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PERFORMANCE OPTIMIZATION OF COGNITIVE RADIO WITH WIDEBAND SPECTRUM SENSING

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Abstract

Cognitive radio (CR) technology allows the unlicensed user to access the licensed spectrum bands. Spectrum sensing is an essential function in cognitive radio to detect the spectrum holes and opportunistically use the underutilized frequency bands without causing interference to primary user (PU). In this paper we are maximizing the throughput capacity of cognitive radio user and hence the performance of spectrum sensing and protection to licensed user improves over a wideband spectrum sensing band. The simulation of cognitive radio is done by analyzing the performance of energy detector spectrum sensing technique to detect primary user and to formulate the optimization using multiband joint detection method (MJD) to achieve suitable trade- off between secondary user access and primary user network. The main aim of this paper is to maximize the probability of detection and to decrease the probabilities of miss detection and false alarm. To maximize the throughput it requires minimizing the throughput loss caused by miss detection and the significant reduction in probability of false alarm helps in achieving the spectral efficiency from the secondary users perspective. The simulation results show that the performance increases with the MJD method.

Keywords:

Cognitive Radio, Multiband Joint Detection Method, Spectrum Sensing, Probability of Detection, Probability of False Alarm, Throughput

1. INTRODUCTION

In wireless communications, due to the rapid growth more and more spectrum resources are needed. Recent study has shown that some frequency bands in the spectrum are unoccupied most of the time, while some are less occupied, whereas few bands are over utilized. This leads to spectrum underutilization. Cognitive radio is one such technique to overcome such underutilization. Within the current spectrum framework, most of the spectrum bands are exclusively allocated to specific licensed services. However, a lot of licensed bands, such as those for TV broadcasting, are underutilized, resulting in spectrum wastage this has promoted Federal Communications Commission (FCC) to open the licensed bands to unlicensed users through the use of cognitive radio technology, wherein the unlicensed users need to continuously monitor the licensed users activities to avoid interference and collisions. Obtaining reliable results for the licensed users activities is the main task under consideration. Based on the sensing results, the unlicensed users should adapt their transmit powers and access strategies to protect the licensed communications. The requirement naturally presents challenges to the implementation of CR in maximizing the achievable secondary throughput over an optimal wideband spectrum sensing [1]. The spectrum sensing performance and the protection to the primary network improves while the sensing time also increases [2]. The sensing throughput tradeoff problem is formulated [3]. A novel wideband spectrum sensing technique referred to as multiband joint detection is introduced in [4]. Joint detection of the primary activities over multiple narrowband channels is presented in [5].

In practice the unlicensed users, also called secondary users (SUs), need to continuously monitor the activities of the licensed users, also called primary users (PUs), to find the spectrum holes (SHs), which is defined as the spectrum ends that can be used by the SUs without interfering with the PUs. This procedure is called spectrum sensing. When there is no PU transmission during a certain time period, the SUs can use the spectrum for transmission. Mainly four functions are performed by the cognitive Radio. (1) It continuously searches for spectrum holes or white space which is known as Spectrum Sensing. (2) After a spectrum hole is found, it selects the appropriate white space for accessing, this is called spectrum management. (3) It allocates this channel to the secondary user till the primary user is not found which is called Spectrum Sharing. (4) Cognitive user vacates the channel when the licensed user is detected and this is known as spectrum mobility. The primary objectives of the cognitive radio are to provide highly reliable communications whenever and wherever needed and to utilize the radio spectrum efficiently. The key issues in the cognitive radio are awareness, intelligence, learning, adaptively, reliability, and efficiency. Cognitive Radio can provide the spectral awareness technology to support FCC initiatives in spectral use.

