

Optimal Sensing Period for the Cognitive Radio Networks

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Abstract—The PHY-layer sensing, as a key component of spectrum sensing in cognitive radio, concerns the sensing mechanism to determine when to sense channel for detection and which channel to access. One of the important issues in the PHY-layer sensing control is to find an available sensing period and trade-off between spectrum sensing and data transmission. The larger sensing time leads to higher sensing accuracy, less interference but shorter transmission time. Oppositely if we want hold much more transmission time, the sensing time should be decreased, and the interference to primary user will increase. In this paper, we show the relationship between spectrum sensing and data transmission according to the sensing period. We analyze and propose the new scheme to evaluate optimal sensing period.

Keywords—Cognitive radio, PHY-layer sensing, sensing control, In-band-sensing, optimal sensing period

I. INTRODUCTION

With the rapidly increasing demands on wireless bandwidth, the scarcity of spectral resource becomes more serious. Motivated by spectrum scarcity and spectrum under utilization, cognitive radio, regarded as a potential technique for future wireless communication, has been recently proposed to dynamically access unused-spectrum [1][2]. Since the spectrum availability for opportunistic access is determined by spectrum sensing, sensing is identified as one of the most crucial issues of cognitive radio networks.

Spectrum sensing can be realized as a two-layer mechanism [3]: PHY-layer sensing and MAC-layer sensing. PHY-layer sensing focuses on the efficient detection and identification of primary signal while MAC-layer sensing concerns when to sense channels and which channel to sense. The main objective of spectrum sensing is to find more spectrum access opportunities without interfering with primary networks. One important issue is sensing control when we design new PHY-layer sensing. In this research area, we need consider main issue on [4]: how long and frequently CR users should sense the spectrum to achieve sufficient sensing accuracy in in-band sensing.

In In-band sensing, CR users need to monitor the spectrum band during the transmission and detect the presence of primary networks so as to avoid interference. In this paper, we will focus on in-band-sensing, and try to evaluate appropriate periodic sensing structure.

The remainder of the paper is organized as follows. Section 2 presents our research model and factors, section 3 presents four important conditions analysis in sensing period, section 4

and section 5 provides simulations and the conclusion of our paper.

II. SYSTEM MODEL

In this CR system model, we consider the energy detection for the transmitter detection. In energy detection, it is optimal to detect the unknown signal if the noise power is known. Energy detection suffers from longer detection time compared to the matched filter detection, and its performance is susceptible to uncertainty in noise power.

In this paper, the appearance of the primary user's traffic is assumed to be an independent and identically distributed ON/OFF random process, where ON and OFF represent the hypothesis H_1 and H_0 respectively.

PU (primary user) detection is utilized to decide whether the primary user is present or not, which can be formulated as the following two hypotheses [6],

$$x(t) = \begin{cases} n(t) & H_0 \\ hs(t) + n(t) & H_1 \end{cases} \quad (1)$$

Where, $s(t)$ and $n(t)$ are the received signal and additive white Gaussian noise (AWGN) at the cognitive user respectively, $s(t)$ is the primary signal, h is the complex channel gain between primary user and the cognitive user. H_0 and H_1 denote the hypotheses corresponding to the idle state and busy state of the channel, respectively.

These important factors we also can define in our proposed scheme as follows:

P_f : false alarm probability which is the probability that sensing result is “busy”, but actually the channel is idle.

P_d : detection probability which is the probability that sensing result is “busy” and the channel is really busy.

P_m : miss probability is defined as the probability that the sensing result is “idle” but actually the channel is busy.

According to the definition of the important factors, we select the analysis of the [5] as follows,

The probability of detection and false alarm

$$P_f(\epsilon, T_s) = Q\left(\left(\frac{\epsilon}{\sigma_u^2} - 1\right)\sqrt{T_s f_s}\right)$$

$$P_d(\varepsilon, T_s) = Q\left(\left(\frac{\varepsilon}{\sigma_u^2} - \gamma - 1\right)\sqrt{\frac{T_s f_s}{2\gamma + 1}}\right) \quad (2)$$

Where, ε is the detection threshold, σ_u^2 is the Gaussian distribution mean value, T_s is the sensing time, f_s is the sample frequency, and the γ is the signal to noise ratio.

According to the $Q(\cdot)$

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty \exp\left(-\frac{t^2}{2}\right) dt \quad (3)$$

Where the $Q(\cdot)$ is the decrease function.

The relationship of P_f and P_d

$$P_f = Q\left(\sqrt{2\gamma + 1}Q^{-1}(P_d) + \sqrt{T_s f_s \gamma}\right) \quad (4)$$

III. OPTIMAL SENSING PERIOD

According to the ON-OFF channel model, there are four different cases for the sequent channel sensing. In this paper, we assumed that the sensing period $T_p \gg$ average ON time and $T_p \gg$ average OFF time, and we do not consider the case that the state change more than twice during the sensing period. Fig. 1 shows the possible channel states in a consecutive sensing time. S1 is the state that channel is busy during the consecutive channel sensing and the busy channel change into idle channel in S2 state. S3 is the state that the idle channel changes to busy channel during the consecutive sensing time, and the S4 state shows the channel is busy during the sensing period.

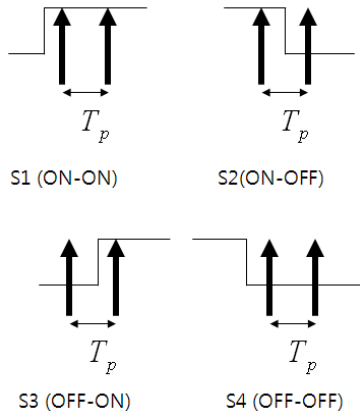


Figure 1. Spectrum sensing period four states in ON-OFF model

To find the probability of each state, we calculate the time portion that each state can occupies in an average ON-OFF time. Each of ON and OFF state are assumed to be independent and exponentially distributed with the mean of is $1/\lambda_X$ and

$1/\lambda_Y$ respectively, and figure 2 shows the consecutive sensing time and average ON-OFF time.

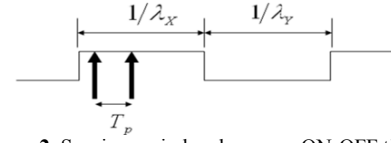


Figure 2. Sensing period and average ON-OFF time

In Figure 1, ON-ON case lasts for the time duration of $1/\lambda_X - T_p$. The ON-OFF and OFF-ON case last for T_p and the OFF-OFF case for last $1/\lambda_Y - T_p$ in an average ON-OFF time. Of course, the total duration of each case is same with the sum of average ON and OFF time. The probability of each states are obtained as follows

$$P_r(s1) = \frac{1/\lambda_X - T_p}{1/\lambda_X + 1/\lambda_Y} = \frac{\lambda_Y - T_p \lambda_X \lambda_Y}{\lambda_X + \lambda_Y} \quad (5)$$

$$P_r(s2) = \frac{T_p}{1/\lambda_X + 1/\lambda_Y} = \frac{T_p \lambda_X \lambda_Y}{\lambda_X + \lambda_Y} \quad (6)$$

$$P_r(s3) = \frac{T_p}{1/\lambda_X + 1/\lambda_Y} = \frac{T_p \lambda_X \lambda_Y}{\lambda_X + \lambda_Y} \quad (7)$$

$$P_r(s4) = \frac{1/\lambda_Y - T_p}{1/\lambda_X + 1/\lambda_Y} = \frac{\lambda_X - T_p \lambda_X \lambda_Y}{\lambda_X + \lambda_Y} \quad (8)$$

For ON-OFF case, even though the CR user detects the primary user in the channel, the channel becomes idle before the next sensing time and the CR user misses the idle time. The average ON and OFF time can be considered to be $T_p/2$, and we can get the average missing time T_m is

$$T_{m,s2} = P_r(s2) \frac{T_p}{2} \quad (9)$$

Similarly, for OFF-ON condition, the channel was idle at the first sensing time but the next sensing the primary user is detected. In that case, if the CR user transmits data, there will be an unexpected interference. The average unexpected interference time T_i is

$$T_{i,s3} = P_r(s3) \frac{T_p}{2} \quad (10)$$

First, we consider the probability of missing idle time T_m , which is the lost available idle time due to the sensing error or channel state change. The case s2 introduce the missing idle time due to the channel state change. For the ON-OFF condition, the missing probability is $P_d P_r(s2)$. For the OFF-OFF or OFF-ON state, CR user can miss the idle time due

to the channel sensing error, and the missing probability is $P_f(P_r(s3) + P_r(s4))$. So we can get the total missing probability

$$\begin{aligned} T_{m,ToT} &= T_{L,s2} + T_{L,s3} + T_{L,s4} \\ &= P_d P_r(s2) \frac{T_p}{2} + P_f P_r(s3) T_p + P_f P_r(s4) T_p \end{aligned} \quad (11)$$

The normalized total missing time

$$T_{nm,ToT} = \frac{1}{T_p} \left(P_d P_r(s2) \frac{(T_p - T_s)}{2} + P_f P_r(s3) (T_p - T_s) + P_f P_r(s4) (T_p - T_s) \right) \quad (12)$$

Even though the sensing result is idle, if channel state changes before the next sensing time, the cognitive user can interfere the primary user. We call it interference probability P_i

$$P_i = (1 - P_d) [P_r(s1) + P_r(s2)] + P_d P_r(s3) \quad (13)$$

The average interfering time can be obtained by

$$T_{i,avg} = (1 - P_d) [P_r(s1) + P_r(s2)] T_p + P_d P_r(s3) \frac{T_p}{2} \quad (14)$$

The normalized average interfering time

$$T_{ni,avg} = \frac{1}{T_p} \left((1 - P_d) [P_r(s1) + P_r(s2)] (T_p - T_s) + P_d P_r(s3) \frac{(T_p - T_s)}{2} \right) \quad (15)$$

The high missing idle time decreases the throughput, and the high interfering time increases the collision with the primary user. Equation (12) and (15) show that mission time, $T_{nm,ToT}$, and interfering time, $T_{ni,avg}$, will increase along with the sensing period, T_p . It means that smaller sensing period reduces missing probability and interfering probability, but the smaller sensing period increases the sensing time and power consumption. The increase of sensing time means the decrease of the time duration to transmit data.

The mission idle time due to the channel sensing can be described by

$$T_{ms} = P_d (P_r(s4) + P_r(s3)) T_s \quad (16)$$

The normalized mission idle time due to the channel sensing is

$$T_{nms} = \frac{1}{T_p} (P_d (P_r(s4) + P_r(s3)) T_s) \quad (17)$$

Where, T_s is the time duration to sense the channel. We assume that the sensing period include two parts: sensing duration and data transmission duration. Although channel is idle, CR user cannot transmit data in sensing duration.

Using the normalized missing time and normalized interfering time, we can get the system cost function according to the length of sensing period and sensing duration as follows

$$C = T_{nm,ToT} + T_{nms} + T_{ni,avg} \quad (18)$$

The interference to the primary user is more serious than the throughput reduction, and the cost function has different weight function for interference time and missing time. The missing idle time and interference time are mainly depends on the sensing period and sensing time. Using the cost function, we can find the optimal sensing period.

IV. SIMULATIONS

When we evaluate the protocol result, we select the single channel in the system. We assume the signal to noise rate γ is -18dB and sample frequency f_s is 6MHz.

The different system have different request for detection probability and false alarm probability. Usually, system have high request for false alarm probability, so we select the false alarm probability is equal to the 0.1. Then according to the different detection probability, we can select the different optimal sensing time. So in our simulation, according to the equation (4), we select the three factors as $P_d = 0.7, P_f = 0.1, T_s = 2.2ms$, $P_d = 0.8, P_f = 0.1, T_s = 3ms$, and $P_d = 0.9, P_f = 0.1, T_s = 4.6ms$.

