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Serial Search of Vacant Channel in Cognitive Radio Devices with Single Radio Frequency Tranceiver

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Abstract

This paper derives the mean channel search time of a serial search scheme in terms of an vacant channel search using single radio frequency (RF) tranceiver. Also, it does the mean channel search time considering a penalty time due to a false alarm when the cognitive radio (CR) system operates multiple frequency channels. The numerical results suggest the optimal channel detection time using the derived mean channel search time of a serial search scheme in case of CR hardware structure with single RF path.

Keywords: Sensing, channel search optimization, vacant channel search, cognitive radio (CR).

I. INTRODUCTION

The licensed spectrum allocation method appears to have low spectrum utilization in many parts of the frequency band. In the Federal Communications Commission (FCC) definition, a cognitive radio (CR) system is a spectrum utilization that allows secondary users to use spectrum licensed to primary users when they are inactive [1]. In order to utilize the inactive frequency bands, the secondary users must perform the spectrum sensing for the CR-used frequency bands frequently or periodically. The main reasons for spectrum sensing in secondary users can be classified into two types. The first is to acquire an communication channel for secondary user, and the second is to check the appearance of primary users for the corresponding channel that a secondary user is utilizing. In conventional research, the tradeoff between sensing time and throughput in a CR system is an important issue for sensing optimization. Because there is a tradeoff between channel monitoring time and throughput, researches on the optimal sensing time have been performed in terms of throughput or throughput efficiency [2]-[4]. On the other hand, this paper evaluates the sensing performance in terms of the mean channel search time of a serial search scheme when the secondary user (SU) searches an vacant channel in multiple frequency channels.

Thus, this paper considers hardware limitation of CR devices [5]. In order to reduce the hardware complexity, this paper handles the case that the CR device can not simultaneously operate both spectrum sensing and data transmission due to single RF path. Based on the hardware limitation, this paper derives the mean channel search time of a serial search scheme in consideration of the penalty time, which is caused by the false alarm due to a missed detection of a primary user (PU) signal. Also, if the CR system does not detect primary users during CR operation, this paper suggests the PU detection delay as the delay time caused by the continuous channel monitoring due to a missed detection. Thus this paper derives the mean channel search time of a serial search scheme considering the penalty time. As a result, it suggests the optimal channel detection time corresponding to the minimum channel search time.

This paper is organized as follows. In section II, the vacant channel search model is suggested. Then the mean channel search time of a serial search scheme is described. Numerical results are presented in section III, and finally a conclusion is offered in section IV.

VACANT CHANNEL SEARCH MODEL

In order to use the license band of primary users, secondary users must investigate the vacancy of frequency channels using spectrum sensing.

Figure 1 shows the procedure of vacant channel utilization and periodic channel monitoring in a CR system. In the figure, the initial channel search time and channel search time, T_{search}, are the times to acquire the CR-operating channel during which a CR system searches the vacant channel due to CR network initialization and the appearance of the primary users. Also, the secondary users perform the spectrum sensing to identify the appearance of a primary user through the periodic channel monitoring process, as shown in Fig. 1.

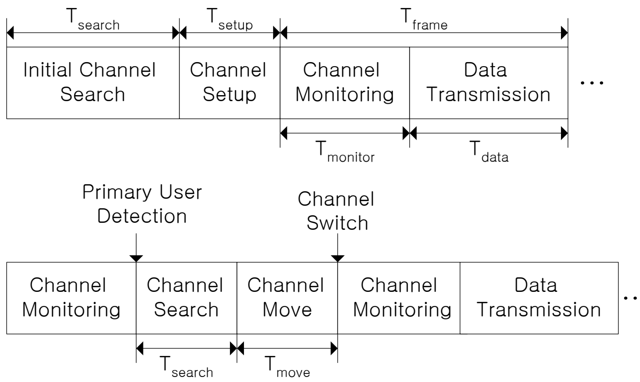

Figure 1. Procedure of vacant channel utilization and periodic channel monitoring in a CR system.

The channel monitoring process to identify the appearance of incumbent users is performed periodically using sensing parameters such as frame length(sensing period), T_{frame}, and channel monitoring time, $T_{monitor}$, as shown in Fig. 1. Then, if the primary user signal appears in the CR-operating channel, the secondary user must switch to another vacant channel.