2. SYSTEM MODEL

2.1 WIDEBAND SPECTRUM SENSING

A wideband channel which is divided into non overlapping narrowband sub channels and is assumed that a number of primary users share this spectrum. Specifically, a multicarrier modulation based primary communication system is considered. Depending on the location and time, some of these sub channels might not be used by primary users and are available for secondary transmission, particularly interested in jointly identifying these underutilized sub bands. For modeling the detection problem on each sub channel, binary hypothesis testing is used in which hypothesis represents the absence and presence of the primary signal. For simplicity, it is assumed that during the time that a cognitive radio performs sensing, other peers remain inactive such that the only signal in the whole bandwidth is the one transmitted by primary users. Since the relative importance and priorities for individual sub channels, from both secondary and primary view points are different, considering a single sub band at a time may not be optimal. Secondary capacity throughput is important for cognitive radio users and interference protection is the key priority for the primary network. Thus, instead of sensing each channel independently and identifying the spectrum vacancies in each sub channel separately, we develop a wideband spectrum sensing framework which jointly takes into account the detection of the opportunities for secondary transmission over the entire target spectral bandwidth.

2.2 CONCEPT OF TWO HYPOTHESES

Spectrum Sensing is a key element in cognitive radio network. In fact it is the foremost step that needs to be performed for communication to take place. Spectrum sensing can be simply reduced to an identification problem, modeled as a hypothesis test. The sensing equipment has to just decide between for one of the two hypotheses

$$H_1 : x(n) = w(n) + s(n) \quad (1)$$

$$H_0 : x(n) = w(n) \quad (2)$$

where,

$s(n)$ is the signal transmitted by the primary users

$x(n)$ being the signal received by the secondary users

$w(n)$ is the additive white Gaussian noise with Variance σ_2

Hypothesis 'H_0' indicates the absence of primary user and that the frequency band of interest only has noise whereas 'H_1' points towards presence of primary user. Thus for the two state hypotheses numbers of important cases are

Case 1: *The probability of detection* is the probability that the primary users are detected to be present while they are actually present, to avoid any interference from the secondary users if they are trying to access the spectrum. A high value of P_d will lead to efficient use of the spectrum without causing interference to the primary user.

$$P_d = P(H_1/H_1) = P(H_0/H_0) \quad (3)$$

Case 2: *The probability of false alarm* is defined as the probability of detecting that primary user is present while it is actually inactive, and this leads to inefficient utilization of the spectrum, because even if the spectrum is free, the *secondary* user will assume that it is occupied by the primary user and hence will not be able to utilize the spectrum. A low value of P_{fa} is expected to increase the channel reuse capability when it is free.

$$P_{fa} = P(H_1/H_0) \quad (4)$$

Case 3: *The probability of miss detection* is a probability when a primary user is detected to be inactive while it is actually active. Higher value of Pm_d leads to higher interference because in this case the secondary user will assume that the spectrum is free while the spectrum is actually utilized by the primary users.

$$Pm_d = P\left(\frac{H_0}{H_0}\right) \quad (5)$$

2.3 RECEIVED SIGNAL

The most well known spectrum sensing technique is the energy detector. It is based on the principle that, at the reception, the energy of the signal to be detected is always higher than the energy of the noise. The energy detector is said to be a blind signal detector because it ignores the structure of the signal. It estimates the presence of a signal by comparing the energy received with a known threshold, derived from the statistics of the noise. A threshold value is required for comparison of the energy found by the detector. Energy greater than the threshold values indicates the presence of the primary user, the energy is calculated as,

$$R = \frac{1}{M}\sum_{m=1}^{M}\left|S_k(m)\right|^2 \quad (6)$$

where, M is the number of samples, R_k is decision statistic and S_k is the Secondary received signal. The probability of false Alarm $P_{fa}^{(k)} = (\varepsilon_k, T)$ and the probability of detection $P_d^{(k)} = (\varepsilon_k, T)$ for the k^{th} sub channel are approximated as,

$$P_{fa}^{(k)}(\varepsilon_k, T) = Q\left(\left(\frac{\varepsilon_k}{\sigma^2}\right) - 1\right) \cdot \sqrt{\tau f_s} \quad (7)$$

$$P_d^{(k)}(\varepsilon_k, T) = Q\left(\left(\frac{\varepsilon_k}{\sigma^2} - \gamma_k\right) - 1\right) \cdot \sqrt{\frac{\tau f_s}{2\gamma_k}} + 1 \quad (8)$$

where, ε_k is the decision threshold and $Q(.)$ denotes the complementary distribution function of the standard Gaussian distribution.

$$Q(x) = \frac{1}{2} erfc \frac{x}{\sqrt{2}} \quad (9)$$

In sensing algorithms, one of the design criteria is to make the probability of false alarm P_{fa} as low as possible, since it measures the percentage of vacant spectrum which is misclassified as busy. On the other hand, in order to limit the probability of interfering with primary users, it is desired to keep the probability of missed detection $P_m = 1\text{-}P_d$ low.

The threshold ε_k is a tradeoff factor between the probabilities of false alarm and missed detection, a low threshold value will result in high false alarm probability in favor of low missed detection probability and vice versa. Alternatively, the choice of the sensing time T offers a tradeoff between the quality and speed of sensing. By increasing the sensing time, the test decision is more accurate but the available time for cognitive transmission is reduced, in consequence.

3. MULTIBAND JOINT DETECTION METHOD

In wideband sensing, an array of energy detectors is employed, each of which detects one frequency band. The MJD method enables CR users to simultaneously detect PU signals across multiple frequency bands for efficient management of wideband spectrum resource. The main objective is to find the optimal threshold vector = $[0, 1, . . ., K-1]^T$, so that the cognitive radio system can make efficient use of the unoccupied spectral segments without causing harmful interference to the primary users.

A cognitive radio sensing the K narrowband sub channels in order to opportunistically utilize the unused ones for transmission is considered. Let r_k denote the throughput achievable over the k^{th} sub channel if used by cognitive radios, and $r = [r_0, r_1. . . r_{k-1}]^T$. Since the opportunistic spectrum measures utilization of sub channel k, we define the aggregate opportunistic throughput capacity as which is a function of the threshold vector. Due to the inherent trade-off and maximizing the sum rate will result in large, hence causing harmful interference to primary users. The interference to primary users should be limited in a cognitive radio network and hence the aggregate interference to j^{th} primary user with tolerable interference limit can be expressed as,

$$\sum\nolimits_{k \in s_j} C_k \cdot P_{md}(T, \varepsilon_k) \le \xi_j,\ j = 1,2,3........J \tag{10}$$

For a wideband primary communication system, the impact of interference induced by cognitive devices can be characterized by a relative priority vector over the K sub channels, i.e., $c = [c_0, c_1. . . c_{K-1}]^T$, where c_k indicates the cost incurred if the primary user at sub channel k is interfered with. Suppose that J primary users share a portion of the K sub channels and each primary user occupies a subset S_j.

The CR system performs data transmissions when the sensing result shows no PU signals on sub bands. There are two events contributing to the throughput of CR network's transmission, namely the inactivity of primary networks and the occurrence of miss detection. Let us denote the achievable throughput of sub bands as $r_0 = r_0^{(1)}, r_0^{(1)}, ...r_0^{(N)}$ where $r_0^{(k)}$ refer to the achievable throughput over k^{th} sub band under H_1can be represented as $r_1 = r_1^{(1)}, r_1^{(1)}......r_1^{(N)}$ Therefore, the aggregate throughput will be the product of the achievable throughput and transmission opportunity. In the first event, no PU signals exists, that is (H_0/H_0) the aggregate throughput in this event can be represented as given by $R_0(\tau, \varepsilon)$.

$$R_0(\varepsilon, \tau) = C_0(1 - P_f(\varepsilon, \tau))P(H_0) \tag{11}$$

where, 1 denotes the all one vector. The major contribution of the throughput comes from this scenario; most studies only considered this event. On the other hand, if a miss detection of the detector occurs, that is (H_0/H_1) the aggregate throughput in this event will

$$R_1(\varepsilon, \tau) = C_1(1 - P_d(\varepsilon, \tau))P(H_1) \tag{12}$$

where, $R(\varepsilon,\tau) = R_0(\varepsilon, \tau)+R_1(\varepsilon, \tau)$ and ξ_j represent the maximum aggregate interference tolerated by the j^{th} PU. The minimum requirements of the miss-detection and the false alarm probabilities to each sub band are $\alpha = [\alpha_1, \alpha_2,. . . \alpha_N]$ and $\beta = [\beta_1,\beta_2,. . . \beta_N]^T$. Since to maximize the aggregate throughput requires minimizing the throughput loss caused by miss-detection, the new optimization problem can be reformulated as min $R_{miss}(\tau,\varepsilon)$.

