Research Article

Channel Sensing without Quiet Period for Cognitive Radio Systems: A Pilot Cancellation Approach

Dong Geun Jeong,[1] Sang Soo Jeong,[2] and Wha Sook Jeon[2]

[1] *Department of Electronics Engineering, Hankuk University of Foreign Studies, Yongin-si, Kyonggido 449-791, Republic of Korea*
[2] *School of Electrical Engineering and Computer Science, Seoul National University, Seoul 151-742, Republic of Korea*

Correspondence should be addressed to Dong Geun Jeong, dgjeong@hufs.ac.kr

The cognitive radio (CR) systems usually arrange for the quiet period to detect the primary user (PU) effectively. Since all CR users do not transmit any data during quiet period, the interference caused by other CR users can be prevented in the channel sensing for PU detection. Even though the quiet period improves the PU detection performance, it degrades the channel utilization of CR system. To cope with this problem, we propose a channel sensing scheme without quiet period, which is based on the pilot cancellation, and analyze its performance. The numerical results show that the proposed scheme highly outperforms the existing PU detection schemes.

1. Introduction

The cognitive radio (CR) system exploits the spectrum band that is originally assigned to licensed primary users (PUs) but not used at a specific time and a specific location. When a PU is activated newly, the CR system should move out the spectrum band. Thus, to detect the appearance of a PU is one of the most important tasks in CR systems. To detect PU without interference from CR users themselves, the CR system usually has "quiet period," during which all CR users do not access the channel [1–3]. However, the use of quiet period degrades the channel utilization of the CR system and also deteriorates the quality of service (QoS) of the CR users [3]. If the CR system performs PU detection when the system is idle (i.e., it has no traffic to be transmitted), the performance degradation can be mitigated. However, since the CR system should detect PU within a given time after its appearance [1], the "regular" channel sensing is unavoidable even when the system is busy.

To maintain high utilization of channel in PU detection essentially, the PU detection schemes without quiet period have been proposed recently. In [4, 5], we have proposed a nonquiet PU detection scheme for the orthogonal frequency division multiple access-(OFDMA-) based CR system, with

which the CR users detect the PU by using the subcarriers that are utilized for the data transmission. Although the scheme can improve the performance of both CR system and PU, it only considers the data subcarriers and does not exploit the pilot subcarriers for the PU detection. In [6], the PU detection scheme exploiting complementary symbol couple (CSC) in pilot signal has been proposed. When the sum of two adjacent pilot symbols of CR system is zero, they satisfy the complementary condition. If two OFDM symbols satisfying the complementary condition are added, the pilot interference becomes zero whereas the noise and the PU signal still remain. Thus, PU detection without quiet period can simply be accomplished. However, its detection performance is limited since only a part of pilot symbols satisfies the complementary condition.

In this paper, we propose a novel nonquiet PU detection scheme which is based on pilot cancellation (see Figure 1). Since the information content of the pilot signal from the CR transmitter is known a priori to all other CR users in the system, the receiver (i.e., the detector) CR users can easily remove it from the received signal (e.g., [7]). If the pilot signal is transmitted via a specific channel(s) (e.g., the pilot subcarriers in OFDM systems) and the CR users check the existence of PU on the channel(s) after the pilot
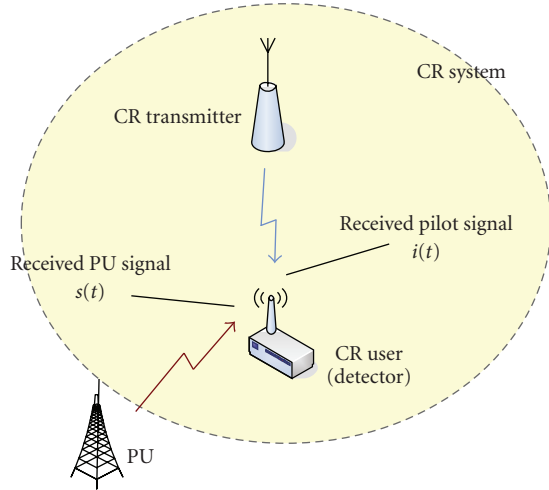
FIGURE 1: PU detection without quiet period.

cancellation, they can accomplish PU detection without quiet period. Although the proposed concept can be applied to any CR systems using pilot signal on a specific channel, for the purpose of convenient description, we in this paper consider only the OFDMA-based CR system such as IEEE 802.22 [1], where some subcarriers are dedicated to the pilot signal. In contrast to the scheme in [6], the proposed scheme can exploit all OFDM symbols of pilot subcarriers for PU detection. Therefore, the CR users can achieve better detection performance with the proposed scheme.

Even though the concept of pilot cancellation is not new and well known, its application to the PU detection in CR system is a novel approach. Moreover, the proposed scheme improves the CR system performance *not from the detection-theoretical aspect but from the system level resource management aspect*. In practice, the latter is more important. The remainder of this paper is organized as follows. Section 2 describes the system model under consideration. The proposed scheme is presented in Section 3, and a theoretical analysis for its performance is given in Section 4. Section 5 discusses the performance of the proposed scheme with some numerical examples from theoretical analysis and simulation. Finally, the paper is concluded with Section 6.

2. System Model

We consider an OFDMA-based CR system. The spectrum band of the CR system is fragmented into multiple subcarriers that are equally spaced. Among them, M subcarriers are used for transmitting pilot sequence which is known to all CR users. The pilot signal is commonly used for the channel estimation and the synchronization. The proposed scheme can be applied to both the system with a single CR transmitter (e.g., downlink of a CR cell) and that with multiple CR transmitters (e.g., uplink of a CR cell). In the former case, the single CR transmitter utilizes all pilot subcarriers; in the latter case, the pilot subcarriers can be distributed among multiple CR transmitters.

The system under consideration adopts the frame structure, where the frame length corresponds to L OFDM symbol durations (see Figure 2). In many existing (non-CR) systems, "frame" is the time unit corresponding to the source and/or channel coding block. Thus, the channel measurement reporting for channel adaptation mechanism (e.g., the power control and the adaptive modulation and coding) is usually carried out frame-by-frame basis. If the channel condition changes largely during a frame, the channel estimation is likely to be inaccurate, and the system performance can be severely degraded. To avoid this situation, the frame length in practical systems is decided so that the channel variation during a frame is small enough to be neglected. In this paper, we design the PU detection scheme that can be implemented into the existing frame-structured systems. Thus, it is assumed that the channel state for a CR transmitter-receiver pair does not vary during a frame.

For pilot signal, a total of $M \times L$ OFDM symbols are transmitted in a frame (see Figure 2). We assume that, in the case with multiple CR transmitters, each pilot subcarrier is assigned to a specific CR transmitter for a whole frame. The frame is the basic time unit of PU detection.

Since there are in-phase and quadrature branches for each pilot subcarrier, $2M$ correlators are needed for a CR receiver to extract all pilot components. Let us index the correlators, respectively, by $1, \ldots, M$ for in-phase components and $M + 1, \ldots, 2M$ for quadrature components. Let t is the time index *defined during a frame*. And let $\phi_{m,l}(t)$ denote the basis function for the OFDM symbol l ($1 \leq l \leq L$) of mth correlator in a frame. When T_O is the OFDM symbol duration, $\phi_{m,l}(t)$ is as follows [8]:

$$
\phi_{m,l}(t)
$$
$$
:= \begin{cases} \sqrt{\dfrac{2}{T_O}} \cos\left[2\pi\left(f_c + \dfrac{m}{T_O}\right)t\right] & \text{if } m = 1, \ldots, M, \\[2ex] \sqrt{\dfrac{2}{T_O}} \sin\left[2\pi\left(f_c + \dfrac{m-M}{T_O}\right)t\right] & \text{if } m = M+1, \ldots, 2M, \end{cases}
$$
$$(1)$$

where $(l-1)T_O \leq t \leq lT_O$ and f_c is the center frequency of CR system. Since the pilot signal is a control signal of vital importance, a modulation technique with high noise immunity such as the binary phase shift keying (BPSK) modulation is generally used for transmitting the pilot signal in practice [2]. We assume a BPSK-modulated pilot signal in describing the proposed scheme. It is also assumed that all users in the CR system are synchronized. (Since the proposed scheme is based on the CR pilot cancellation, its performance is affected by the synchronization error between the CR transmitter and the CR receiver (PU detector) in sensing. However, according to our simulation results, the performance degradation can be negligible when the synchronization error is less than the allowable error for the reliable data transmission (e.g., in [9]).

Let $r(t)$ denote the signal received by a CR user. Depending on whether the PU signal exists or not, there can be the following two hypotheses on the pilot subcarriers:
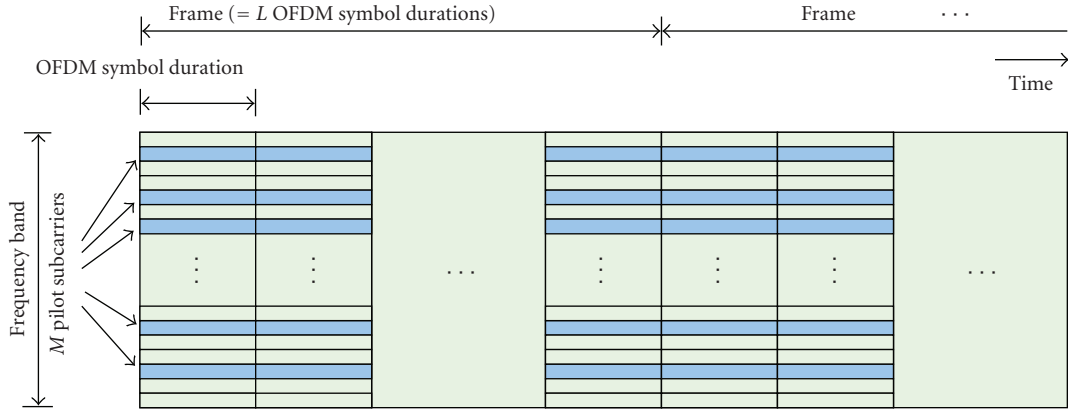
FIGURE 2: Frame structure.

(i) *PU present hypothesis, $H_1 : r(t) = i(t) + n(t) + s(t)$,*

(ii) *PU absent hypothesis, $H_0 : r(t) = i(t) + n(t)$,*

where $i(t)$, $n(t)$, and $s(t)$ are the received CR pilot signal, the noise, and the received PU signal, respectively, (see Figure 1). We assume that $n(t)$ is a white Gaussian noise with two-sided power spectral density σ_N^2. It is noted that the received signal *includes the CR pilot signal*, in contrast to the case with the quiet period, since we consider the nonquiet PU detection.

3. Proposed Scheme

3.1. Operation Overview. With the proposed scheme, a CR user carrying out PU detection first removes the pilot signal from the signal received on the pilot subcarriers (i.e., $i(t)$ is removed from $r(t)$) and then makes a decision on the existence of PU. This procedure consists of the following four steps on a per frame basis: (1) *sampling:* the CR user collects the received signal samples (i.e., correlator outputs) during a frame; (2) *channel estimation:* at the end of the frame, the CR user estimates the channel coefficient from the transmitter CR user by using the received signal samples and the (known) pilot sequence; (3) *pilot cancellation:* the CR user removes the pilot interference from the received signal samples; (4) *decision making:* the CR user generates the test statistic and compares it with a threshold in order to decide the presence of a PU.

It is noted that the first two steps are the normal operations in the system using pilot signals. The last step is needed for any PU detection scheme. Only the third step is additionally required for implementing the proposed scheme, of which complexity is low as described in the next section.

3.2. PU Detection with Pilot Cancellation. Now, we describe in detail the proposed channel sensing scheme without quiet period. Various PU signal detection methods, including the energy detection, the cyclostationary feature detection [10], the eigenvalue detection [11], and the correlation matching approach [12], can exploit the proposed scheme. However, for the convenient description of the proposed concept

within a limited page length, we only consider the energy detection herein. (For employing energy detection, the noise power should be estimated. There can be several estimation methods. As an example, the estimation can be done when all CR users in the system have no traffic to be sent.)

The received signal is passed through the correlators to generate signal samples. As stated before, the PU detection is performed at the end of a frame which corresponds to L OFDM symbol times indexed by $1, 2, \ldots, L$. If $r_{m,l}$ denotes the signal sample from the mth correlator ($1 \leq m \leq 2M$) at OFDM symbol time l ($1 \leq l \leq L$),

$$r_{m,l} = \int_{(l-1)T_O}^{lT_O} r(t)\phi_{m,l}(t)dt \qquad (2)$$
$$= i_{m,l} + u_{m,l},$$

where $i_{m,l}$ is the in-phase or the quadrature component of the received CR pilot symbol; $u_{m,l} = n_{m,l} + s_{m,l}$ under H_1 and $u_{m,l} = n_{m,l}$ under H_0, where $n_{m,l}$ is a zero mean Gaussian random variable with variance σ_N^2 [8] and $s_{m,l}$ is the sampled value of the PU signal. The statistical property of $s_{m,l}$ depends on the symbol duration, the information bit sequence, and the modulation type of the PU signal.

For a CR user, (2) can be rewritten as $r_{m,l} = h_m \cdot d_{m,l} + u_{m,l}$, where h_m is the channel coefficient which is constant during a frame and $d_{m,l}$ is the deterministic quantity contributed by both the pilot sequence and the transmission amplitude which are known to CR users. It is noted that $d_{m,l} = d_{m-M,l}$ for $M + 1 \leq m \leq 2M$ since only the phase-shifted version of the in-phase component of pilot signal is received at the quadrature branch with BPSK modulation, which we assume in this paper.

A CR user can estimate the channel coefficient by applying the least-squares channel estimation technique to the received signal samples. When $\tilde{h}_{m,l}$ denotes the estimate of channel coefficient, $\tilde{h}_{m,l} \cdot d_{m,l} = h_m \cdot d_{m,l} + u_{m,l}$, then, $\tilde{h}_{m,l} = h_m + u_{m,l}/d_{m,l}$. If there are neither PU signal nor noise, perfect channel estimation can be achieved (i.e., $\tilde{h}_{m,l} = h_m$ for $1 \leq l \leq L$). However, due to the effect of PU signal and noise, the estimate of channel coefficient inevitably has the uncertainty, $u_{m,l}/d_{m,l}$. Since the least-squares estimator

for multiple samples is the sample mean estimator [13], the estimate of channel coefficient *for a frame* becomes

$$\widetilde{h}_m = \frac{1}{L}\sum_{l=1}^{L}\widetilde{h}_{m,l}$$

$$= h_m + \frac{1}{L}\sum_{l=1}^{L}\frac{u_{m,l}}{d_{m,l}}. \tag{3}$$

After the channel estimation is finished, the pilot cancellation is performed for each received signal sample. Let $\hat{r}_{m,l}$ denote the cancellation result for the mth correlator output of OFDM symbol l, then,

$$\hat{r}_{m,l} = r_{m,l} - \widetilde{h}_m \cdot d_{m,l}$$

$$= u_{m,l} - d_{m,l} \cdot \frac{1}{L}\sum_{i=1}^{L}\frac{u_{m,i}}{d_{m,i}}, \tag{4}$$

where the last term in (4) represents the residual pilot cancellation error. (In (4), the strength of the CR pilot signal contributes equally (on average) to both the denominator and the numerator of the pilot cancellation error. Therefore, the pilot signal strength has little effect on the amount of pilot cancellation error.)

Finally, the "test statistic," which corresponds to the energy received during a frame, is generated using the cancellation results. That is, the test statistic is the squared sum of $2ML$ cancellation results

$$\Delta := \sum_{m=1}^{2M}\sum_{l=1}^{L}\hat{r}_{m,l}^2. \tag{5}$$

Then, the resulting test statistic is compared to the threshold value, ϵ. If $\Delta > \epsilon$, the CR user decides that the PU exists. Otherwise, the CR user regards the spectrum band as empty.

There can be two types of detection errors, respectively, called the "false alarm" and the "missdetection." The false alarm is issued when $\Delta > \epsilon$ even though the PU is not activated; the missdetection is the case that $\Delta < \epsilon$ when the PU exists actually. These detection errors, respectively, degrade the performances of CR system and PU and are very sensitive to the decision threshold.

3.3. Application Remarks. In this paper, we consider the pilot cancellation for the PU detection without quiet period. The proposed concept can also be applied to the CR systems using "frame preamble." The frame preamble containing the sequence known to the receiver is originally utilized for channel estimation and synchronization, as the pilot does. Since there is no conceptual difference between the PU detection with the preamble cancellation and that with the pilot cancellation, we do not treat the detailed procedure herein.

On the other hand, the proposed scheme can be easily adopted in the sequential and the cooperative detection structures. That is, if a CR system has multiple test statistics that are generated during multiple frames and/or produced

from multiple CR users, the CR system can combine them by using an appropriate combining technique. In this case, the detection performance can be improved as the number of combined test statistics increases. In order to concentrate upon the main issue (i.e., the nonquiet sensing by using pilot cancelation), we do not treat the application of the proposed scheme to the sequential and cooperative detection.

4. Performance Analysis

In this section, we analyze the performance of proposed PU detection scheme. We adopt the following two assumptions for simplifying the analysis.

   (i) The PU signal sample, $s_{m,l}$, is a zero mean Gaussian random variable with variance of σ_S^2 [13, 14]. Moreover, PU signal samples are independent with respect to each other.

   (ii) The CR pilot subcarriers always transmit the information bit "1".

It is noted that these assumptions do not hold generally in practice. Nevertheless, the numerical results of this analysis well meet with the simulation results obtained without these assumptions, as will be presented in Section 5, which shows the practical usefulness of the analysis herein. We define the PU signal-to-noise ratio (SNR) as the ratio between the received signal power from a PU and the noise power. That is, the PU SNR is σ_S^2/σ_N^2.

With the above assumptions,

$$\sum_{l=1}^{L}\hat{r}_{m,l}^2 = \sum_{l=1}^{L}\left(u_{m,l} - \frac{1}{L}\sum_{i=1}^{L}u_{m,i}\right)^2$$

$$= \sum_{l=1}^{L}u_{m,l}^2 - \frac{1}{L}\left(\sum_{l=1}^{L}u_{m,l}\right)^2. \tag{6}$$

First, let us consider the hypothesis H_1. Then, $u_{m,l}$ is a zero mean Gaussian random variable with variance of $\sigma_S^2 + \sigma_N^2$. Thus, $\Theta_m := (1/(\sigma_S^2 + \sigma_N^2))\sum_{l=1}^{L}u_{m,l}^2$ follows the central chi-square distribution with L degrees of freedom and $\Lambda_m := (1/(\sigma_S^2 + \sigma_N^2))(1/L)(\sum_{i=1}^{L}u_{m,i})^2$ is a central chi-square random variable with one degree of freedom.

Let $\Phi_m := (1/(\sigma_S^2 + \sigma_N^2))\sum_{l=1}^{L}\hat{r}_{m,l}^2$. And let $E[X \mid H]$ and $V[X \mid H]$, respectively, denote the mean and variance of a random variable X under the hypothesis H ($\in \{H_0, H_1\}$). Then,

$$E[\Phi_m \mid H_1] = L - 1, \tag{7}$$

$$V[\Phi_m \mid H_1] = E\left[(\Theta_m - \Lambda_m)^2 \mid H_1\right] - (E[\Phi_m \mid H_1])^2$$

$$= E[\Theta_m^2 \mid H_1] - 2E[\Theta_m \cdot \Lambda_m \mid H_1] \tag{8}$$

$$+ E[\Lambda_m^2 \mid H_1] - (L-1)^2.$$

By using the fact that the fourth moment of $u_{m,l}$ is $3(\sigma_S^2 + \sigma_N^2)^2$, one can easily verify that $E[\Theta_m \cdot \Lambda_m \mid H_1] = L + 2$. Therefore, $V[\Phi_m \mid H_1] = 2(L - 1)$.

