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Optimization Cooperative Sensing in Cognitive Radio Networks: A Sensing-Throughput

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Abstract

In cognitive radio networks, the performance of the spectrum sensing depends on the sensing time and the fusion scheme that are used when cooperative sensing is applied. In this paper, we consider the case where the secondary users cooperatively sense a channel using the k-out-of-N fusion rule to determine the presence of the primary user. A sensing-throughput tradeoff problem under a cooperative sensing scenario is formulated to find a pair of sensing time and k value that maximize the secondary users' throughput subject to sufficient protection that is provided to the primary user. An iterative algorithm is proposed to obtain the optimal values for these two parameters. Computer simulations show that significant improvement in the throughput of the secondary users is achieved when the parameters for the fusion scheme and the sensing time are jointly optimized.

Index Terms—Cognitive radio, cooperative sensing, sensing throughput tradeoff.

I. INTRODUCTION

Cognitive radio, which enables secondary users/networks to utilize the spectrum when primary users are not occupying it, has been proposed as a promising technology to improve spectrum utilization efficiency [1], [2]. Spectrum sensing to detect the presence of the primary users is, therefore, a fundamental requirement in cognitive radio networks. A longer sensing time will improve the sensing performance; however, with a fixed frame size, the longer sensing time will shorten the allowable data transmission time of the secondary users. Hence, a sensing-throughput tradeoff problem was formulated in [3] to find the optimal sensing time that maximizes the secondary users' throughput while providing adequate protection to the primary user. Another technique to improve the spectrum sensing performance is cooperative sensing [4]–[10]. There are various cooperative schemes to combine the sensing information from the secondary users, such as the k-out-of-N fusion rule, soft decision based fusion, and weighted data based fusion. Both the sensing time and the cooperative sensing scheme affect the spectrum sensing performance, such as the probabilities of detection and false alarm. These probabilities affect the throughput of the secondary users since they determine the reusability of frequency bands. In this paper, we propose joint optimization of the sensing time and the parameters of the cooperative sensing scheme that are used to maximize the throughput of the secondary users.The main contributions of this paper are as follows:

- First, using the k-out-of-N fusion rule as the basis, we formulate an optimization problem using the sensing time and the fusion parameter k as the optimization variables to jointly maximize the throughput of the secondary users while giving adequate protection to the primary user.

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- Second, we propose an iterative algorithm to obtain both the optimal sensing time and the k value for the optimization problem. In this paper, we prove the unimodal characteristics of the secondary users' throughput as a function of the sensing time when the k-out-of-N fusion rule is used.
- Last, using computer simulations, it is shown that optimizing both the sensing time and the fusion scheme together significantly increases the throughput of the secondary users.

2 Literature Survey

In this section we provide a literature survey of the problems of our interest. Spectrum sensing An introduction to Cognitive Radio is provided in literature. Fundamental issues involving noise, interference and channel uncertainties are discussed in the literature. For spectrum sensing, primarily three Signal Processing Techniques are proposed in literature:

Matched Filter: This is the optimal detector (in the sense of maximising SNR) if there is a complete knowledge about the primary signal: demodulation schemes used by the primary and apriori knowledge of primary user signal. Thus it may not be possible to use this method in many situations. Under low SNR conditions Matched Filter requires O(1/SNR) samples for reliable detection.

CycloStationary Feature Detection: This method does not require complete knowledge about the primary signal. In this method the inherent periodicity of the mean, autocorrelation, etc in a typical modulated signal is used for detection of a random signal in the presence of noise. The main advantage of this technique is its ability to work at very low SNR's. However its implementation is complex.

Energy Detector: When the only known apriori information is noise power then the optimal detector in Neyman-Pearson framework is Energy Detector. This is the simplest approach to spectrum sensing. At low SNR an energy detector requires about $O(1/SNR^2)$ samples for reliable detection. A disadvantage of energy detectors is that to obtain the thresholds used by them for a certain performance one needs to know the noise power and fading levels. Also this method does not work for spread spectrum signals.

3. SYSTEM MODEL

We consider a cognitive radio network where there are $N - 1$ secondary users and one secondary base station that act as sensor nodes to cooperatively detect the presence of the primary user. Denote H_0 and H_1 as the hypotheses of the absence and the presence of the primary user, respectively. The sampled signals that are received at the ith sensor node during the sensing period are given as $y_i(n) = u_i(n)$ and $y_i(n) = h_i(n)s(n) + u_i(n)$ at hypotheses H_0 and H_1, respectively, where s(n) denotes the signal from the primary user, and each sample is assumed to be an independent identically distributed (i.i.d.) random process with zero mean and variance $E[|s(n)|^2] = \sigma^2_s$. The noise $u_i(n)$ is assumed to be i.i.d. circularly symmetric complex Gaussian with zero mean and variance $E[|u_i(n)|^2] = \sigma^2_u$.we assume that the distances between any secondary users are small compared with the distance from any secondary user to the primary transmitter. Therefore, it is assumed that each channel gain $|h_i(n)|$ is Rayleigh-distributed with same variance $E[|h_i(n)|^2] = \sigma^2_h$. Assume that s(n), $h_i(n)$, and $u_i(n)$ are independent of each other, and the average received SNR at each sensor node is given as $\gamma = \sigma^2_h \sigma^2_s / \sigma^2_u$.

