# Time Scheduling Based on Tradeoff between Detection Performance and QoS Requirement

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**Abstract.**[1] A time scheduling scheme satisfying both the detection performance of a cognitive node in cognitive networks and the QoS requirement of a secondary user under fading channels is proposed in this paper. First, an optimal sensing time is obtained by maximizing the achievable throughput of a secondary user under the constraint that the primary user is sufficiently protected. Then, according to the second order statistic characteristics of fading channels, the transmission time is defined under the outage capacity constraint of a secondary user. Finally, a secondary sensing time is defined for the necessary of both primary protection and the guarantee of transmission QoS. It turns out to be an efficient scheme of spectrum utilization and time scheduling.

**Keywords:** dynamic scheduling, cognitive node, channel characteristics, optimal sensing time, detection performance, QoS requirement.

## 1 Introduction

Spectrum sharing [1]-[4] is a promising and efficient technique for solving the problem of spectrum crisis. Cognitive technique, or cognitive radio [5]-[7], is considered as a necessary and key technique for the implement of spectrum sharing as well as cognitive networks. In a cognitive network, from a secondary user point of view, the maximum throughput which is necessary for a certain QoS requirement should be guaranteed when a secondary user is permitted to access a licensed spectrum band. The longer the transmission time, the more data rate a secondary user can be transmitted. However, from a primary user point of view, it is hoped that the interference from a secondary user is as little as possible. On the other words, the secondary user must sense the presence of a primary user as soon and accurate as possible. This means the detection performance correlated to the sensing time should be guaranteed for a cognitive node. The longer the sensing time, the higher detection probability can be obtained. So, the sensing

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time for detecting the primary user and the transmission time for a secondary user is a contradiction.

There are many achievements considering some points of above problem, such as papers [8]-[13]. In [9], the authors proposed an adaptive scheduling scheme considering the channel side information (CSI) and QoS guarantee separately. In [10], the authors studied the fundamental tradeoff between sensing capability and achievable throughput and proposed the design scheme for sensing slot duration to maximize the achievable throughput under no-fading channels. Here, we consider both sides in paper [9] jointly and extend the results in [10] to fading channels. This results in a novel and more efficient time scheduling scheme which satisfies both the detection performance of a cognitive node and the QoS requirement of a secondary user under fading channels.

The paper is organized as following. Section II gives the novel scheduling scheme. The conceptions in this scheme are explained in detail in section III. The results are given in section IV. Section V is conclusions.

## 2 Time Scheduling Scheme

Figure 1 is the framework of our new scheduling scheme. It shows an available spectrum band for a single cognitive node of a single secondary user in one cognitive network. The time axis is divided into frames. Each frame of duration $T_f$ is further divided into some slots. The wide gray slot duration $T_s$ is used to sense the presence of a primary user on this spectrum band. The white slot duration $T_d$ is used to transmit data of a secondary user. The narrow gray slot duration $T_{ss}$ is named as secondary sensing time here which is a new definition in our scheme. At the beginning for a spectrum band, a cognitive node sensing whether the primary user is absent on this band during $T_s$ which is optimized in the next section. If the band is free, the secondary user is permitted to transmit its data during $T_d$ which is determined by the outage probability as well as the fading channel characteristics. This will be explained in the next section. If

