the P_d increases and the P_f decreases. The P_d of more than 0.9 is achieved for P_f less than 0.1 in case of five cooperating user hence highlighting the advantage of cooperation. Fig. 4 shows the variation of probability of detection according to the average SNR from which it can be seen that as cooperation increases the performance of the spectrum sensing improves with the increase in the SNR. It can be seen from the figures that fusing the decisions of different secondary users cancels the deleterious impact of shadowing/fading effectively. Moreover, with increasing n, cooperative scheme is capable of outperforming AWGN local sensing (n = 1). This is due to the fact that for larger n, there will be a user with a channel better than that of the non-fading AWGN case. Fig. 5 shows the variation of Q_d under different probability of false alarm setting. As the number of cooperating user increases the Q_d increases and in order to achieve $Q_d > 0.9$ at $Q_f = 0.01$ around 10 nodes are required. Fig. 6 shows plots of SNR versus the number of cooperating users in i.i.d. Rayleigh fading environment under different Q_f setting. Results indicate a significant improvement in terms of the average SNR required for detection. The single node requires SNR ≈ 16 dB to achieve $Q_d = 0.9$ whereas 10 nodes requires SNR ≈ 10 dB.

Fig. 7 shows the variation of Q_d with the speed of CR users and it can be seen that as the speed of CR user increases the probability of detection increases due to spatial diversity experienced by the mobile CR. As the user moves rapidly the current observation decorrelates with the past observation hence providing

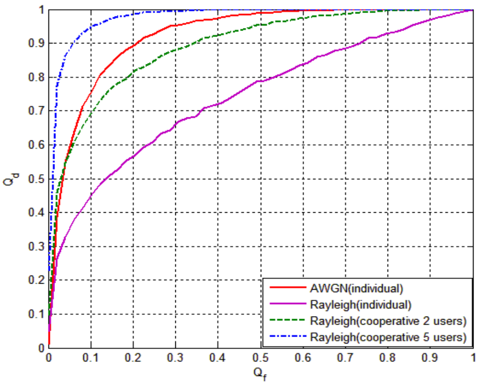


Fig. 3: Simulated results for Q_d and Q_f for Rayleigh fading channel with different cooperating nodes at 10 dB.

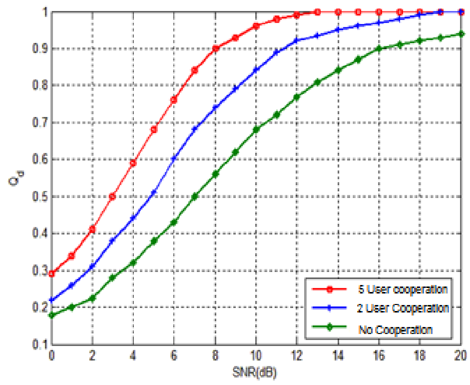


Fig. 4: Simulated results for Q_d at different SNR values for 2-user and 5-user cooperation with P_f = 0.1.

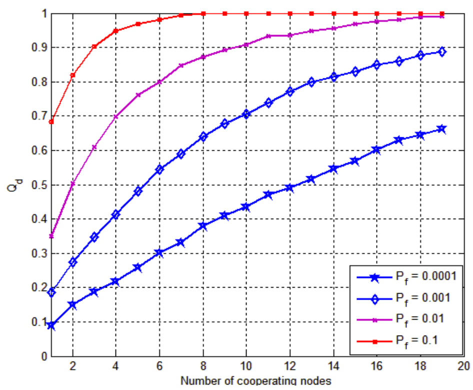


Fig. 5: Simulated results for Q_d with varying number of cooperative nodes at different P_f.

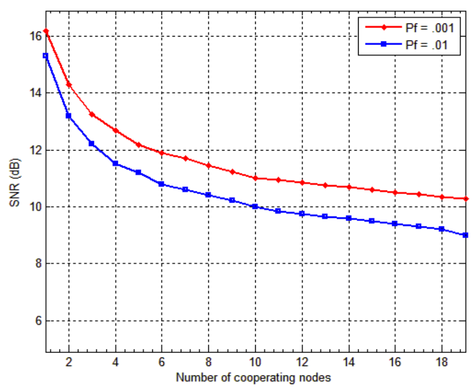
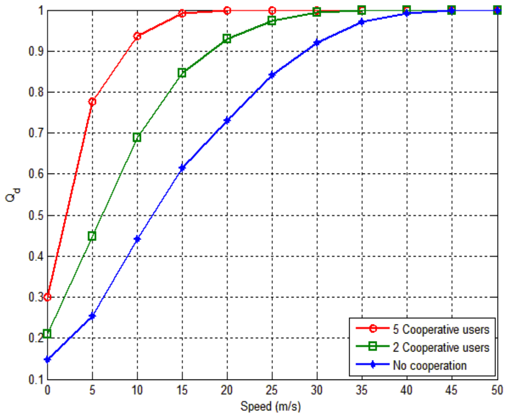


Fig. 6: Variation of SNR vs. number of cooperating nodes (Q_d = 0.9)



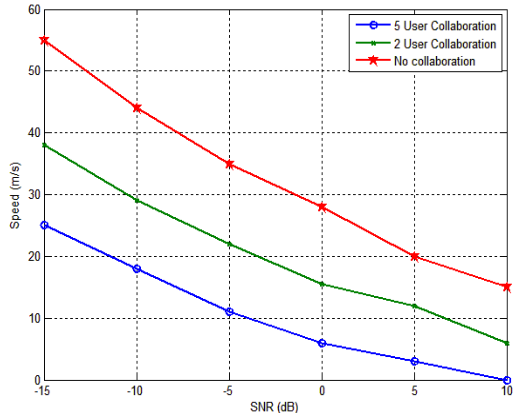


Fig. 7: Variation of Q_d and CR speed (P_f = 0.1 and SNR = 0 dB)

Fig. 8: Variation of speed of CR to achieve P_f = 0.1 and P_d = 0.9

better performance. It can be seen that even for single CR, P_d = 0.9 can be achieved without cooperation at 0 dB when CR is moving at a speed of 30 m/s. In the same way Fig. 8 shows how the required SNR varies with the speed of the CR to achieve target P_d = 0.9 and P_f = 0.1. The required SNR decreases to achieve target performance level as the mobility of the CR increases. Mobility along with cooperation results in much better detection performance as compared to cooperation alone as evident from Fig. 7 and Fig. 8. Comparing Fig. 7 and Fig. 4 we find that five nodes at 10 m/s can achieve P_d = 0.9 at 0 dB whereas five static CR need 8 dB to achieve the same performance.

5. Conclusion

In this paper cooperative spectrum sensing based in energy detection is studied as a means to improve spectrum sensing for cognitive radio. It has been shown that by using cooperation among users even a simple detector can achieve adequate performance. Our simulation results confirm the intuition that sensor mobility increases diversity in received signal thus improves the sensing performance. The simulation results indicate that the sensing gain increases with fast moving sensors. Interestingly mobile CR requires less degree of cooperation so as to achieve targeted performance.

6. References

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