Consider that each of the sensor nodes employ an energy detector and measure their received powers during the sensing period. Then, their measured received powers are given as $V_i = (1/M) \sum_{n=1}^{M} |y_i(n)|^2$ for i = 1,...,N. Denote M as the number of signal samples that are collected at each sensor node during the

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sensing period, which is the product of the sensing time τ and the sampling frequency fs. Denote εi as the threshold parameter of the energy detector at the ith sensor node. When the primary user'ssignal is a complex-valued phase-shift keying signal, the energy detector's probabilities of detection and false alarm at each sensor node are, respectively.

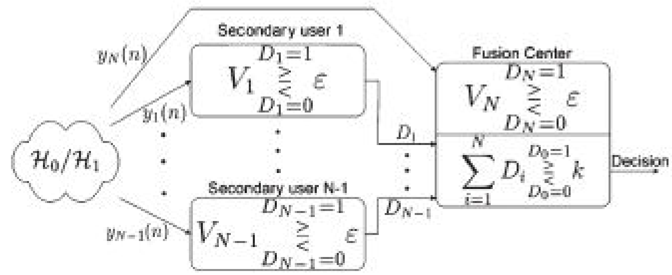

Fig. 1. Structure of cooperative sensing using the k-out-of-N fusion rule.

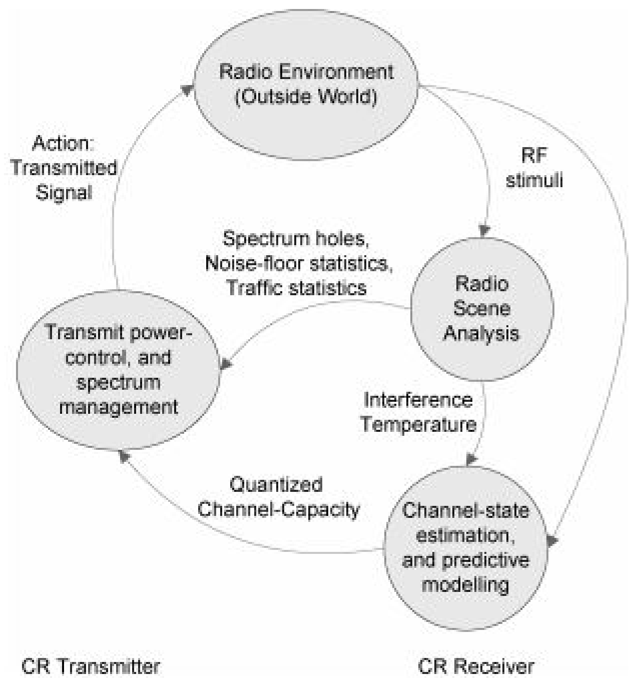

Figure 2: Cognitive Cycle

The main aspects in current spectrum policies which lead to spectrum scarcity are fixed allocation of the spectrum, very little sharing and rigid requirements on using methodologies. Dynamic Spectrum Access (DSA) covers a broad range of reformations in spectrum access to address these issues. Different techniques for DSA are illustrated in Figure 2. The first classification, Dynamic Exclusive Use Model, retains the structure of the current spectrum regulation policy, i.e., licence for exclusive use. Flexibility in allocation and spectrum usage are the key factors in this model. Spectrum Property Rights allow licensees to sell and trade spectrum. This allows present economy and market to determine the most profitable use of spectrum. Dynamic Spectrum Allocation allows dynamic spectrum assignment to different services by exploiting spatial and temporal traffic statistics, i.e., in a given region and at a given time, spectrum is

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allocated to certain services for exclusive use. Open sharing model is based upon the idea of unlicensed ISM bands: open sharing among peer users. Hierarchical Access Model, which is adapted in this thesis, is based on creating a hierarchical structure of the primary users (PU) and the secondary users (SU). The essential idea here is to give access to the licensed spectrum, to the secondary users provided the interference perceived by primary users (licensees) is limited. Two techniques here are Spectrum Underlay and Spectrum Overlay. In Spectrum Underlay approach SU's transmit power is below the noise floor of the PUs, with the assumption that PUs are present all the time. Here the idea is to spread transmitted signals over a wide frequency band (UWB) to achieve high data rate with low transmission power. This approach does not use any detection mechanisms. Spectrum Overlay approach, in contrast to Spectrum Underlay, relies on when and where to transmit and put little restrictions on transmit power. The algorithms in Spectrum Overlay method detect the spectrum availability and use this knowledge for SUs transmission. Note that in this thesis we aim at developing algorithms for Spectrum Overlay approach in Hierarchical Access Model. Cognitive Radio is an autonomous reconfigurable Software Defined Radio platform (SDR)- a multiband system supporting multiple air interfaces and reconfigurable through software, which can learn from and adapt to the working scenario. They can exploit the spectrum availability in various dimensions. Spectrum can be shared in time, space, frequency, power or combination of the above. Spectrum availability arising in these domains is called spectrum holes or white spaces. Even if the white spaces are not available, a Cognitive Radio can be permitted to use the spectrum with a power level that is not enough to breach the interference thresholds of primary users, in any of time, frequency or space domains. This type of spectrum availability corresponds to grey spaces.

4.SIMULATION RESULTS

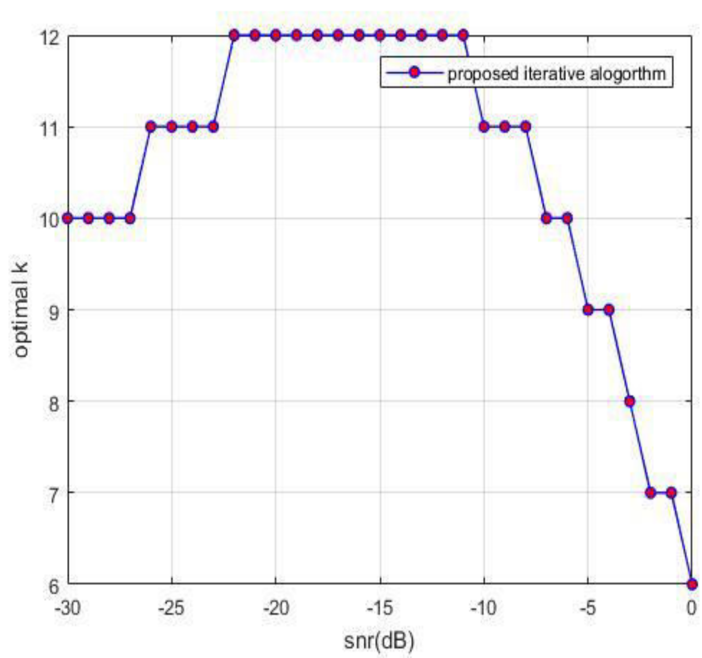

Fig. 3. Optimal k-out-of-N fusion rule that maximizes the throughput for N = 25.

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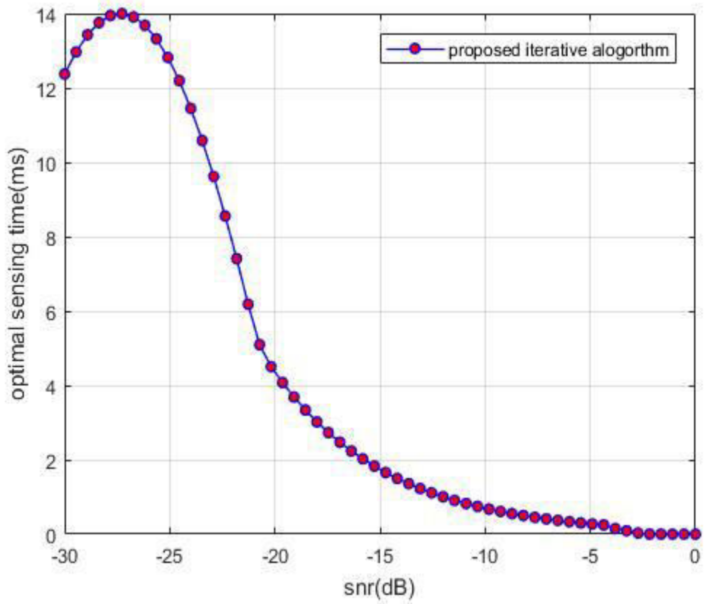

Fig. 4. Optimal sensing time that maximizes the throughput.