Hence the probabilities of miss detection can be written in a vector as

$$P_m^{(k)}(\tau) = Q\left(\frac{1}{\sqrt{2\gamma_k + 1}}\right)\left(\sqrt{\tau f_s \gamma_k}\right) - Q^{-1}(\beta_k) \tag{13}$$

4. SIMULATION RESULTS

When the sensing time increases the probability of false alarm decreases. This significant reduction in P_{fa} helps in achieving the spectral efficiency from the secondary user's perspective. Higher the threshold value will result in lower the probability of false alarm. The probability of false alarm is defined as the probability of deciding H_1 when H_0 is true $P_{fa} = P(H_1/H_o)$, the design criteria is to make the probability of false alarm P_f as low as possible since it measures the percentage of vacant channels which are misclassified as busy ones. On the other hand, in order to limit the probability of interfering with primary users. Consider a single primary user communication (i.e. j = 1,) over a wideband spectrum of 6.4 MHz and assumed to be QPSK.

Where we set $r_1^k \approx 0.8 \cdot r_0^k$. The signal to noise ratio at the cognitive user is assumed to be -20dB. Furthermore, in each sub channel, we assume a minimum primary user protection level of 90%, i.e., α_k = 0.1 and an opportunity detection margin of β_k = 0.2 and minimum requirement for spectrum sufficiency is $Q(1/\sqrt{3})$. Moreover, the maximum time for which the secondary network is unaware of the primary activity is chosen such that f_sT = 3000.

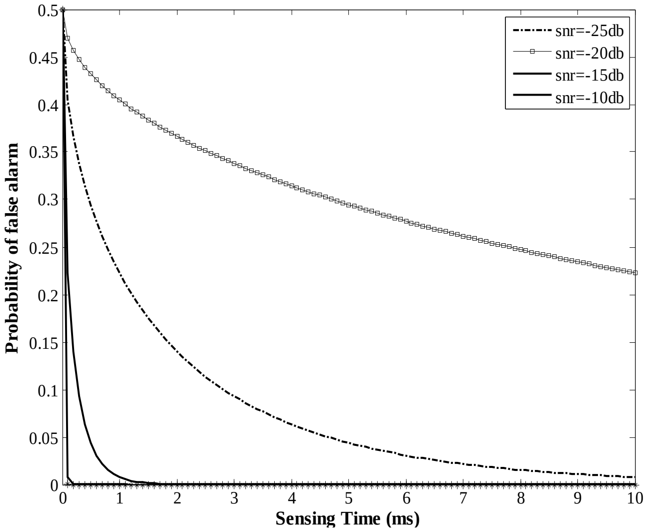

Fig.1. Probability of False Alarm v/s Sensing Time

The probability of detection is the probability that the primary users are detected to be present while they are actually present, to avoid any interference from the secondary users if they are trying to access the spectrum. A high value of P_d will lead to efficient use of the spectrum without causing interference to the primary user $P_d = P(H_1/H_1)$ .Longer the sensing time the longer probability of detection, hence the primary user are protected. The secondary network can use the channel with a higher chance. The probability of detection occurs with increase of number of samples and P_d is chosen to be close to but less than 1.

In order to limit the probability of interfering with primary user, it is desired to keep the probability of miss detection P_m =1-P_d low. This is the probability when a primary user is detected to be inactive while it is actually active, is called the probability of missed detection.