According to the definitions of Δ and Φ_m, $\Delta = \sum_{m=1}^{2M}(\sigma_S^2 + \sigma_N^2)\Phi_m$. Thus, Δ can be viewed as a sum of independent and identically distributed random variables. When $2M$ is a large number, according to central limit theorem,

$$\Delta \sim \mathcal{N}\left[2M(L-1)(\sigma_S^2+\sigma_N^2), 4M(L-1)(\sigma_S^2+\sigma_N^2)^2\right] \text{ under } H_1, \tag{9}$$

where $\mathcal{N}[\mu, \sigma^2]$ denotes a Gaussian distribution with mean of μ and variance of σ^2 and "$\sim$" means "is distributed as." With a similar procedure, the distribution of the test statistic under H_0 can be derived as follows:

$$\Delta \sim \mathcal{N}\left[2M(L-1)\sigma_N^2, 4M(L-1)\sigma_N^4\right] \text{ under } H_0. \tag{10}$$

Let q_{FA} and q_{MD} denote, respectively, the false alarm and the missdetection probabilities, when PU detection is carried out just once (i.e., for one-time decision on PU existence). Most existing studies focus only on these performance measures. However, we consider some additional measures that represent the performance of CR systems more effectively in practice.

The detection delay is defined as the time from the appearance of a PU to its successful detection. Since the detecting decision is made every frame, the detection delay increases as q_{MD} becomes high. In the practical CR systems (e.g., IEEE 802.22 WRAN), one of the system requirements is to detect PU appearance within a time limit (i.e., a required detection delay), with the probability higher than a given value. Let us denote this time limit by T_{limit}. The *final missdetection probability* for a CR user is defined as the probability that, when a PU is activated, the CR user cannot detect the presence of the PU within T_{limit}. The *final false alarm probability* is defined as the probability that at least one false alarm is issued during T_{limit}. Let us denote the final false alarm and the final missdetection probabilities by P_{FA} and P_{MD}, respectively. In general, not from the detection-theoretical point of view but from the system-wide point of view, the detection delay, the final false alarm probability, and the final missdetection probability are more practical performance measures than the false alarm and the missdetection probabilities for one-time PU detection.

The system requirements on the PU detection performance can be given by T_{limit} and the target P_{FA} (or the target P_{MD}). In this paper, we consider the system adopting the target P_{FA} as system requirement. For the given T_{limit} and P_{FA}, the target q_{FA} is calculated as follows:

$$q_{FA} = 1 - (1 - P_{FA})^{1/\lfloor T_{limit}/(L \cdot T_O)\rfloor}. \tag{11}$$

Then, based on the distribution of test statistic (10), a CR user can determine the decision threshold value ϵ for one-time PU detection as follows.

$$\epsilon = 2M(L-1)\sigma_N^2\left(\frac{Q^{-1}(q_{FA})}{\sqrt{M(L-1)}} + 1\right), \tag{12}$$

where $Q^{-1}(\cdot)$ is an inverse Q-function.

We now compute q_{MD} when this threshold value is used. Let us assume that a PU is activated at the beginning of an OFDM symbol which is randomly selected within a frame. When a PU is activated at OFDM symbol l in a frame ($1 \leq l \leq L$), a CR user receives PU signal only during $(L - l + 1)$ OFDM symbol times. Thus, q_{MD} under this condition can be expressed as

$$
\begin{aligned}
q_{MD}(l) \\
= 1 - Q\Bigg(\sqrt{M(L-1)} \\
\times \left(\frac{\epsilon}{2M(L-1)(((L-l+1)/L)\sigma_S^2 + \sigma_N^2)} - 1\right)\Bigg).
\end{aligned}
\tag{13}
$$

Using $q_{MD}(l)$, we have the final missdetection probability P_{MD}:

$$P_{MD} = \frac{1}{L}\sum_{l=1}^{L}\left(q_{MD}(l)(q_{MD}(1))^{n(l)}\right), \tag{14}$$

where $n(l) = \lfloor (T_{limit} - (L-l+1)T_O)/(L \cdot T_O)\rfloor$. Note that $n(l) + 1$ corresponds to the number of PU detection trials within T_{limit}.