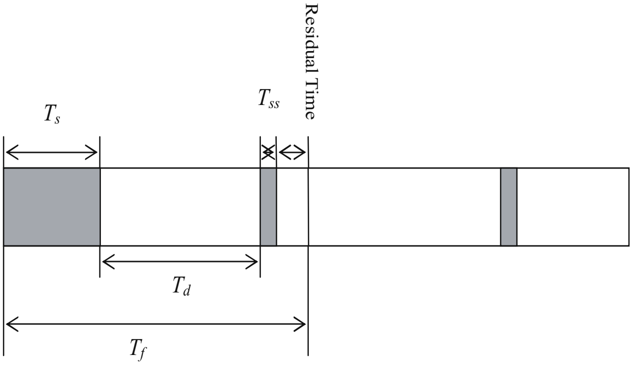

**Fig. 1.** The time scheduling scheme proposed in this paper

$T_s + T_d < T_f$, It is necessary in the same frame to sense the primary user again since the channel states may change because of the presence of the primary user. This sensing is done during $T_{ss}$. If $T_s + T_d + T_{ss} < T_f$, there is residual time in the same frame where the secondary user can continue to transmit its data sequence if the primary is absent. If $T_s + T_d \geq T_f$, $T_{ss}$ is set in the next frame. If there is no primary user, the secondary user goes on transmitting its data in the second $T_d$. Then, the whole processing is in a cycle until the primary user appears again.

## 3 Definitions of the Parameters

### 3.1 Average Detection Threshold

First of all, the average detection threshold should be defined. In [14], the author gave the expressions of detection probability and false alarm probability under no-fading channels in $Q$ functions. While, in [8], these expressions were transformed into $Erfc$ functions. Here, we use the latter format and rewrite these functions as following.

$$P_f = \frac{1}{2} Erfc(\frac{1}{\sqrt{2}} \frac{\gamma_{th1} - 2m}{\sqrt{4m}}) \tag{1}$$

$$P_d = \frac{1}{2} Erfc(\frac{1}{\sqrt{2}} \frac{\gamma_{th1} - 2m(\gamma + 1)}{\sqrt{4m(2\gamma + 1)}}) \tag{2}$$

Where, $\mathrm{Erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2} dt$. The quantity $\gamma_{th1}$ is a chosen channel-signal-noise rate (CSNR) threshold for detection. The quantity $\gamma$ is the CSNR of the primary user received at the receiver of the secondary network. The quantity $m$ is the time-bandwidth product. If the sampling frequency of the band-pass filter is $f_s$ which is also equal to the bandwidth of the signal and the observation interval is $T_s$, $m = T_s f_s$. From Equation (2), the detection threshold under no-fading channels as

$$\gamma_{th1} = 2\mathrm{Erfc}^{-1}(2\overline{P}_d)\sqrt{2m(2\gamma + 1)} + 2m(\gamma + 1) \tag{3}$$

Where, $\bar{P}_d$ is the target detection probability. In a fading channel, Equation (3) should be averaged as

$$\begin{aligned} \overline{\gamma_{th1}} &= \int_\gamma \gamma_{th1} f_\gamma(\gamma) d\gamma \\ &= \int_\gamma [2\mathrm{Erfc}^{-1}(2\overline{P}_d)\sqrt{2m(2\gamma + 1)} + 2m(\gamma + 1)] f_\gamma(\gamma) d\gamma \end{aligned} \tag{4}$$

Here, $f_\gamma(\gamma)$ is a probability density function (PDF) of CSNR for fading channels. For a Rayleigh channel,

$$f_\gamma(\gamma) = \frac{1}{\overline{\gamma}} e^{-\gamma/\overline{\gamma}} \tag{5}$$

Substituting (5) into (4), after some manipulation, there is

$$\begin{aligned}\overline{\gamma_{th1}} &= \int_{\gamma}\gamma_{th1}f_{\gamma}(\gamma)d\gamma \\ &= \tfrac{1}{\overline{\gamma}}\int_{0}^{\infty}[2\mathrm{Erfc}^{-1}(2\overline{P}_d)\sqrt{2m(2\gamma+1)}+2m(\gamma+1)]e^{-\gamma/\overline{\gamma}}d\gamma \\ &= 4\sqrt{m\overline{\gamma}}Erfc^{-1}(2\overline{P}_d)e^{1/2\overline{\gamma}}\Gamma(\tfrac{3}{2},\tfrac{1}{2\overline{\gamma}})+2m\overline{\gamma}e^{1/\overline{\gamma}}\Gamma(2,\tfrac{1}{\overline{\gamma}})\end{aligned} \tag{6}$$

The quantity $\bar{\gamma}$ is the average CSNR of fading channels.