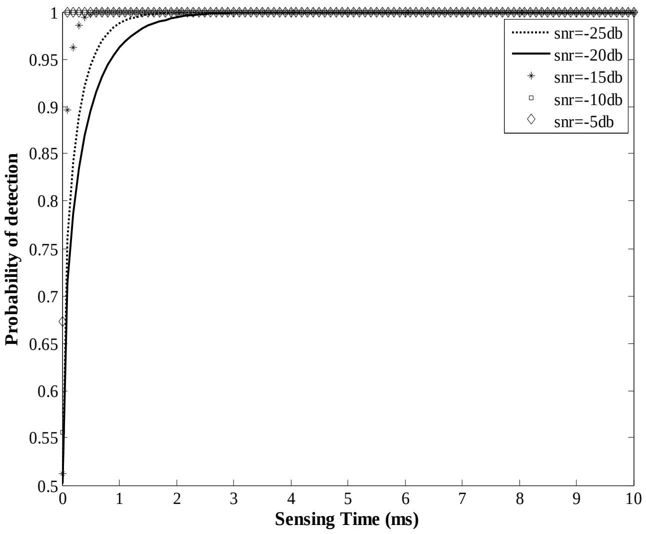

Fig.2. Probability of Detection v/s Sensing Time

Higher value of P_{md} leads to higher interference because in this case the secondary user will assume that the spectrum is free while the spectrum is actually utilized by the primary users $P_{md} = P(H_0/H_1)$.The occurrence of miss detection should be reduced in order to give better spectral efficiency. This regime of probabilities of false alarm and missed detection is of practical interest for achieving rational opportunistic throughput and interference levels in CR networks.

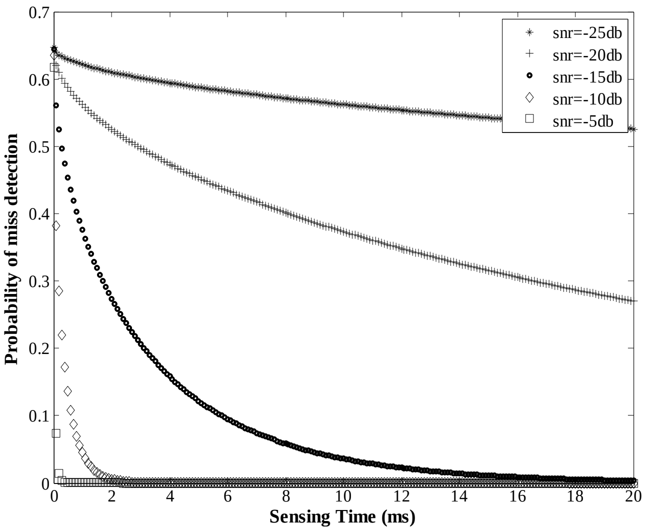

Fig.3. Probability of Miss Detection v/s sensing time

In this graph, as the sensing time increases the throughput also increases. To maximize the throughput it requires minimizing the throughput loss caused by miss detection. As the throughput of secondary network is maximized while the primary users are sufficiently protected. By increasing the sensing time the test decision is more accurate.