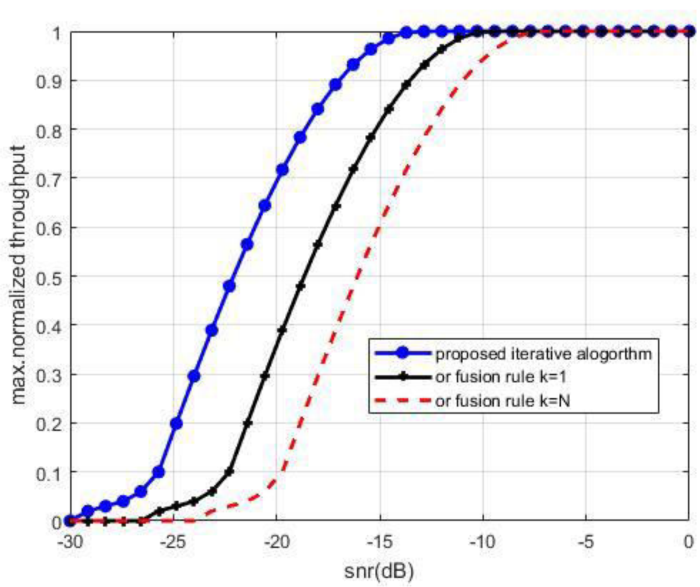

Fig. 5. Maximum achievable throughput by various k-out-of-N fusion rules.

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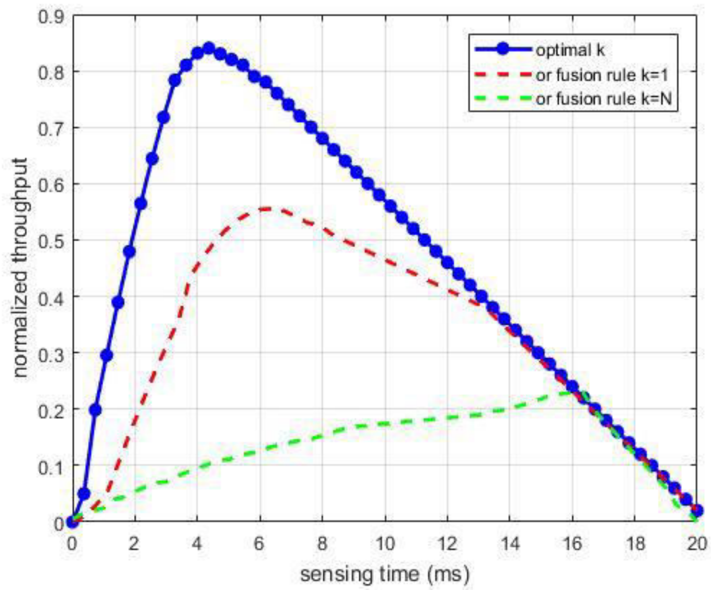

Fig. 6. Sensing-throughput tradeoff with various k-out-of-N fusion rules.

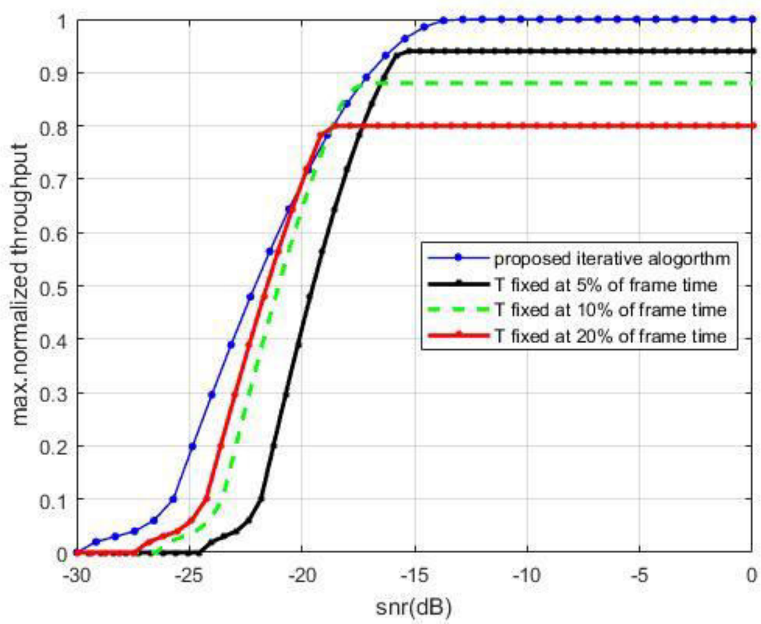

Fig. 7. Maximum achievable throughput for various sensing time.

5.CONCLUSION

In this paper, we have proposed an iterative algorithm to obtain the sensing time and the k value of the parameter of the fusion scheme that maximizes the throughput of the secondary users, subject to adequate protection to the primary user. The results of the proposed iterative algorithm have been verified to be optimum by comparing them with exhaustive search results. We have shown that significant improvement

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in the throughput of the secondary users has been achieved when both the parameters for the fusion scheme and the sensing time are jointly optimized.

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