### 3.2 Optimal Sensing Time

According to paper [10], the achievable throughput for a secondary user is defined as

$$R = \frac{T_f - T_s}{T_f}(1 - P_f)C_0 \tag{7}$$

Where, $C_0$ denotes the throughput of the secondary user when it operates in absence of primary user. Obviously, the achievable throughput is a function of sensing time $T_s$. So, the optimal $T_s$ can be obtained by the following optimization problem

$$\begin{aligned}&\max\ \ R = \tfrac{T_f - T_s}{T_f}(1 - P_f)C_0 \\ &s.t.\ \ \ P_d \geq \overline{P}_d\end{aligned} \tag{8}$$

### 3.3 Transmission Time

To guarantee a requirement maximum throughput for a secondary user, the transmission must be under a certain outage probability which defined as [15]-[16]

$$P_{out} = P_r\{\frac{1}{2}\log(1+\gamma_s) < R\} \leq \varepsilon \tag{9}$$

Where, the parameter $\varepsilon$ is the given outage probability and $\gamma_s$ is the received CSNR at the secondary receiver. In order to guarantee the throughput $R$, $\gamma_s$ should be greater or equal to the CSNR threshold which is defined as

$$\gamma_{th2} = e^{2R} - 1 \tag{10}$$

Besides, the transmission is also determined by fading channel states. Here, the data transmission time $T_d$ for the achievable throughput of the secondary user is defined as the average fading time [17] when the CSNR of the secondary user falls in $[\gamma_{th2}, \overline{\gamma_{th1}})$, that is

$$\overline{T}_d = \frac{p(\gamma_{th2} \leq \gamma < \overline{\gamma_{th1}})}{N_2 - N_1} \tag{11}$$

$$N_j = \sqrt{\frac{2\pi\gamma_j}{\overline{\gamma}}}f_D e^{-\gamma_j/\overline{\gamma}} \tag{12}$$

Where, $p(\gamma_{th2} \leq \gamma < \overline{\gamma_{th1}})$ is the probability when the CSNR falls in $[\gamma_{th2}, \overline{\gamma_{th1}})$. And $N_j$ is the level crossing rate (LCR). The expression of LCR in Rayleigh channel is defined in (12) where $f_D$ is the maximum Doppler frequency.

### 3.4 Secondary Sensing Time

After $T_d$, the CSNR maybe changed because of the change of channel states or the presence of the primary user. It is necessary to sense the channel again. This is why to defined secondary sensing time $T_{ss}$. Because it is a tough sensing, it is defined as a part of $T_s$ from the frequency efficiency point of view, that is,

$$T_{ss} = kT_s \tag{13}$$

Here, the factor $k$ is obtained by

$$P_f = \frac{1}{2}Erfc([\sqrt{2\overline{\gamma}}Erfc^{-1}(2\overline{P}_d)e^{1/(2\overline{\gamma})}\Gamma(\frac{3}{2}, \frac{1}{2\overline{\gamma}}) + \sqrt{\frac{kT_s f_s}{2}}(\overline{\gamma}e^{1/\overline{\gamma}}\Gamma(2, \frac{1}{\overline{\gamma}}) - 1)]) \leq \overline{P}_f \tag{14}$$

Given a target false alarm probability $\overline{P}_f$, the minimum value of factor $k$ can be obtained by solving (14). Till now, all the parameters in our time scheduling scheme in Fig.1 are determined.