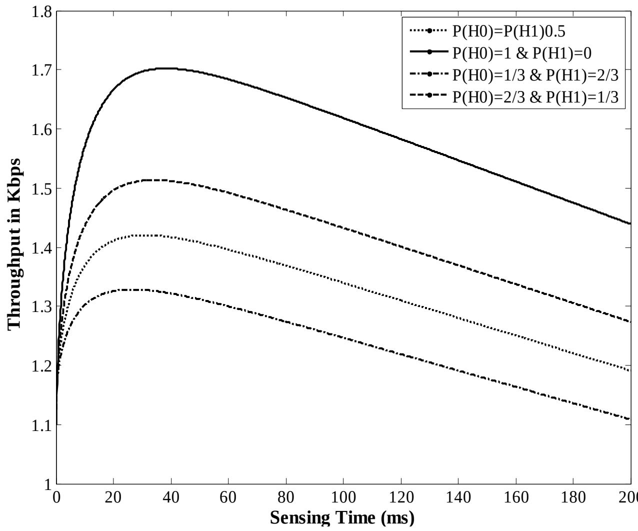

Fig.4. Optimization of Throughput v/s sensing time

5. CONCLUSION

An optimal multiband joint detection method is proposed to increase the performance of secondary user over multiple frequency bands. The problem of designing both the sensing slot duration and threshold is done to maximize the achievable throughput for secondary user network under the constraints that the primary users are protected from interference. It can be seen that the multiband joint detection algorithm with the optimized threshold can achieve a much higher opportunistic rate than that achieved by the one with uniform threshold for cognitive radio the cooperative spectrum sensing is done to improve the performance of spectrum sensing by using the sensing information obtained from several nodes. The joint detection problem is taken into a class of optimization problem; moreover the MJD algorithm efficiently solves the formulated optimization problem to improve the spectral efficiency and to reduce the interference. From these graphs it is very clear that, increasing the SNR increases the probability of detection while lowering the probabilities of false alarm and miss detection. To summarize, the multiband joint detection method efficiently achieves a suitable tradeoff between the secondary user access and the primary network protection over a wideband frequency spectrum.

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REFERENCES

[1] P. Paysarvi Hoseini and N. C. Beaulieu, "Optimal wideband spectrum sensing framework for cognitive radio systems", *IEEE Transactions on Signal Processing*, Vol. 59, No. 3, pp. 1170-1183, 2011.

[2] Chin-Liang Wang, Han-Wei Chen and Zong-Ying Tsai, "Throughput Maximization for Cognitive Radio Networks

with Wideband Spectrum Sensing", *IEEE International Conference on Wireless Communications and Networking*, pp. 1293-1298, 2012.

[3] Y.-C. Liang, Y. Zeng, E. C. Y. Peh and A. T. Hoang, "Sensing-throughput tradeoff for cognitive radio networks", *IEEE Transactions on Wireless Communications*, Vol. 7, No. 4, pp. 1326-1337, 2008.

[4] Z. Quan, S. Cui, A. H. Sayed and H. V. Poor, "Optimal multiband joint detection for spectrum sensing in cognitive radio network", *IEEE Transactions on Signal Processing*, Vol. 57, No. 3, pp. 1128-1140, 2009.

[5] P. Paysarvi Hoseini and N. C. Beaulieu, "An optimal algorithm for wideband spectrum sensing in cognitive radio systems", *Proceedings of the IEEE International Conference on Communications*, pp. 1-6, 2010.

[6] F. F. Digham, M.-S. Alouini and M. K. Simon, "On the energy detection of unknown signals over fading channels", *IEEE Transactions on Communications*, Vol. 55, No. 1, pp. 21-24, 2007.

[7] Y. Zeng and Y.-C. Liang, "Spectrum-sensing algorithms for cognitive radio based on statistical covariances", *IEEE Transactions on Vehicular Technology*, Vol. 58, No. 4, pp. 1804-1815, 2009.

[8] Y.-C. Liang, Y. Zeng, E. Peh and A. T. Hoang, "Sensing-throughput tradeoff for cognitive radio networks", *Proceedings of the IEEE International Conference on Communications*, pp. 5330-5335, 2006.

[9] A. Ghasemi and E. S. Sousa, "Optimization of spectrum sensing for opportunistic spectrum access in cognitive radio networks", *Proceedings of the 4th IEEE Consumer Communication on Networking Conference*, pp. 1022-1026, 2007.

[10] J. Hillenbrand, T. A. Weiss and F. Jondral, "Calculation of detection and false alarm probabilities in spectrum pooling systems", *IEEE Communications Letters*, Vol. 9, No. 4, pp. 349-351, 2005.

[11] S. M. Mishra, A. Sahai and R. W. Brodensen, "Cooperative sensing among cognitive radios", *Proceedings of the IEEE International Conference on Communications*, pp. 1658-1663, 2006.

[12] A. Goldsmith, "*Wireless Communications*", Cambridge University Press, 2005.

[13] M. Gandetto and C. Regazzoni, "Spectrum sensing: A distributed approach for cognitive terminals", *IEEE Journal on Selected Areas on Communications*, Vol. 25, No. 3, pp. 546-557, 2008.

[14] J. Mitola and G. Q. Maguire, "Cognitive radios: making software radios more personal", *IEEE Personal Communications*, Vol. 6, No. 4, pp. 13-18, 1999.