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An Approach to maximize throughput for Energy Efficient Cognitive Radio Networks

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Abstract

In this paper, we consider the problem of designing optimal sensing time and the minimization of energy consumption in the Cognitive radio Network. Trade-off between throughput and the sensing time are observed, and the equations are derived for the optimal choice of design variables. In this paper, we also look at the optimization problem involving all the design parameters together. The advantages of the proposed scheme for the spectrum sensing and access process are shown through simulation.

Keywords: *Energy Efficient Cognitive Radio, Optimal Sensing Time, Throughput, Sensing Performance.*

1. Introduction

Radio spectrum resources have an unprecedented increment in the demand for the emerging wireless application, which results in the spectrum scarcity. Cognitive Radio (CR) is now considered as a potential technique to solve the issue of spectrum availability [1].The spectrum sensing is used to scan the vast range of frequency to observe white spaces that is spatially available for transmission such that the unlicensed user (SU) can be allowed to access in the frequency band of the licensed user (PU), while the PU is being absent. To avoid interference, SU needs to monitor the activity periodically and vacate the channel in the presence of PU [2] - [6].

The probability of detection and probability of false alarm are two metrics used for the measurement of the sensing performance. As the probability of detection increases, sensing period increases for a target probability of detection. From the perspective of PU protection, the higher probability of detection is needed. On the other hand, the decrement in the probability of false alarm causes the increment in sensing period for a target probability of false alarm. From the SU point of view, the lesser probability of false alarm is needed to create more opportunities for secondary transmission. Thus, the longer sensing period is necessary to obtain better and reliable spectrum sensing. Nevertheless, the increment in the sensing period will result in the decrements of the SU's achievable throughput. To enhance the throughput with the optimization of sensing time has been taken into account much. While PU is transmitting, SU needs to transfer its current transmission to a new spectrum and this whole process take 2 seconds only with the probability of false alarm less than 0.1 and the probability of detection is higher than 0.9 [5]. In [2], the sensing time has been considered to maximize the achievable throughput of a single channel Cognitive network, under the constraint of the detection probability. Minimization of energy consumption was studied without considering the trade-off fact in the increment of detection probability and in the decrements of the false alarm probability [4].The decrements in the throughput creates the impact on sensing time and accuracy.

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In this paper, the frame structure has been followed by the proposed network model of the Federal Communications Commission (FCC), which is based on the IEEE 802.22 WRAN [1]. More specifically, our objective is to maximize throughput of secondary user, whereas the optimal sensing time and energy efficient approach has been preferred. For minimizing total energy cost of the SU, the optimal sensing and access mechanism has been considered to justify reliability of sensing and throughput.

The rest of this paper is devised as follows. In section II, System model, spectrum sensing and access model are described. In section III, we present the detailed description of proposed system model with optimization problem. The simulation results are shown in section IV. Finally, the conclusions are drawn in section V.

2. System Model

We consider a CR system with one secondary link and one primary link which can access wide spectrum band by using opportunistic method. For the simplicity, we assume that a channel is shared between the PU and the SU. The activity of PU is assumed to be independent to each other. Each frame consists of sensing slot duration, τ_s and a transmission slot of duration, T . The SU may choose to transmit data on the current channel or, stay on the current channel without transmitting at the beginning of each transmission slot. Unlike the secondary transmission, the primary transmission is assumed to be continuous, and it follows an on/off traffic model [9], where the probability of the primary transmission being on or off is the same for each channel.