## 4 Simulation Results

In this section, computer simulation results are presented to evaluate the time scheduling scheme satisfying both the detection performance of a cognitive node in cognitive networks and the QoS requirement of a secondary user under fading channels proposed in this paper. According to [10] and IEEE 802.22 standard, the primary user is assumed to be a M-PSK modulated signal with bandwidth of $6MHz$ and the sampling frequency is the same as the bandwidth of the primary user. The SNR for primary user received at the secondary user's receiver is $-15dB$. The frame duration $T_f = 200ms$, and the target probability of detection is assumed $P_d = 0.9$. First of all, Fig.2 shows the normalized achievable throughput for the secondary network, which is defined as $(T_f - T_s)(1 - P_f)/T_f$. It is the comparison between the result in [10] which is denoted by the real line and the result of our scheme according to (6) which is denoted by the x-mark line. It reveals a maximum point of the throughput at the sensing time of about $3.0ms$ under fading channels. It is same as that of no-fading channels case. However, the maximum value of the throughput is less than that of no-fading channels case. Then, Fig.3 shows the result of the normalized average spectral efficiency (ASE) which is defined as

$$\overline{ASE} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{n} T_{d_{ij}}}{\sum_{i=1}^{N} T_{fi}} \tag{15}$$

The parameter $N$ denotes the number of frames and n denotes the number of data transmission duration for a secondary user. The real line denotes the result using the new scheme proposed in Fig.1 of this paper. The x-mark line denotes the result of optimal CSI-based scheduling policy shown in [9]. It reveals that the new scheme can obtain a higher ASE than that of CSI-based scheme especially at low average CSNR.

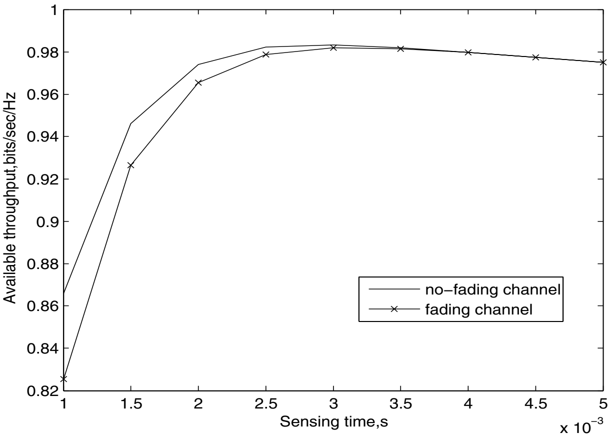

**Fig. 2.** The normalized achievable throughput for a secondary user

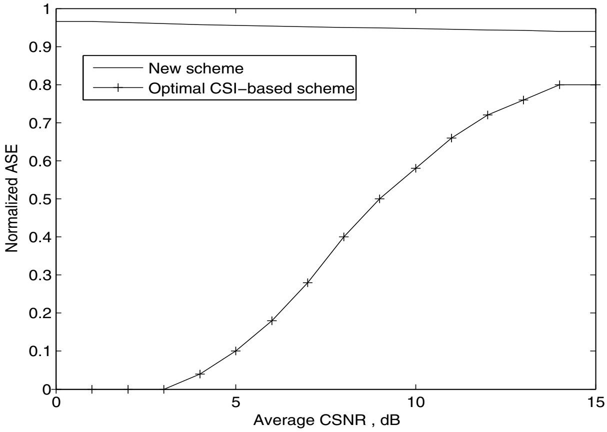

**Fig. 3.** The normalized ASE for a secondary user

## 5 Conclusions

In this paper, we propose a time scheduling scheme satisfying both the detection performance in cognitive networks and the QoS requirement of a secondary user under fading channels. The optimal sensing time is obtained under the new defined detection threshold in fading channels. Both the simulation result and the theoretic result show that the maximum throughput of the secondary user corresponding optimal sensing time exists. The optimal sensing time duration is the same for both no-fading channels and fading channels. But the maximum throughput is different for two cases. The normalized ASE shows that the new scheduling scheme can obtain a higher ASE than that of the current optimal scheme. It is necessary to research the frame error rate and power efficiency for both the secondary network and the primary network in our scheme for our future work.

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