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Joint optimization of sensing duration and detection threshold for maximizing the spectrum utilization

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ABSTRACT

Sensing-throughput trade-off has been widely discussed in the literature of cognitive radio networks. The constraint of the probability of detection is generally used for the protection of primary users. However, defined detection probability does not fully satisfy the goal of primary user protection. Even in the perfect sensing case, the primary user may appear in between two sensing epochs and suffer interference from the secondary user's transmission. Moreover, fixing detection probability may lead to decrease in the chances of utilization of possibly available spectrum holes. Motivated by the above-mentioned facts, in this paper, we have formulated a new objective function by the name of spectrum utilization, which considers the spectrum used by both primary user and the secondary user. While formulating the objective function, we have also considered the interference caused by the sudden appearance or disappearance of primary user in both perfect and imperfect sensing case, which will be having an impact on effective spectrum utilization. Thereafter, we jointly optimize threshold and sensing duration which can be applied to energy detection based spectrum sensing in cognitive radio models for maximizing the spectrum utilization. Finally, the simulation results are provided to evaluate the performance of the proposed joint optimization.

1. Introduction

Cognitive Radio (CR) is a new paradigm in wireless communication to increase the spectrum utilization [1,2]. In cognitive radio networks, Secondary Users (SUs) are allowed to temporarily access the band of Primary User (PU) if it is not currently being used. To enable this, SUs have to sense the spectrum periodically to detect the presence or absence of PU. If the band is detected as idle, then it can be used by SUs but the band is required to be vacated as soon as any PU activity is found. Spectrum sensing is, therefore, a fundamental requirement in cognitive radio networks. There are many spectrum sensing algorithms available in the literature out of which Energy Detection (ED) has gained more interest owing to its simple implementation and moreover, it does not require any prior information about PU [3,4]. Therefore, we have considered ED scheme for our analysis.

The performance of any spectrum sensing algorithm is determined by the metrics called probability of detection (P_d) and the probability of false alarm (P_f). The probability of detection means detecting the presence of PU accurately. The higher the probability of detection, more the PUs are protected. The probability of false alarm means detecting the PU as present when actually PU is absent. Lower the probability of false alarm, more are the chances of spectrum utilization by SU. Therefore, there exists a fundamental trade-off problem between PU protection and SU throughput. This problem was first proposed in [5] to find the optimal sensing duration to maximize the throughput of the secondary users under the constraint that PUs are sufficiently protected. In [6], authors jointly optimized two parameters, i.e. sensing duration and number of cooperative users in Cooperative Spectrum Sensing (CSS) with the same objective of maximizing the SU throughput under the constraint of PU protection. A sensing-throughput tradeoff problem was formulated in cooperative environment and iterative algorithm is proposed to obtain the optimal value of sensing time and number of cooperative users in K-out-of-N fusion rule of CSS. Using the optimal value of the parameters results in the improvement of the SU throughput. In [7], authors jointly optimized threshold and sensing duration for maximizing the secondary throughput under the constraint of PU protection. The impact of joint optimization is studied for two performance criteria i.e. (a) minimization of sensing duration, and (b) maximization of SU throughput by keeping detection probability as constant. It has been shown by the results that joint optimization of the parameters results in the reduction

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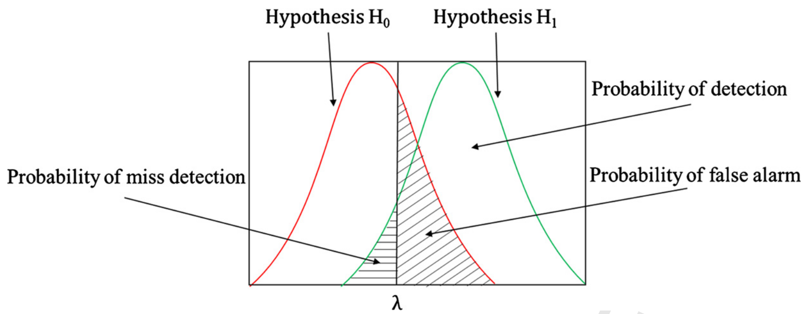

Fig. 1. Illustration of probability of detection and probability of false alarm.

of sensing time and improvement of the SU's throughput. In [8], sensing-throughput trade-off is studied from a cross-layer perspective. The joint impact of access contention and imperfect sensing is studied by taking the interference probability as the optimization constraint. Authors in [9], jointly optimized the sensing parameters and transmit power of SU to maximize the spectrum efficiency under the PU outage constraint. Further, the impact of joint optimization of the parameters is studied on the hard and soft fusion schemes. In [5–9] and other literature studied, objective is usually to maximize the throughput of the secondary network under PU protection constraint.

