Spectrum Sensing Using Matched Filter Detection

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Spectrum Sensing Using Matched Filter Detection

Suresh Dannana, Babji Prasad Chapa and Gottapu Sasibhushana Rao

Abstract Increasing use of wireless applications is putting a pressure on licensed spectrum which is insufficient and expensive. Indeed, because of allocation of fixed spectrum, more portion of spectrum is underutilized. Spectrum sensing can be used for efficient use of the radio spectrum. It detects the unused spectrum channels in cognitive radio network. In cognitive radio, spectrum sensing techniques such as energy detection, cyclostationary feature-based spectrum sensing technique, matched filter detection, etc., have been used. When user information is available, matched filter-based sensing gives better performance. In this paper, the probability of detection (PD) and probability of false alarm (PFA) at different SNR levels are observed. Matched filter detection performance depends on threshold value to detect the primary user. At 25 dB SNR, better probability of detection is observed for a given PFAs.

1 Introduction

At present, wireless users have enormously increased. Allocation of spectrum to the users is cumbersome. Cognitive radio networks have been introduced to meet the demand for spectrum. Since radio spectrum is limited, some users' needs spectrum continuously while others underutilize its allocated spectrum, it causes spectrum scarcity. Research on cognitive radio [1–4] has developed the interest on spectrum sensing and detection of spectrum users. Maximizing the probability of detection is without sacrificing much probability of false alarm while minimizing

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the hardware and the time to sense the spectrum is the main intention of the spectrum sensing. The radio spectrum can be sensed by various detection techniques, i.e., energy detection, [5] matched filter [6–8], cyclization feature detection, [9] and stochastic process techniques to detect PU signal in the channel. When the secondary user has complete information (such as type of modulation, frequency of carrier, bit rate, shape of the pulse, etc.) of primary user, matched filter detection is the better choice than other techniques.

2 Spectrum Sensing

In this paper, to sense primary user, matched filter-based likelihood ratio test introduced. Consider a signal model, having binary hypotheses H_0 and H_1 to represent the presence of radio signal.

Under binary hypothesis H_0, signal model is

$$x(n) = w(n) \tag{1}$$

Under hypothesis H_1, signal model is

$$x(n) = s(n) + w(n) \tag{2}$$

where x(n) is received signal, s(n) is primary user signal, typically binary phase shift keyed signal follows the Gaussian distribution. w (n) is the Gaussian noise signal with a zero mean, and variance σ^2.

2.1 Likelihood Ratio Test

Consider the signal s(i) and Gaussian noise w(i), having zero mean, variance $\boldsymbol{\sigma}^2$. Likelihood ratio test [7, 8, 10] is used to detect primary user. Here all N signals are independent, so that the joint probability density function (PDF) under $H_{0,}$ i.e., primary user is absent in,

$$\prod_{i=1}^{N} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{[x(i)]^2}{2\sigma^2}} \tag{3}$$

where x(i) is *i*th received signal.

The joint PDF under $H_{1,}$ i.e., primary user is present in,

$$\prod_{i=1}^{N} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{[x(i)-s(i)]^2}{2\sigma^2}} \tag{4}$$

Likelihood ratio is the ratio of $p(H_1)$ and $p(H_0)$, which is used to detect PD and PFA. This ratio is compared with threshold value to detect primary user under two hypothesis conditions.

$$\gamma(x) = \frac{p(H_1)}{p((H_0)} = \frac{\left(\frac{1}{\sqrt{2\pi\sigma^2}}\right)^N e^{-\frac{1}{2\sigma^2}\|\bar{x}-\bar{s}\|^2}}{\left(\frac{1}{\sqrt{2\pi\sigma^2}}\right)^N e^{-\frac{1\|\bar{x}\|^2}{2\sigma^2}}} \tag{5}$$

where p(H_0) and p(H_1) are priori probabilities. The decision can be taken accordingly

$$\gamma(x) = \begin{cases} \geq \gamma & \text{choose } \mathrm{H}_1 \\ < \gamma & choose\, H_0 \end{cases}$$

where γ is the threshold value used to detect primary user. Likelihood ratio test is tedious one to detect primary user.

2.2 Matched Filter

Since likelihood ratio test is tedious, so that log-likelihood ratio test is used to simplify Eq. (5).

Under H_1 is

$$\begin{aligned} \ln\gamma(x) &= -\frac{1}{2\sigma^2}\left[\|\bar{x}-\bar{s}\|^2 - \|\bar{x}\|^2\right] \geq \ln\gamma \\ &= \|x\|^2 - \|\bar{x}-\bar{s}\|^2 \geq (\ln\gamma)2\sigma^2 \\ &= \bar{s}^{\mathrm{T}}\bar{x} \geq \frac{2\sigma^2\ln\gamma + \|\bar{s}\|^2}{2} \\ \gamma' &= \frac{2\sigma^2\ln\gamma + \|\bar{s}\|^2}{2} \end{aligned}$$

where γ' represents a new threshold value.

Where $\bar{s}^{\mathrm{T}}\bar{x}$ represents matched filter, which is having maximum value when the received signal matched with the transmitting signal.

$$\begin{array}{ll} \text{If } \bar{s}^{\mathrm{T}}\bar{x} \geq \gamma' & choose\, H_1 \\ \text{Otherwise} & choose\, H_0 \end{array}$$

$$\begin{array}{lll} H_1 & if & \bar{s}^{\mathrm{T}}\bar{x} \geq \gamma' \\ H_0 & if & \bar{s}^{\mathrm{T}}\bar{x} < \gamma' \end{array}$$

Under hypothesis H_0, $\bar{s}^T\bar{x} = s(1)w(1) + s(2)w(2) + \ldots s(N)w(N)$
Signal $\bar{s}^T\bar{x}$ is Gaussian with mean which is zero, variance is $\|\bar{s}\|^2\sigma^2$
variance of $\bar{s}^T\bar{x}$ is $\tilde{\sigma} = \|s\|^2\sigma^2$
Probability of false alarm (PFA) is

$$
\begin{aligned}
P_{FA} &= P_r(\bar{s}^T\bar{x} \geq \gamma'/H_0) \\
&= P_r\left(\frac{\bar{s}T\bar{x}}{\sigma||s||} \geq \frac{\gamma'}{\sigma||s||}/H_0\right) \\
P_{FA} &= Q\left(\frac{\gamma'}{\sigma||s||}\right)
\end{aligned}
\tag{6}
$$

so that threshold

$$\gamma' = \sigma\|s\|Q^{-1}(PFA) \tag{7}$$

Under H_1
Probability of detection PD

$$P_D = P_r(\bar{s}^T\bar{x} \geq \gamma'/H_1)$$
$$\text{Here}\bar{x} = \bar{s} + \bar{w}$$

Signal $\bar{s}^T\bar{x}$ is Gaussian with mean $\|\mathrm{s}\|^2$ and Variance = $\sigma^2\|\mathrm{s}\|^2$

$$P_D = P_r(\bar{S}^T\bar{x} \geq \gamma^{|}/H_1)$$
$$P_r\left(\frac{\bar{S}^T\bar{X} - \overline{\|\mathrm{S}\|}^2}{\sigma\|\mathrm{S}\|} \geq \frac{\gamma^{|} - \|\bar{S}\|^2}{\sigma\|\mathrm{S}\|}/H_1\right)$$

$$P_D = [\mathrm{Q}\ (\frac{\gamma^{|} - \|\bar{S}\|^2}{\sigma\|\mathrm{S}\|})] \tag{8}$$

From Eqs. (7) and (8), probability of detection is

$$P_D = \mathrm{Q}(Q^{-1}(\mathrm{PFA}) - \sqrt{\frac{\varepsilon}{\sigma^2}}) \tag{9}$$

where $\sqrt{\frac{\varepsilon}{\sigma^2}}$ is deflection coefficient. $\frac{\varepsilon}{\sigma^2}$ is signal to noise ratio.

Probability of detection increases by either increasing SNR or by increasing the PFA.

3 Results

The matched filter performance is observed for various SNR values as well as for a given probability of false alarms (PFAs).

The sensing performance of the proposed scheme, in terms of its receiver operating characteristics (ROC) curve, is evaluated using Monte Carlo simulations. The performance of matched filter detection technique mainly depends on signal to noise ratio (SNR) gained by secondary users. Figure 1 shows analysis between probability of detection (PD) and probability of false alarms (PFAs) for different SNR values. In this paper, four SNR values (−5, 0, 5 and 10 dB) are considered. From Fig. 1, it is observed that at 10 dB SNR, more PD is achieved. As the SNR increases, matched filter performs well. Simulation results are compared with analytical values.

Figure 2 shows plot between probability detection and SNR for a fixed value of PFA. Here four values of PFA are considered. They are 10^{-4}, 10^{-3}, 10^{-2}, and 10^{-1}. From Fig. 2, it is observed that as SNR increases, the probability of detection is improved. It can be verified from Eqs. (8) and (9). Simulation results are also compared with analytical values.