We set the sensing period from 0.005second to 0.1second, and the $\lambda_\gamma, \lambda_x$ are the 1.5 and 0.8.

According to what we get the results of normalized total missing time and normalized average interfering time in part 3. We can get the figure 3 base on equation 12 and equation 15.

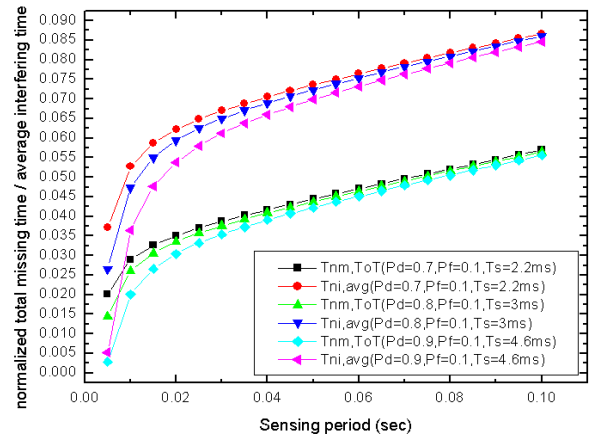


Figure 3. The normalized total missing time and the normalized average interfering time according to the sensing period T_p

From figure 3, we can know the normalized total missing time and normalized average interfering time will increase

when the sensing period increase. It is same with what we have supposed. Because if the sensing period is larger, the channel ON and OFF state have much more chance to change between each other, so the chance of missing idle hole and interference to primary user will increase in one sensing period. So we do not select the larger sensing period when we design the protocol. At the same time, when the sensing time is increased, the normalized total missing time and normalized average interfering time will be decreased, because the sensing time is increased, the data transmission to sensing period ratio will be decreased, the chance of missing idle hole and interfering time will be decreased.

Until here, we can know that there are two increase functions in figure 3. Of course we also can know the normalized mission idle time due to the channel sensing is the decreased function from equation (17). So we can find some appropriate sensing period value from the equation (18) when we design the sensing period for cognitive radio. All of these values can be the trade-off value between the spectrum sensing and data transmission.

According to the equation (18), we can get the figure 4 as follows

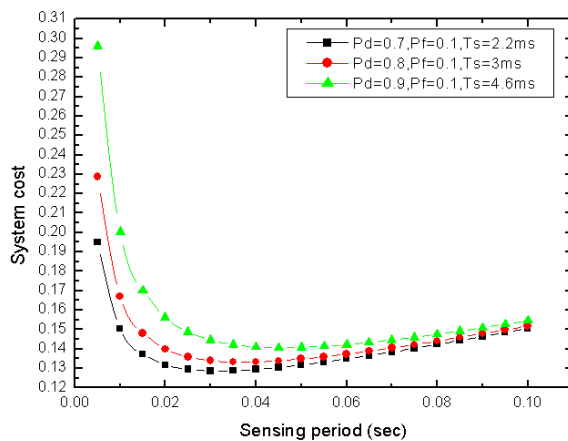


Figure 4. System cost is according to the sensing period base on different detection and false alarm probability and sensing time

From the figure 4, we can system cost minimum values in different lines. This minimum value is the optimal sensing period base on different detection and false alarm probability of system request and optimal sensing time. When the optimal sensing time is increased, the system cost also increase, because the normalized mission idle time due to the channel sensing is increased.

V. CONCLUSIONS

In this paper, through analyzing four important conditions in sensing period, we know relationship between spectrum sensing and data transmission in sensing period. Proposed algorithm shows us optimal sensing period is better trade-off between spectrum sensing and data transmission and simulations approve that. According to the different system request, the algorithm can be selected by setting different weight value for meeting the system request.

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