The referred paper to be studied early has handled the sensing optimization for the sensing structure of two separate RF paths [4]. However, this paper does sensing parameters related to the optimal selection of the channel detection time in a serial search scheme. In general, the single RF tranceiver has been required in order to reduce the hardware complexity of CR devices [4],[5]. Thus, this paper handles the serial search scheme in terms of the hardware limitation of single RF tranceiver and derives the mean channel search time of a serial search scheme.

In this paper, the serial search scheme for an vacant channel search is performed as follows. If the secondary user acquires an vacant channel of N frequency channels, the channel search success is declared, and then the vacant channel to be acquired is assigned to the SU-operating channel.

For cases when a primary user signal appears during a CR operation, the previous research proposes a serial search method in which a secondary user searches another vacant channel without penalty time due to a missed detection of a primary user signal [2]. A state diagram of a serial search scheme for the channel search performed on N frequency channels, except for the *k*-th SU-operating channel, when the number of total frequency channels in the CR system is given as N+1, is shown in Fig. 2.

In Fig. 2, a search success (SS) state is defined as the state that acquires an vacant channel successfully, while a missed detection (MD) state is described as a case in which a vacant channel is declared incorrectly due to a false alarm on the existence of a primary user signal. From Fig. 2, $C_i, i = 0,1,...,N-1$ is the *i*-th frequency channel, $h_v(z)$ is the path function that searches an vacant channel successfully, and $h_d(z)$ is the path function that detects correctly the existence of a primary user signal. Finally, $h_{md}(z)$ is the path function that declares incorrectly an vacant channel during the existence of a primary user signal, and z^J is the penalty time that is given by a false alarm of an vacant channel due to a missed detection of a primary user signal in the channel search process.

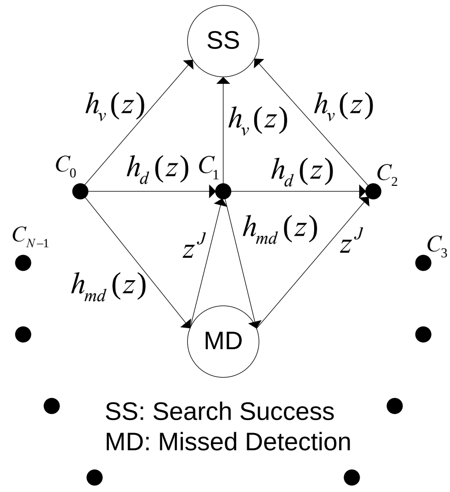

Figure 2. State diagram of the serial search process.

From Fig. 2, $h_v(z)$, $h_d(z)$, and $h_{md}(z)$ are represented by

$$h_v(z) = P(H_0)(1-P_f^s)z, \quad (1)$$

$$h_d(z) = \left\{P(H_0)P_f^s + P(H_1)P_d^s\right\}z, \quad (2)$$

and

$$h_{md}(z) = P(H_1)(1-P_d^s)z, \quad (3)$$

where $P(H_0)$ is defined as a probability that a primary user signal is inactive, and $P(H_1)$ is defined as a probability that a primary user signal is active, $P(H_0)+P(H_1)=1$ [3][4]. P_d^s and P_f^s are the probabilities of signal detection and false alarm in the channel search process, respectively. In Fig. 2, if $h_v(z)$ is the success function of the channel search of an vacant channel, $h_{nv}(z)$ is the failure function of the channel search of an vacant channel. Thus, $h_{nv}(z)$ is given by

$$\begin{aligned} h_{nv}(z) &= h_d(z) + h_{md}(z)z^J \\ &= \left\{P(H_0)P_f^s + P(H_1)P_d^s\right\}z + P(H_1)(1-P_d^s)z^{J+1} \end{aligned} \quad (4)$$

From Fig. 2, performing a serial search for N available channels, the success function of the channel search, $H_V(z)$ is given by

$$\begin{aligned} H_V(z) &= h_v(z) + h_{nv}(z)h_v(z) + h_{nv}^2(z)h_v(z) + ... \\ &\quad + h_{nv}^{N-1}(z)h_v(z) \\ &= h_v(z)\sum_{i=0}^{N-1} h_{nv}^i(z) \end{aligned} \quad (5)$$