It has been established in the literature [10,11] that to meet the necessary constraint of PU protection which is to keep a watch on the probability of miss detection (say 0.1), the threshold is usually kept low which in turn will increase the probability of false alarm thus leading to decrease in the chances of leveraging spectrum holes. The relationship between the detection and false alarm probability as a function of threshold is illustrated in Fig. 1. Further, spectrum sensing is usually done periodically to check the presence or absence of any possible PU activity. If we assume that spectrum sensing done by SU is perfect (i.e. 100% P_d and 0% P_f), still there are chances that PU can appear in between two sensing epochs and may suffer interference from the SU transmission. Further, in imperfect sensing case when there is a miss detection, PU may disappear suddenly in between two sensing epochs and will not result in interference to SU. This sudden appearance and disappearance of PU affect the effective utilization of the spectrum.

To address the above-mentioned problems, we have formulated a new objective function in our previous work [12] which considers the spectrum used by both PU and SU for successful data transmission. While formulating the objective function, sudden appearance/disappearance of PU has also been considered. The main advantage of using spectrum utilization as the objective function in place of SUs throughput (considers spectrum utilized only by SU) that it considers the spectrum utilized by both PU and SU (overall spectrum utilization) and moreover, collisions due to sudden appearance/disappearance are also considered.

1.1. Our contributions

The main contributions of this paper may be summarized as follows:

- Formulating a new objective function Spectrum Utilization (φ).
- Maximizing the objective function by Threshold Only Optimization (TOO) considering constant sensing duration.
- Maximizing the objective function by Sensing Duration Only Optimization (SDOO) considering constant threshold under PU protection constraint.
- Maximizing the objective function by Joint Threshold and Sensing Duration Optimization (JTSDO).

Finally, simulation results are provided to compare the performance of TOO, SDOO and JTSDO schemes for maximizing the spectrum utilization and it has been observed that joint optimization results in better spectrum utilization.

The rest of this paper is organized as follows: System model is explained in Sec. 2. Problem formulation has been described in Sec. 3. Sec. 4 covers the proposed optimization schemes. Sec. 5 provides the simulation results and conclusion is drawn in Sec. 6.

2. System model & preliminaries

In this section, we first present the general model for spectrum sensing and then discuss the basics of energy detection scheme.

2.1. Spectrum sensing model

We consider a non-cooperative CR model where there is one SU and one PU. The SU uses the channel when the PU is detected as inactive. The problem of PU detection can be formulated as a testing of two hypotheses H_o and H_1. When PU is considered as absent, the received signal can be represented as:

$$H_o : y(n) = u(n) \tag{1}$$

When PU is considered as present, the received signal can be represented as:

$$H_1 : y(n) = s(n) + u(n) \tag{2}$$

Here, $u(n)$ is assumed as Independent and Identically Distributed (i.i.d.) Additive White Gaussian Noise (AWGN) random process with zero mean and variance σ_u^2. Similarly, $s(n)$ is PU signal also assumed to be an i.i.d. AWGN signal having zero mean and variance σ_s^2 [5–7,11,12]. The signal $s(n)$ and noise $u(n)$ assumed to be independent of each other. Where, $n = 1, 2, \ldots, N$ is the index of the signal sample. Signal to Noise Ratio (SNR) on PU-SU link is defined as the ratio of signal variance to noise variance ($SNR\ (\gamma) = \frac{\sigma_s^2}{\sigma_u^2}$).

2.2. Energy detector

Conventional energy detector measures the energy (X) associated with the received signal and compares it with a predetermined threshold (λ) to decide among the two hypotheses. The joint Probability Distribution Function (PDF) for N number of samples under hypothesis H_o can be derived as [13, Chapter 3]:

$$p(y/H_o) = \frac{1}{(\sqrt{2\pi\sigma_u^2})^N} \exp\left(-\frac{\sum_{n=1}^{N}(y(n))^2}{2\sigma_u^2}\right) \tag{3}$$

where $N = \tau$ (sensing time) $* f_s$ (sampling frequency). Under H_1, joint PDF can be written as [11, Chapter 3]: