Improved Reliability of Spectrum Sensing using Energy Detector in Cognitive Radio System

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Abstract — We propose a novel structure where the energy detector has multiples of verification using time delay, in order to improve its performance. Additionally, the performance is investigated by simulation and compared to that of the original energy detector. The simulation result shows that the proposed scheme improves the performance when SNR is compared with the misdetection probability for both 1% and 10% of false alarm probability. The performance is also described in terms of ROC curve.

Keyword — Cognitive radio, spectrum sensing, energy detector, time delay.

1. Introduction

With the development of wireless application technology, the demand on spectrum resource was rapidly increased. However most of spectra have already been allocated to licensed user or primary user, especially in the frequency below a few GHz bands which it is extremely competitive to acquire. The problem is that spectrum utilization concentrate only in several frequency bands, while the majority of frequency bands are utilized inefficiently. According to the FCC’s (Federal Communications Commission) spectrum policy task force report, the usage of allocated spectrum varied around 15% to 85% depending on temporal and geographic situation [1]. Therefore, the new paradigm of using spectrum more efficiently than in the past has urged to create a new wireless communication technology.

Cognitive radio (CR) technique has been proposed as an attractive solution to improve spectrum utilization by sharing the spectrum [2]. In IEEE 802.22, CR technique is introduced for the standardization of wireless regional area network (WRAN) to use frequency resource, which was originally allocated for broadcasting (54~862MHz). The CR technique could recognize the condition in surrounding wireless environment and calculate optimum parameters to avoid interference. By adopting the concept of dynamic spectrum management, the CR technique is aiming at usage of unoccupied spectrum, while ensuring the right of privileged primary users.

In order to protect the primary user from by unlicensed users or secondary users, spectrum sensing is a key function to decide whether frequency band is empty or not. Therefore, the secondary users should monitor licensed bands, and opportunistically transmit whenever no primary signal is detected. In this paper, we propose a novel structure where the energy detector has multiples of verification using time delay to enhance the reliability of sensing. Additionally, the performance is investigated by simulation and compared to that of the original energy detector.

This paper is organized as follows: Section 2 briefly reviews the existing detection methods. In section 3, we describe the proposed sensing scheme. In section 4, simulation results are analyzed. Finally, discussion and conclusion are presented in section 5.

2. Conventional spectrum sensing methods

Various methods for spectrum sensing such as matched filter detection, feature detection, and energy detection have been suggested.

- Matched Filter Detection: This method can maximize the SNR (Signal-to-Noise Ratio) inherently. However it is difficult to do detection without signal information such as pilot and frame structure.

- Feature Detection: This method also have a constraint that they must have information about received signal sufficiently. In practice, CR system is in the lack of knowledge about primary signal’s structure and information.

- Energy Detection : It is possible to detect primary signals quickly, even if the feature is unknown. Furthermore, its implementation is quite simpler than the feature detection. Figure 1 shows the block diagram of energy detector ; received signal passing the desiring band-pass filter (BPF) and multiplying by itself and integrating as required time and comparing with threshold.

Figure 1. The Block Diagram of Energy Detector

As widely known, the performance of the energy detection is mainly dependent on the channel fading, shadowing and interferences [3]. If detector made a decision that there is no primary user, but the primary user actually exists, it could make interference to the primary user. Conversely, if detector made a decision that there is primary user, but there is no primary user actually, it could miss out the chance to transmit. In order to overcome fading environment collaborative sensing was proposed [4,
The collaborative sensing scheme may improve sensing performance compared to the individual sensing with cooperation between some numbers of secondary users under the assumption that all user suffer the same channel environment. Recently, Weighted-collaborate sensing scheme was proposed that assigns the dynamic weight factors to different collaborative users based on their contributions because collaborative user may experience different channel environment separately [6]. However both collaborative sensing schemes are a lack of experimental data that shows the feasibility and practical performance limits of these approaches under real wireless channel [7]. Moreover, there is lack of possibility that collaborative user exist at any time. Therefore we focus to enhance the reliability using simple energy detection and thus improve the performance.

3. Proposed spectrum sensing method

In this section, we describe a novel structure where the energy detector has multiples of verification using time delay to enhance the reliability of sensing. In Fig. 2, the received signal is delayed accumulatively and goes through energy detector respectively. Then collaborative decision device make a final decision whether signal is exist or not, according to decision information from energy detector.

![Figure 2. The Block Diagram of Proposed Spectrum Sensing](image)

The each energy detector decides $H_1 (= 1)$ or $H_0 (= 0)$ by comparing pre-defined threshold value (= Ec). Figure 3 illustrates example of collaborative decision’s majority rule. In the Figure 3, $H_1 (= 1)$ is six out of eleven decision values, collaborative decision device finally decides that channel is occupied.

![Figure 3. The Illustration of Collaborative Decision](image)

The detector is under the test of the following two hypotheses:

$$H_0 : y(t) = n(t) \quad \text{Channel Vacant}$$

$$H_1 : y(t) = h(t) \ast x(t) + n(t) \quad \text{Channel Occupied}$$

where $y(t)$ denotes the received signal by secondary user, $x(t)$ denotes the transmitted signal by primary user, $n(t)$ denotes the AWGN (Additive White Gaussian Noise) and $h(t)$ denotes the amplitude gain of the channel. The detector can make one of two decisions:

$$D_0 : \quad \text{Channel Vacant}$$

$$D_1 : \quad \text{Channel Occupied}$$

There are two types of errors that the spectrum sensor can have. When channel is vacant ($H_0$) the spectrum sensor can declare that the channel is occupied ($D_1$). This is referred to as a false alarm. The probability of this event is referred to as the probability of false alarm, denoted $P_{FA}$.

$$P_{FA} = P(D_1 | H_0)$$

(1)

When channel is occupied ($H_1$) the spectrum sensor can declare that the channel is vacant ($D_0$). This is referred to as a misdetection. The probability of this event is referred to as the probability of misdetection, denoted $P_{MD}$.

$$P_{MD} = P(D_0 | H_1)$$

(2)

Refer to (3), One minus the probability of misdetection is the probability of detection.

$$P_D = 1 - P_{MD}$$

(3)

4. Simulation result

In our simulation, the Suzuki channel was considered by calculating MED (Method of Equal Distance). The characteristic of the MED is such that the difference between two adjacent discrete Doppler frequencies is equidistant [8]. The Suzuki model is a statistical model that has been developed for the land mobile radio channel on the assumption that the local mean of the Rayleigh process follows a lognormal statistic and accounts therefore for the effects caused by shadowing. Table 1 summarizes the simulation parameters. Through the verification processes, we get three decision values and then make the final decision by the majority law.

![Table 1. The Simulation Parameters](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
<td>900MHz</td>
</tr>
<tr>
<td>Mobile Speed</td>
<td>3, 6, 110km/h</td>
</tr>
<tr>
<td>Law of majority</td>
<td>two out of three</td>
</tr>
<tr>
<td>Time Delay Devices</td>
<td>2</td>
</tr>
<tr>
<td>Sensing Duration</td>
<td>0.33ms</td>
</tr>
</tbody>
</table>

There is always a trade-off between having a high probability of detection and having a low probability of false alarm. This trade-off can be made by changing the detection threshold [9]. In order to allow evaluation of
various spectrum sensing techniques, we will select the threshold so as to get both 10% and 1% of the probability of false alarm and then calculate the probability of misdetection. The noise value will be fixed and the signal power will be varied to accommodate the different values of SNR and the mobile speed of secondary user. When $P_{FA}$ is not 1% but 10%, the probability of misdetection shows the better performance. Meanwhile the probability of detection is lower. Threshold value with 10% of $P_{FA}$ has lower than 1% of $P_{FA}$ [10].

The simulation results are shown in Figs. 4, 5 and 6. As shown in these figures, the performance of the proposed spectrum sensing scheme is much better than conventional energy detector through whole SNR. When we focus on the high SNR, we can see that low mobile speed may degrade the performance of proposed sensing scheme. For example, under the deep fading, the verification effect using time delay decreases since the mobile speed is highly related to channel variation. Also the performance of proposed sensing scheme with 1% of $P_{FA}$ is approximately identical with that of conventional sensing scheme with 10% of $P_{FA}$. When we need to enhance the reliability of spectrum sensing using energy detector under the high $P_{FA}$, the proposed sensing scheme may be very useful method.

In order to analyze a different point of view, Figures 7, 8, and 9 illustrate ROC curve ($P_{FA}$ vs. $P_{D}$) under Suzuki channel. ROC (Receiver Operating Characteristics) curve is known to be a useful tool for organizing classifiers and visualizing their performance. Since we set the SNR to 10dB, there is not such a big difference in the performance of three cases of mobile speed with 0.1 of $P_{FA}$, but it is certain that the performance of proposed sensing scheme is about 10% better than the conventional sensing scheme. In the Figures 7, 8 and 9, we can confirm the performance gap between the proposed scheme and the conventional scheme.
5. Conclusions

In this paper, we proposed a novel spectrum sensing scheme, which is a key function in CR technique, of the energy detector combined with time delay devices as well as collaborative decision device. It was shown that the proposed sensing scheme showed better performance in terms of misdetection probability under Suzuki channel environment. In addition, the performance of proposed sensing scheme with 1% of $P_{FA}$ is approximately identical with that of conventional sensing scheme with 10% of $P_{FA}$. Therefore, the proposed sensing scheme may be very useful method to enhance the reliability of spectrum sensing using energy detector under the high $P_{FA}$. Further work will be continued to evaluate more related parameters such as the optimal delay duration and number of times of delay and to apply to weighted-collaborative spectrum sensing based on proposed sensing scheme.

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REFERENCES