The transfer function that starts a channel search at the *i*-th channel is given by

$$U_i(z) = \frac{H_V(z)}{1-h_{nv}^N(z)} \tag{6}$$

From Fig. 2, since all channels are equally likely a priori, the total transfer function averaged over all N frequency channels is represented by

$$\begin{aligned} U(z) &= \frac{1}{N}\sum_{i=0}^{N-1} U_i(z) \\ &= \frac{H_V(z)}{1-h_{nv}^N(z)} \end{aligned} \tag{7}$$

Thus, the mean channel search time of serial search scheme is given by

$$\begin{aligned} \bar{T}_{search} &= \frac{d}{dz}\ln U(z)\Big|_{z=1} \tau_D \\ &= \left[\frac{H_V^{'}(1)}{H_V(1)} + \frac{Nh_{nv}^{'}(1)h_{nv}^{N-1}(1)}{1-h_{nv}^N(1)}\right]\tau_D \end{aligned} \tag{8}$$

where τ_D is the channel detection time in the channel search process. Also, $H_V(1)$, $H_V^{'}(1)$, $h_v(1)$, $h_v^{'}(1)$, $h_{nv}(1)$, and $h_{nv}^{'}(1)$ are given by-

$$H_V(1) = h_v(1)\frac{1-h_{nv}^N(1)}{1-h_{nv}(1)}, \tag{9}$$

$$\begin{aligned} H_V^{'}(1) &= h_v^{'}(1)\frac{1-h_{nv}^N(1)}{1-h_{nv}(1)} \\ &+ h_{nv}^{'}(1)h_v(1)\left[\frac{1-h_{nv}^N(1)-Nh_{nv}^{N-1}(1)}{1-h_{nv}(1)}\right] \end{aligned}, \tag{10}$$

$$h_v(1) = P(H_0)(1-P_f^s), \tag{11}$$

$$h_v^{'}(1) = P(H_0)(1-P_f^s), \tag{12}$$

$$h_{nv}(1) = P(H_0)P_f^s + P(H_1), \tag{13}$$

$$h_{nv}^{'}(1) = P(H_0)P_f^s + P(H_1) + JP(H_1)(1-P_d^s) \tag{14}$$

NUMERICAL RESULTS

In this paper, a primary user signal for the numerical results is assumed to be a binary phase shift keying (BPSK) signal with the 10 kHz bandwidth. Energy detection is performed for the primary user signal, and the sampling rate of the energy detector is assumed to be 10 kHz. The channel model of the CR systems is assumed to be the Rayleigh fading channel. Considering the Rayleigh fading channel [6][7], the probabilities of signal detection and false alarm during the channel search are given by

$$P_d^s = e^{-\lambda/V_F}\sum_{k=0}^{L-1}\frac{(\lambda/V_F)^k}{k!}, \tag{15}$$

$$P_f^s = e^{-\lambda/V_N}\sum_{k=0}^{L-1}\frac{(\lambda/V_N)^k}{k!}, \tag{16}$$

where L is the time-bandwidth product and λ and V_N are detection threshold and noise variance, respectively. V_F is given by

$$V_F = V_N(1+\bar{\mu}), \tag{17}$$

where $\bar{\mu}$ is the average SNR of a primary user signal for the Rayleigh fading channel.

The total number of the frequency channels is assumed to be 31 with a bandwidth of 10 kHz in the operating bandwidth of the CR system. The frame length of the CR system, T_{frame}, is assumed to be 100 ms, and then the channel move time, T_{move}, is assumed to 10 ms. The channel detection time, τ_D of the energy detector is set to be selected from 0.5 ms to 10 ms variably.

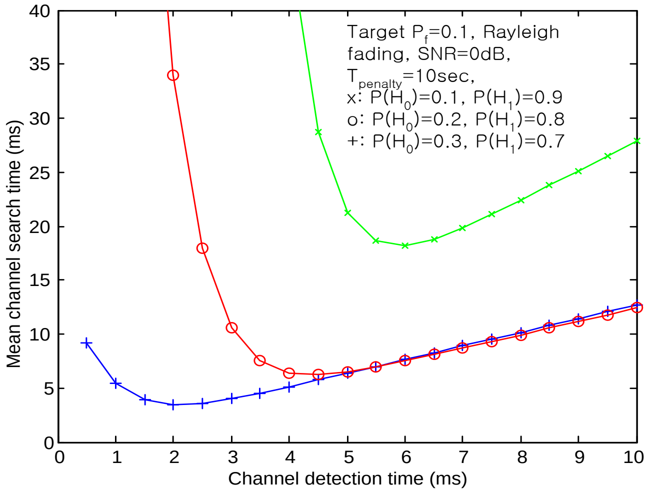

Figure 3. Mean channel search time versus channel detection time according to vacant channel distribution.