During the PU detection delay, the CR system may interfere with the PU irrespective of whether or not the delay exceeds T_{limit}. Therefore, we use the mean detection delay D, as another performance measure

$$
\begin{aligned}
D = \frac{T_O}{L}\sum_{l=1}^{L}\Bigg(& (1 - q_{MD}(l))(L-l+1) \\
& + q_{MD}(l)\sum_{i=1}^{\infty}\Big((q_{MD}(1))^{i-1}(1 - q_{MD}(1)) \\
& \times (L-l+1+iL)\Big)\Bigg).
\end{aligned}
\tag{15}
$$

5. Numerical Results

We examine the PU and the CR systems with parameter values listed in Table 1, which are based on IEEE 802.22 WRAN specifications [1]. It is noted that the last five parameter values in Table 1 are for simulation only. Unless noted otherwise, the target P_{FA} is set to 0.01. In this section, we present not only the numerical results from the above analysis but also those from simulation. To generate the pilot signal in simulation, the long pseudonoise sequence in [1] is used. As a PU, we consider the analog TV system transmitting the random data by using the vestigial sideband (VSB) modulation. We have also conducted the simulation when PU is a wireless microphone using the frequency modulation (FM), of which bandwidth is 200 kHz. Since the results are almost the same as those with an analog TV for the given PU SNR, we do not include them herein.

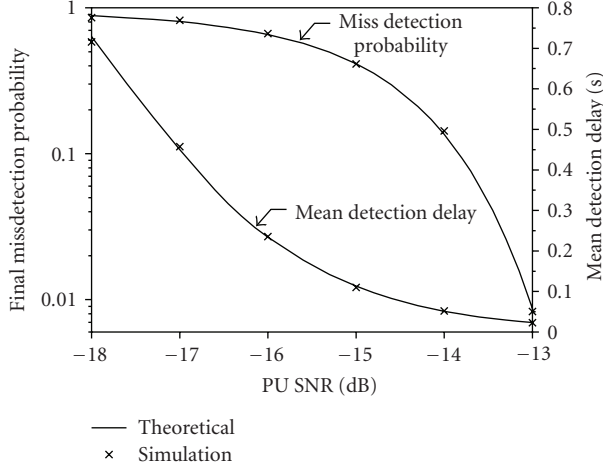First, we investigate the performance of the proposed scheme according to the PU SNR, when $L = 10$. In

FIGURE 3: Performance of the proposed scheme according to PU SNR.

TABLE 1: Parameter values for performance evaluation.

Parameter	Value
Number of pilot subcarriers, M	240
OFDM symbol duration (msec), T_O	0.341
Required detection delay (msec), T_{limit}	100
Number of subcarriers	2048
Bandwidth of CR system (MHz)	6
Center frequency of CR system (MHz)	500
Bandwidth of PU (MHz)	6
Center frequency of PU (MHz)	500

Figure 3, it is clear that the PU with stronger signal can be more easily detected by the CR user. Figure 3 also shows that the simulated and the theoretical results well match with each other. This indicates that the theoretical analysis in Section 4 is accurate although it is derived under the simplified assumptions for the PU signal and the pilot sequence. From now on, we present only the theoretical results for the proposed scheme.

Next, we compare the performance of the proposed scheme with those of the PU detection scheme adopting quiet period and the PU detection scheme exploiting CSC [6]. The performance results for these two schemes are obtained by using simulation. In simulation, the scheme with quiet period performs the energy detection for the entire band of the CR system during one OFDM symbol time per frame. The scheme with CSC exploits the complementary OFDM symbols transmitted by the pilot subcarriers on frame-basis, to detect the presence of PU. As for the proposed scheme, the detection delay, the final false alarm probability, and the final missdetection probability are obtained by carrying out the PU detection during multiple frames, for the schemes with quiet period and with CSC.