Table 1 shows threshold values for different SNR for a fixed PFA. Here four values of PFA are considered. They are 10^{-4}, 10^{-3}, 10^{-2}, and 10^{-1}. From Table 1, it is observed that at SNR = 0 dB, the threshold values are 119.008, 98.8874, 74.4431, and 41.0097 obtained for different values of PFA such as 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}, respectively. That is, as PFA increases, threshold value is decreased

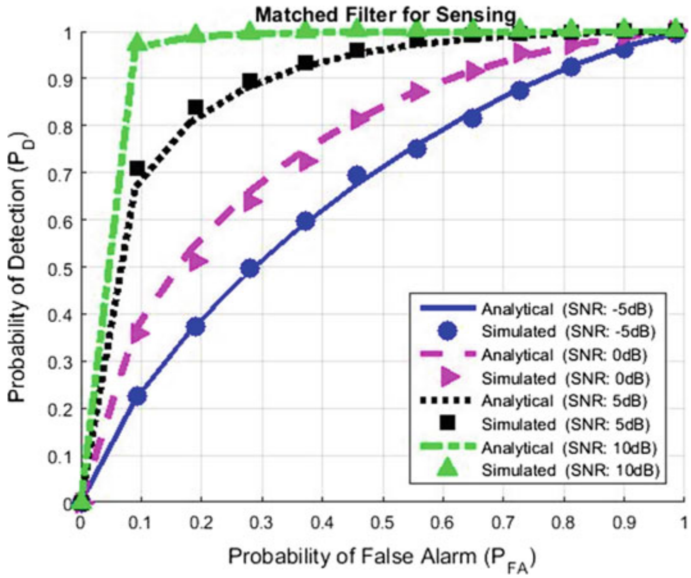

Fig. 1 Receiver operating characteristics

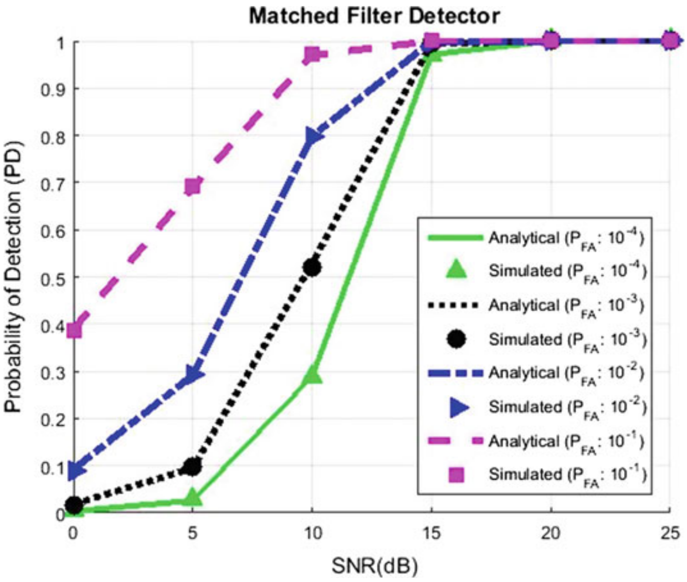

Fig. 2 Probability of detection versus SNR

Table 1 Threshold values for probability of detection

SNR in dB	PFA = $\mathbf{10^{-4}}$	PFA = $\mathbf{10^{-3}}$	PFA = $\mathbf{10^{-2}}$	PFA = $\mathbf{10^{-1}}$
0	119.008	98.8874	74.4431	41.0097
5	66.9234	55.6085	41.8624	23.0614
10	37.6338	31.2710	23.5410	12.9684
15	21.1630	17.5849	13.2381	7.2927
20	11.9009	9.8887	7.4443	4.1010
25	6.6923	5.5608	4.1862	2.3061

which leads to better probability of detection. Similarly, as SNR increases, the corresponding threshold values are decreased for a fixed PFA.

4 Conclusion

In order to sense the spectrum holes consistently and resourcefully, this paper proposed a spectrum sensing based on matched filter detection in CR networks. It needs complete information (such as type of modulation, frequency of carrier, bit rate, shape of the pulse, etc.) of primary user in advance. Monte Carlo simulation is used, which shows good performance. Simulations are carried out to measure the performance of matched filter to detect primary user over AWGN channel.

For 25 dB SNR, better probability of detection is achieved for a given PFA. As PFA increases, threshold values are decreased. This can be observed from Table 1. For a 0 dB SNR, lower threshold is achieved for PFA 0.1. If the signal characteristics are known, matched filter gives better probability of detection.

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