Figure 3 shows the mean channel search time for the sensing structure with single RF path when the penalty time is given as $100T_{frame}$. In this figure, the changes of mean channel search time for the channel detection time are largely shown when $P(H_0)$ is small and $P(H_1)$ is relatively large. Thus, the selection of the optimal channel detection time becomes an important issue when $P(H_0)$ is less than 0.2 as shown in Fig. 3.

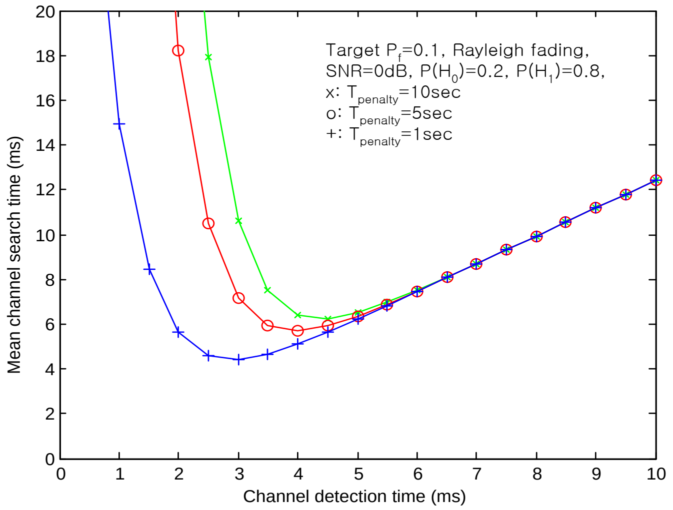

Figure 4. Mean channel search time versus channel detection time according to penalty time length.

Figure 4 shows the mean channel search time for the variations of penalty time length due to false alarm caused by a missed detection. In this figure, the mean channel search times are the same when the channel detection times are larger than 5ms in case of $P(H_0)$=20% and $P(H_1)$=80%. Those results are attributed to the reason that a signal detection probability is more than 95%.

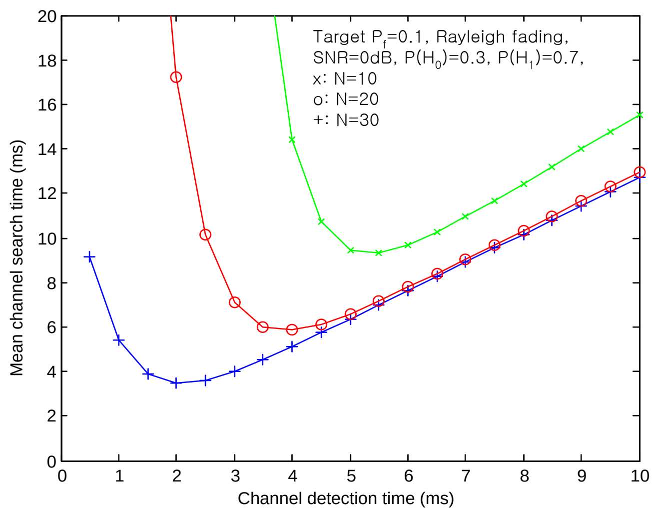

Figure 5. Mean channel search time versus channel detection time according to number of frequency channels.

Figure 5 shows the mean channel search time for variations of the number of frequency channels. This figure shows that the channel detection time to obtain the optimal channel search time increases gradually when the number of frequency channels reduce from 30 to 10 in case of SNR=0dB and $P(H_0)$=30%

CONCLUSION

This paper handles the optimal selection of a channel detection time in terms of the mean channel search time of a serial search scheme. It also derives the mean channel search time of a serial search scheme in consideration of the penalty time, which is caused by the false alarm due to a missed detection of a primary user signal. The numerical results suggest the optimal channel detection time in terms of vacant channel distribution, penalty time length, and the number of frequency channels using the mean channel search time.

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