Figure 4 shows the final missdetection probability according to the final false alarm probability when the PU SNR is −14 dB. In the figure, the performance of the detection with CSC is poorer than that of the proposed scheme
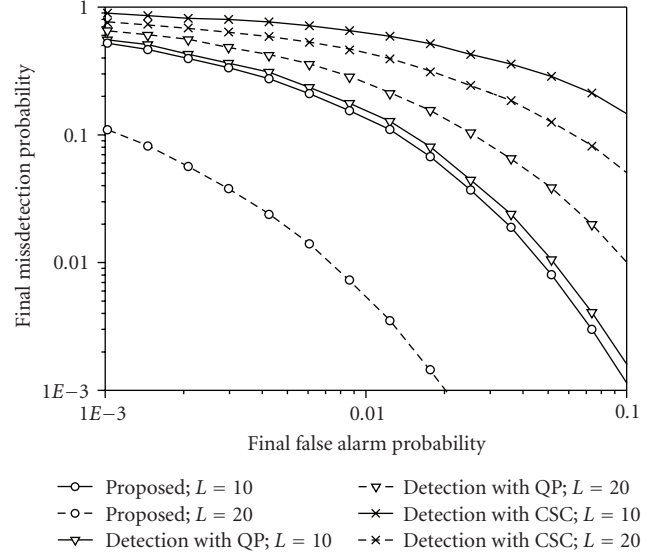

FIGURE 4: Miss detection probability according to false alarm probability (QP: quiet period).
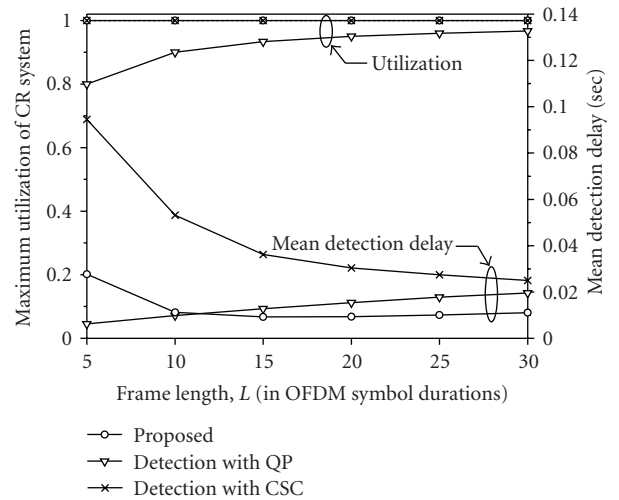

FIGURE 5: Maximum utilization of CR system and mean detection delay according to L (QP: quiet period).

for the same L. This is because only a part of OFDM symbols transmitted by pilot subcarriers satisfy the required complementary condition. From the figure, we can see that the missdetection probability of the proposed scheme decreases as L increases. This results from the fact that more samples can be involved in one-time PU detection with a larger number of OFDM symbols in a frame. However, since the number of frames (thus, the number of PU detection trials) within T_{limit} is reduced as L increases, the marginal decrease in the final missdetection probability becomes very small when $L \geq 20$. Figure 4 also shows that the detection performance of the proposed scheme is better than that of the scheme with quiet period if L is not less than 10.

Figure 5 shows the maximum utilization of CR system and the mean detection delay according to L, when the PU

SNR is -12 dB. It is clear that the proposed scheme and the scheme with CSC can always achieve the utilization of 1.0 since they are nonquiet detection schemes, whereas that of the scheme with quiet period is less than 1.0. Moreover, the mean detection delay of the proposed scheme is much less than that of the scheme with CSC. Therefore, we can conclude that the proposed scheme can greatly increase the system utilization while accomplishing the better detection performance in comparison to other schemes. (The operating value of L is larger than 20 in usual, when considering the simulation parameters in Table 1.) Figure 5 also shows that, as L increases, the mean detection delay of the proposed scheme decreases first and then slightly increases. This is because the mean detection delay is affected by not only the frame length but also the missdetection probability of one-time PU detection.

6. Conclusion

We have suggested an efficient PU detection scheme for CR systems, which performs the nonquiet channel sensing by using the pilot cancellation technique. The theoretical analysis and simulation results show that the proposed scheme can detect the PU effectively while improving the utilization of the CR system significantly. Since the complexity of the proposed scheme is very low, specifically for the CR systems already utilizing pilot subchannels, it has the practical merit in implementation. In this paper, we have demonstrated the performance of the proposed scheme only when the energy detection is applied. If more complex but efficient detection scheme (e.g., cyclostationary feature detection) is used, the performance will be further improved.

Acknowledgments

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