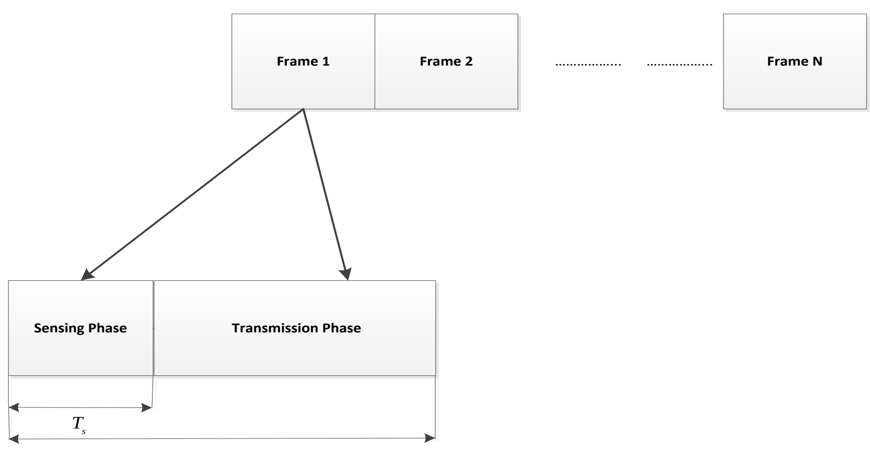

Fig.1 Frame structure for sensing and data transmission

In Fig.1, the SU performs spectrum sensing to obtain the available status from all channels. To sense all the channels, energy detection has been selected to perform simultaneously due to low complexity and excellent feature of detecting PU without any prior information. The spectrum sensing can be formulated as a form of binary hypothesis testing problem [1].

$$\begin{cases} H_0 : x(t) = n(t) \\ H_1 : x(t) = n(t) + h(t)s(t) \end{cases} \quad (1)$$

where H_0 and H_1 are correspondent to hypotheses of absence and presence of PU's signal, respectively, $x(t)$ represents the received data at SU, $h(t)$ denotes the amplitude gain of the channel and $n(t)$ is the additive white Gaussian noise. The detection and false alarm probability can be computed using the following formulas [1]:

$$P_d(\tau_s) = Q\left(\frac{1}{\sqrt{2\gamma+1}}\left(Q^{-1}(P_{ft}) - \sqrt{\tau_s f_s \gamma}\right)\right)$$
$$P_f(\tau_s) = Q\left(\sqrt{2\gamma+1}\left(Q^{-1}(P_{dt}) + \sqrt{\tau_s f_s \gamma}\right)\right) \quad (2)$$

where P_{dt} and P_{ft} are the target detection and false alarm probability. The sampling frequency, f_s is taken into Hz. Within the fixed sampling frequency f_s, minimum sensing time τ_s could satisfy the target probability detection and false alarm, which is given by [1]:

$$T_{s_{\min}} = \frac{1}{f_s}\gamma^2\left(Q^{-1}(P_{ft})\text{-}Q^{-1}(P_{dt})\sqrt{2\gamma+1}\right)^2 \quad (3)$$

For getting more accurate sensing result, sensing time would be increased which is not desirable as it is the reason of decreasing the throughput. To protect the LU with the certain level of detection probability, optimal sensing time is needed to design. The optimal sensing time will affect the throughput of SU. On the other hand, the optimal sensing time has an effect on the consumed energy of SU. We will compute the optimization problem which shows the optimal sensing time, with the minimization of the energy consumption, whereas the constraints on the throughput and sensing accuracy of secondary users are given preference.

3. Proposed scheme with optimization Problem

We consider a Cognitive Radio Network setup, where we can find the optimal sensing time that satisfies a certain level of detection, false alarm and energy consumption. In this section, we consider that the secondary user's network throughput is maximized subject to a constraint on the false alarm, detection. To obtain the optimal sensing time, we define the following optimization problem:

$$\max_{\tau_s} \; Thr(\tau_s)$$
$$\text{subject to} \quad (4)$$
$$P_d(\tau_s) \ge P_{dt}$$
$$P_f(\tau_s) \le P_{ft}$$

where the average throughput is denoted as *Thr*. The probability of detection and false alarm is written respectively as P_d, P_f whereas the corresponding target probability of detection and false alarm are named as P_{dt}, P_{ft} . We introduce here some derivation of throughput, sensing time in terms of channel condition. While presenting our calculation, we assume that throughput of all channels are independent. Our manipulation is dependent on the function of τ_s.

For derivation of $Thr(\tau_s)$, let's denote the busy channel as β. On the other hand, $1-\beta$ is taken as idle channel. The sensed idle channel will be given as

$$I(\tau_s) = (1\text{-}\beta)(1\text{-}P_f) + (1-P_d)\beta \quad (5)$$

The received SNR is taken at the secondary receiver. While the frequency band is idle, we will prefer to use SNR1.The perfect sensing can not be achieved due to shadowing or fading. Therefore, we consider the case that the frequency band is active. Then, the average achievable throughput of cognitive radio system is formulated as

$$Thr(\tau_s) = \left(\frac{T-\tau_s}{T}\right)\{(1-\beta)(1-P_f)log_2(1+SNR_1)) + (1-P_d)\beta(log_2(1+SNR_2))\} \quad (6)$$

where *SNR1* and *SNR2* are considered as the case that the status of LU is absent and present respectively. In the equation (6), the frame duration is represented as *T* in Fig.1. The function of τ_s plays a vital role in the calculation of the achievable throughput. In practice, LU is protected only when it is not allowed to use the SU frequency band. In IEEE 802.22 WRAN, the worst case PU signal is low as -20dB [2]. We can show that our proposed scheme exposes the higher average achievable throughput compared to the calculated throughput in [2]. It is known from the classical detection theory that the target detection probability will make higher sensing time, and the lower probability of false alarm [7].

The energy consumption for cognitive radio is important for low power enable CR network [11]. The average energy consumption is given as follows

$$E(\tau_s) = e_s\tau_s + e_t d^{\alpha}(T-\tau_s)\{(1-\beta)(1-P_f) + \beta(1-P_d)\} \qquad (7)$$

where e_s and e_t are used as energy consumption in sensing and data transmission respectively. The distance between transmitter and receiver is denoted as d . We will use a constant, α which is taken into account in

the environment with attenuated signal. The consumed energy will be calculated from the equation (8). For the simplicity, we assume that energy cost remains same in all possible cases.

In order to find the optimal sensing time τ_s , we are using optimization problem with numerical enumeration [8]. At the end, we find the maximum value in the throughput based on the optimal sensing time.

4. Simulation Results and Analysis

In this section, we deliver the simulation results for the proposed opportunistic spectrum access mechanism in the cognitive radio system using the energy detection scheme and compare the performance of the SU's throughput. We assume here that a number of secondary users are available The frame duration is taken as *T=100ms* [2].The received SNR of PU signal is -20dB in all the figures. The target probability of detection and false alarm are taken as P_{dt} =0.9 and P_{ft} =0.1. The sampling frequency is 6MHz.Also we consider the busy channel as $\beta = 0.35$.

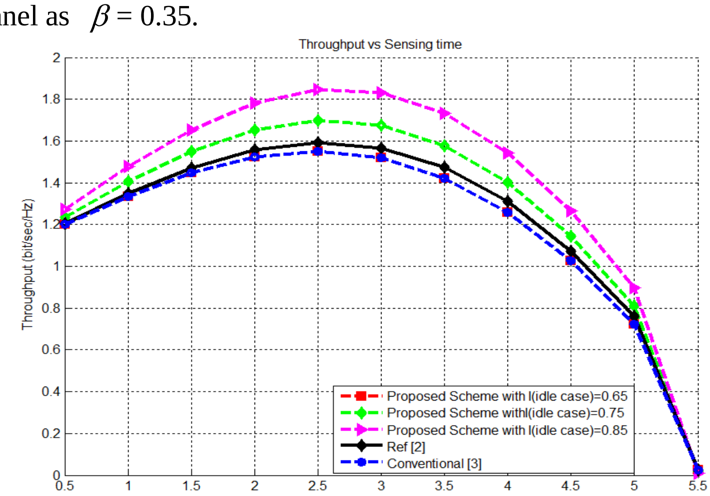

Fig. 2 Throughput as a function of Sensing time

In Fig2., we observe that our scheme in idle case with 0.65 or busy case 0.35 has gain the throughput approximately 1.5 bit/sec/Hz while the sensing time is 0.5 ms. The conventional approach [2] is also shown the similar pattern. After that the sensing time is increased at 5.5ms as the throughput is decreased which is less than 0.2 bit/sec/Hz. On the other hand, idle case with 0.85 or, busy case with 0.15 has shown the maximum throughput approximately 1.84 bit/sec/Hz whereas sensing time is minimum 2.5ms. Meanwhile, our proposed scheme outperforms the conventional approach in [2]. In [2], the optimal sensing time is 2.5ms which is also comparable with our proposed scheme.

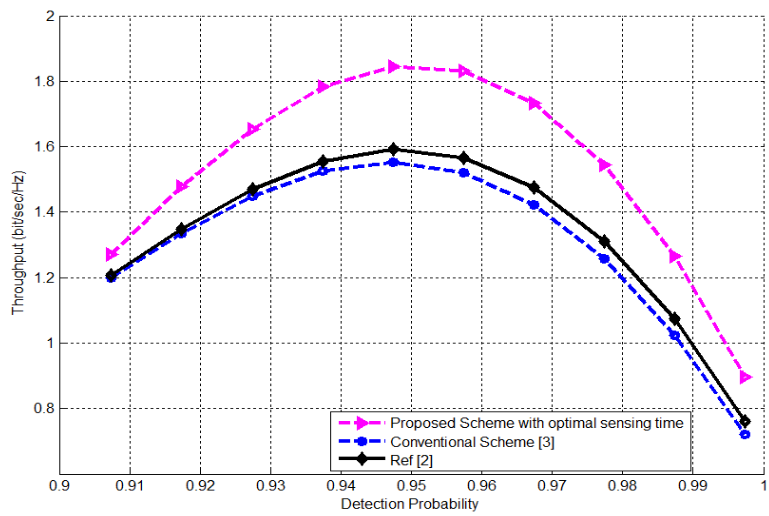

Fig. 3 Throughput as function of the probability of detection

In Fig.3, we demonstrate that the probability of detection as a function of throughput, where the value of P_d is considered more than 0.9. Among all the values, the optimal value has been selected as 0.946.According to the optimal value, conventional scheme [3] has throughput 1.5516 bit/sec/Hz. In ref [2], the value of the throughput is 1.5915.In our proposed scheme, we calculate throughput which is 1.8453 bit/sec/Hz. Therefore, our proposed scheme gives the best performance compare to other scheme.

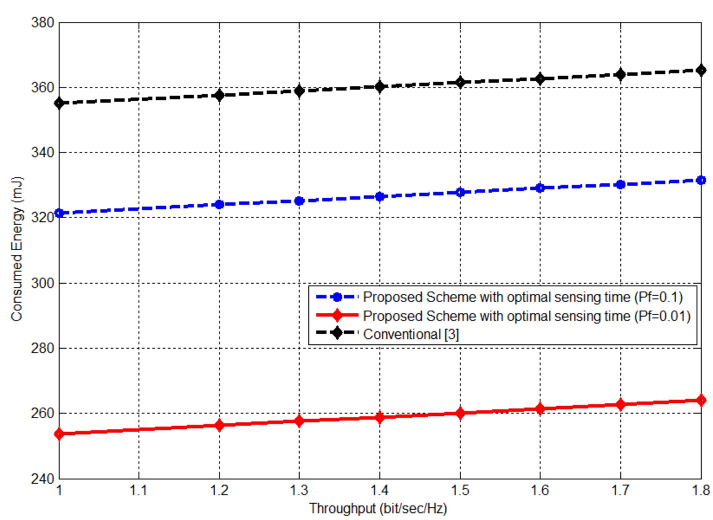

Fig. 4 Consumed energy as a function of the throughput

In Fig.4, we investigate the consumed energy of SU in terms of throughput and sensing time. We have taken energy consumption in sensing, e_s = 50x10^{-9} mJ, and the data transmission, e_t = 100x10^{-12} mJ [9]. The constant α =2 is also considered. It is observed that $\tau_{s,\min}$ is less than optimal sensing time which having an effect on throughput as well as the energy consumption. We can see that the throughput increases as the consumed energy increase at the certain point. From our scheme we ensure that the optimal sensing time has taken less energy cost with the value of P_f =0.1, 0.01. However, the proposed scheme can provide optimal sensing time 2.5ms, where we can take the maximum value of throughput 1.8453 bit/sec/Hz. in the energy cost of 331.5mJ when P_f =0.1. We also show that the energy cost is 264mJ in case of P_f =0.01. On the other hand, the scheme proposed in [3] consumed more energy, i.e. 365.2mJ than the proposed scheme.

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