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Spectrum Sensing in a Cognitive Body Area Network: Detection of a Bonded Channel in the MICS Band

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Abstract

In this paper, we present a novel algorithm for detecting a bonded channel in a cognitive radio network where channel bonding is allowed for a higher data rate. The envelope detection algorithm is proposed to distinguish the center frequency of the received signal in order to determine whether the signal is transmitted by a primary user occupying a single channel or a secondary user occupying more than two channels when the channel is in use.

Key words: Cognitive Radio, Spectrum Sensing, Channel Bonding, WBAN.

Ⅰ. Introduction

The Wireless Body Area Network (WBAN) is a network that consists of a set of mobile sensors associated with the human body. The dedicated frequency band for implant devices in WBAN is the Medical Implant Communication System (MICS) band between 402 and 405 MHz. The authorized bandwidth (BW) of the emission from an implant device operating in the MICS band shall not exceed 300 kHz according to Federal Communications Commission (FCC) regulations [1]. However, some particular health-care implant applications require high data rates. In such cases, opportunistic channel bonding, which gathers consecutive idle channels, could be an effective method to obtain higher transmission rates [2], [3]. Currently, occupying more than a single channel is prohibited by regulation. However, channel bonding can be implemented by exploiting the cognitive radio (CR) paradigm in which the secondary user is allowed only when the primary user's transmission is not disturbed. For the channel bonding scheme, the bonded channel user and the single channel users can be considered as being the secondary and the primary users respectively. In [2] and [3], the performance of several channel bonding strategies in CR networks were analyzed to obtain an optimal strategy.

Many studies have been conducted on spectrum sensing to detect the primary user in CR. Most previous works assume that the primary user's transmission occurs without consent of any secondary users [4], [5]. This can be true for systems such as TV or FM/AM broadcasting, but systems can exist where a device that is considered to be a primary user has to perform carrier sensing before establishing communication channels. In general, if a channel is in use by secondary users, another user determines that the channel is busy and waits until the channel becomes idle by the coordination function as in WLAN [6]. Consider a situation where channel bonding is possible, and the priority of the usage of the bonded channel is lower than that of single (not bonded) channel. In such cases if a user who desires to transmit is able to find any bonded channels (assuming no empty channel slots remained), a part of the bonded channel can be assigned to the user for communication without waiting to sense for the prefixed amount of time before the bonded block in use is fully released.

In this letter, we propose a novel spectrum sensing algorithm that recognizes the bonded channel for ensuring the priority of a primary user. In the next section, the system model is given. The details of the proposed algorithm are presented in the subsequent section. At the end, the simulation results and the conclusions will be given.

Ⅱ. System Model

The transmitted QPSK signal is expressed as

$$x(t) = h(t)\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + (2n-1)\frac{\pi}{4}), n = 1,2,3,4 \quad (1)$$

where E_b, T_b and f_c are the bit energy, bit duration and carrier frequency respectively. A root raised cosine $h(t)$ is used for pulse shaping.

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A frequency band between 402 and 405 MHz is assigned for medical implants. In WBAN, the center frequency f_c of a single MICS channel is set as

$$f_c = 402.15 + 0.30n_c[\text{MHz}], \quad n_c = 0, 1, \ldots, 9 \tag{2}$$

where n_c is the channel number.

Suppose that a network exists where channel bonding is allowed to increase the data rate in the MICS band. If a user decides to transmit a large amount of data, it will attempt to concatenate the available channels. The number of channels to be concatenated can be an even number such as 2, 4, 6, 8, and 10.

In this letter, a user occupying a single channel slot is called a primary user and a user occupying more than two channel slots (i.e., bonded channel) is called a secondary user. In the channel allocation scenario, when a user starts transmitting signals, it will search for any empty channel slots. If only one channel is available, the user begins transmission at low data rate as a primary user. If there are multiple adjacent channels available, the user concatenates the channels to establish one bonded channel for a higher data rate, and begins transmission as a secondary user. If all of the channels are busy, the user looks for a channel that might have been occupied by a secondary user (a user occupying more than one channel). If this type of channel is detected, the user, as a primary, transmits data through the channel while ignoring the secondary user's transmission. After the primary user begins transmission, the secondary user can detect the signal transmitted by the primary user during the quiet period.

The secondary user then restarts transmission in the channel not occupied by the primary user. If only one channel is assigned for the restart of the secondary user, that user becomes another primary user. If more than two available channels are available to the secondary user, that user continues operating as the secondary user. Note, until the secondary user detects the appearance of a primary user, the packet transmitted by the primary user risks colliding with the signal of the secondary user, and retransmission will be needed after receiving a NAK message.

Note that the performance of the aforementioned channel bonding protocol remains to be evaluated in the future.

Ⅲ. Channel Sensing in the MICS Band

Here we propose a scheme that identifies if a channel is a part of the bonded channel.

The center frequency f_i of each baseband channel slot is given as

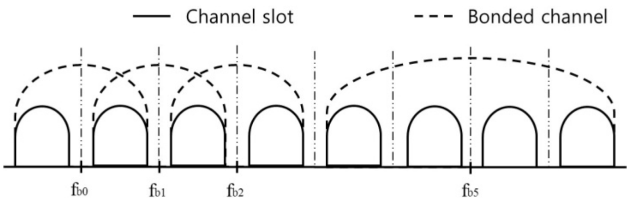


Fig. 1. Center frequencies of bonded channel.

$$f_i = 150 + 300i[\text{kHz}], i = 0, 1, \ldots, 9. \tag{3}$$

A secondary user concatenates multiple adjacent channels to yield a bonded channel for wider bandwidth if more than two adjacent idle channels are available. Depending on how the channel slots are concatenated, the center frequencies of bonded channels can lie on slot edge frequencies as shown in Fig. 1.

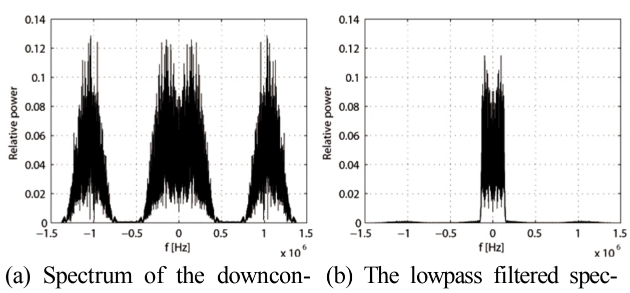
Consider that a user searches for an available channel slot for communication. First, the signal in the frequency slot of interest is downconverted to the baseband. If it is a part of a signal in the bonded channel, the spectrum peak of the downconverted signal will not exist at the zero Hz frequency as shown in Fig. 2(a). Otherwise, the spectrum peak will be at the zero frequency.

After downconversion and lowpass filtering of the signal in the bonded channel, only the side-lobe component of the signal spectrum is observed, as seen in Fig. 2(b).

The peak of the spectrum is identified using envelope detection. Let $Y[N]$ be the N-point FFT samples of the downconverted received signal. The FFT samples are summed to yield $S(r)$

$$S(r) = \sum_{t=1}^{T} |Y[t + (r-1)T]|, r = 1, 2, \ldots, R \tag{4}$$

where T is the integration interval, and R is the number of integration windows. Now, by observing the integ-



(a) Spectrum of the downconverted QPSK signal

(b) The lowpass filtered spectrum of downconverted QPSK signal

Fig. 2. Spectrum of the downconverted secondary user's signal (BW=550 kHz), and the produced frequencies are 600±450 kHz in channel 1 (f_1=450 kHz).

ration output, $S(r)$, we can obtain the location of the spectrum peak.

$$\hat{r} = \arg\max_r S(r) \tag{5}$$

The level of the peak deviation from the center, $d = |R/2 - \hat{r}|$ is a good criterion for the sensing decision. Let

$$b(T) = \begin{cases} 0 & \text{if } d > f_\lambda \ \text{(Hypothesis 0)}, \\ 1 & \text{if } d < f_\lambda \ \text{(Hypothesis 1)} \end{cases} \tag{6}$$

for $T = 1, 2, 4$. That is, if $d > f_\lambda$, it is understood that the channel slot sensed is owned by the secondary user (call it Hypothesis 0, otherwise Hypothesis 1).

Consider a case of Hypothesis 0. Although the peak of the spectrum is expected to be located on the right-hand side of the threshold f_λ the peak could be located on the left-hand side of f_λ. This is largely due to the fluctuations in the spectrum, and because in the baseband the positive and the negative part of the passband signal is put together after down conversion. This will occasionally yield the peak of the spectrum at the center, which results in a decision error.

A smoothing technique is required to reduce the decision error. The moving average is a well-known method for smoothing the envelope. A moving average is the mean of the previous *k* samples of the received signal $Y[N]$. In this letter, the global decision method is applied to reduce the decision error. Multiple $b(T)$ for $T = 1, 2, 4$ are observed to yield the global decision variable $B = b(1)b(2)b(4)$ and the final decision is made as

$$\text{Accept } \begin{cases} H_0 & \text{if } B = 0, \\ H_1 & \text{if } B = 1 \end{cases} \tag{7}$$

The proposed channel sensing algorithm is summarized in Table 1. The simulation results of the moving average and the proposed decision algorithm are given in the next section.

Ⅳ. Simulation Results

A MATLAB simulation was conducted to evaluate the performance of the proposed algorithms. During the spectrum sensing, a false alarm is categorized an event where the channel slot, which is owned by a primary user, is determined to be owned by a secondary user. In contrast, a missed detection occurs when a channel slot, owned by a secondary user, is determined to be owned by a primary user.

The probabilities of a false alarm and a missed detection, P_f and P_m,, respectively, were evaluated as follows.

Table 1. Channel sensing algorithm.

```
For T = 1,2,4
  For r = 1,2,...,R
     Where S(r) = Σ_{t=1}^{T} |Y[t + (r − 1)T]|
  Next r
  Where r̂ = arg max_r S(r)
  d = |R/2 − r̂|
  If d > f_λ, b(T) = 0
  else b(T) = 1
Next T
B = b(1)b(2)b(4)
If B = 0
  Accept H_0
else
  Accept H_1
```

4-1 Evaluation of False Alarm Probability

To compute the false alarm probability P_f a primary user's signal with a 250 kHz bandwidth was transmitted in Ch. 1 (f_1=450 kHz). The signal to noise ratio (SNR) was fixed at 0 dB. The sensing results were averaged over 1,000 trials to compute P_f and are shown in Fig. 3. The false alarm probabilities for the intermediate decisions based on $b(1)$, $b(2)$, $b(4)$ are plotted along the false alarm probability for the final decision. As shown in Fig. 3 the threshold frequency f_λ should be greater than or equal to 1.2 kHz to ensure that P_f is close to zero. The simulations were performed at various SNRs from 0 to 25 dB. However, the effect of SNR on the sensing decision was minimal.

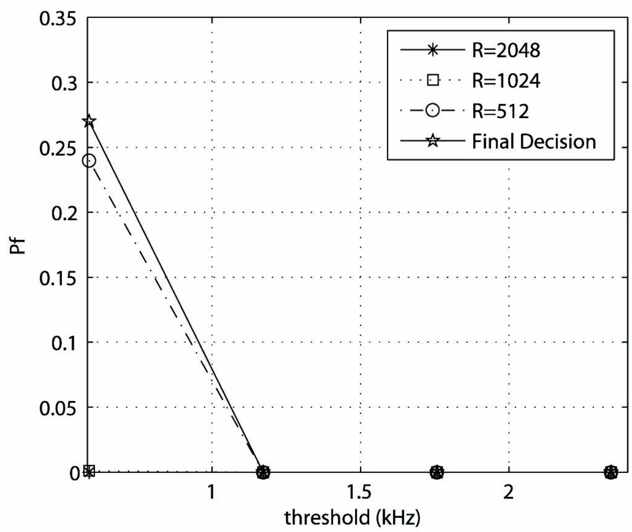


Fig. 3. False alarm probability for Ch. 3.

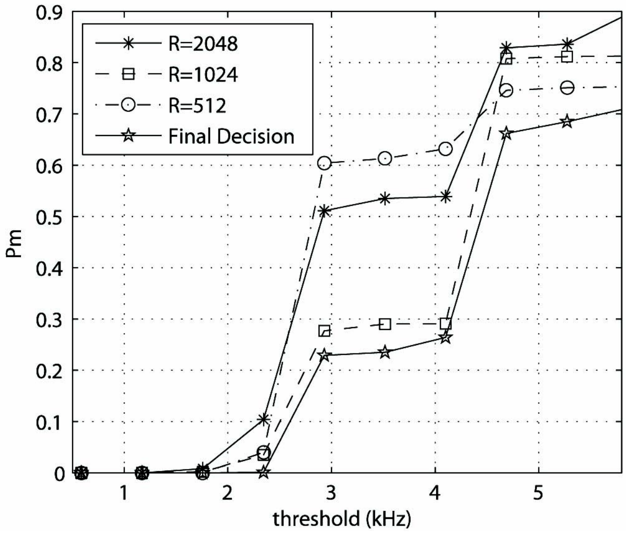


Fig. 4. Missed detection probability for Ch. 3.

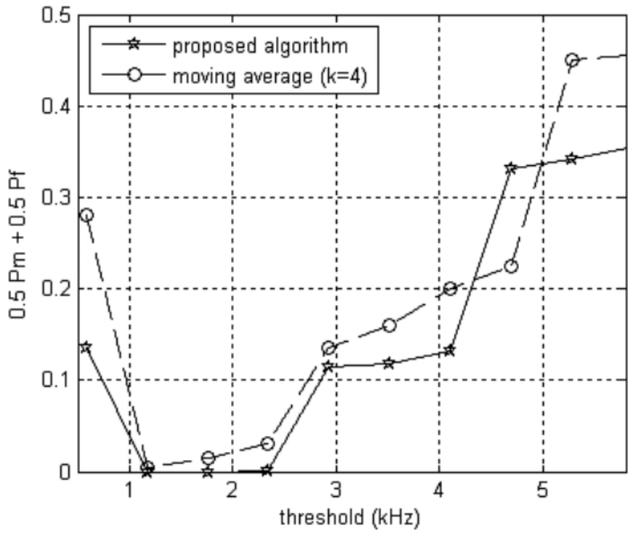


Fig. 5. Cost function $(0.5P_m + 0.5P_f)$ in Ch. 3.

4-2 Evaluation of Missed Detection Probability

For the bonded channel, a QPSK signal with an 1,150 kHz BW, 250 kHz × 4 + guard interval (50 kHz) × 3, (occupying four channel slots from Ch. 1 to Ch. 4) were generated, and the center frequency of the signal is lying on the band-edge frequency 900 kHz between Ch. 2 and Ch. 3. In the spectrum sensing stage, a primary user probes only one channel slot. In the simulation, Ch. 3 is selected. The signal in Ch. 3 is downconverted to baseband by the amount equal to 1,050 kHz which is the center frequency of Ch. 3. The downconverted signal is lowpass filtered and processed by the proposed sensing algorithm. The missed detection probability P_m computed over 1,000 trials is plotted in Fig. 4. From Fig. 4, we see that the global decision method made by multiplying the decisions with the number of integration windows from 512 to 2,048 provides a good performance for lowering the missed detection probability.

Note, that due to the symmetry of the spectrum, we can expect the identical results for Ch. 2 and Ch. 3, and similarly for Ch. 1 and Ch. 4. In the case of Ch. 4, the missed detection probability is much lower than Ch. 3 since the center frequency of Ch. 4 deviates 300 kHz farther from the center of the bonded channel.

4-3 Comparison of the Proposed Algorithm with the Moving Average Method

Given both the missed detection and the false alarm probabilities the optimal threshold frequency can be chosen. The threshold frequency f_{th} for the decision is obtained such that

$$f_{th} = \min_f \frac{P_m(f) + P_f(f)}{2} \tag{8}$$

As shown in Fig. 5, for the proposed algorithm zero probability of the decision error $(P_m + P_f)/2$ was observed with f_{th} from 1.2 kHz to 2.4 kHz whereas for the moving average method with K = 4 the probability of the decision error was 0.005 at 1.2 kHz. The simulation results verify the improved performance of the proposed algorithm over the conventional moving average method.

Although more systematic approaches might exist for finding the optimal threshold, we resort to the heuristic method for now with the intention of emphasizing the feasibility of the proposed algorithm.

V. Conclusion

In this letter, we presented a novel algorithm for detecting a bonded channel in a cognitive radio network. In-body WBAN was considered where channel bonding is allowed for a higher data rate. The envelope detection algorithm was proposed to distinguish the center frequency of the received signal in order to determine whether the signal is transmitted by a primary user or a secondary user.

A user who desires to access the network probes the channels to check the availability. When the channel of interest is occupied by a user, the proposed algorithm allows us to confirm whether the channel is owned by a primary user occupying a single channel or a secondary user occupying more than two channels. MATLAB simulations showed that the proposed algorithm is effective and feasible with band and time limited QPSK signals.

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