International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Spectrum Sensing in Cognitive Radio using Bayesian Approach

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Abstract: ***In this paper on the basis of probability of detection and probability of false alarm the performance of suboptimal detector is analyzed. To maximize the spectrum utilization Bayesian Detector is proposed. This method makes use of prior statistics and signalling information of primary user to improve secondary user throughput and spectrum utilization of both primary user and secondary user.***

Keywords: Spectrum Sensing, Cognitive Radio, Bayesian Detector, Probability of detection, Probability of false alarm

1. Introduction

During past few years wireless communication and utilization of the radio frequency spectrum is increased tremendously. Due to which Radio frequency spectrum is becoming more crowded. The frequency spectrum allocations are decided by the regulatory authorities in each country such as federal communication commission (FCC) in USA [1].

When new wireless system is introduced, a frequency band needs to make available for it which requires worldwide cooperation. This resulted in spectrum scarcity, which results in heavy congestion in certain frequency bands. Current approach to spectrum allocation is a Fixed allocation to licensed users (Primary users). And Existing scenario is Under-utilization of spectrum And Spatial and temporal “spectral holes” as it is observed that most of the allocated frequencies are heavily under-utilized. The observation also shows that there is a high probability that the primary users are likely idle for most of the time.

This is the research motivation of cognitive radio. Using cognitive radios (CRs), the secondary users (SUs) are allowed to use the spectrum originally allocated to primary users (PUs) as long as the primary users are not using it temporarily this operation is called opportunistic spectrum access (OSA).Cognitive radios are the unlicensed users that opportunistically utilize the licensed band, with the condition to vacate the licensed users spectrum as soon as the Primary User is back in operation.

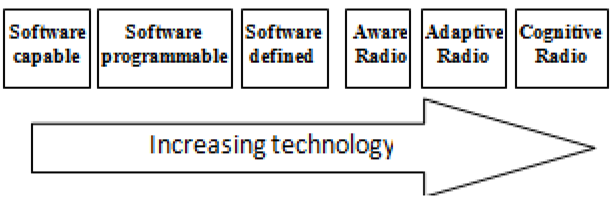

Figure 1: Flow from SDR to CR

Cognitive radio is a term that refers to an intelligent radio that is aware of its surrounding environment.

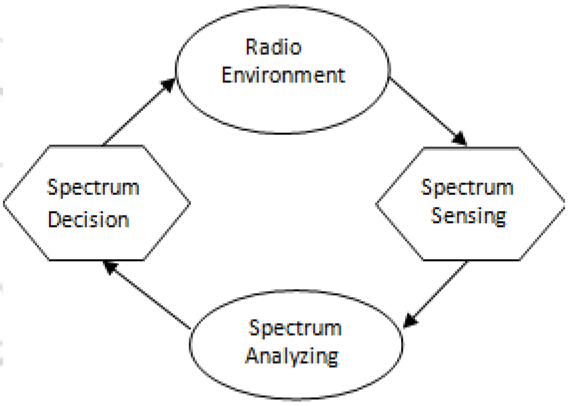

Figure 2: Cognitive Radio working procedure

In Spectrum Sensing the unlicensed users must detect the presence of the licensed user before they could use the spectrum and should vacate the channel as soon as the licensed user enters the channel. For example, the IEEE 802.22 standard requires a secondary user to vacate the channel or reduce power within two seconds of a primary user becoming active. Thus, the cognitive radio must quickly detect this appearance to prevent interfering with the primary user, which implies that a cognitive radio must constantly perform spectrum sensing.

To avoid interference to the primary users, the SUs have to perform spectrum sensing before their attempts to transmit over the spectrum. Upon detecting that the PU is idle, the SUs can make use of the spectrum for transmission, and the overall utilization efficiency of the spectrum is enhanced. Many detection methods, for example, energy detector, covariance based detector, cyclostationarity based detector, Matched filter based detector and wavelet-based sensing method [1][2], have been proposed and studied extensively. But these detectors have some drawbacks also the spectrum utilization is not efficient so we propose the Bayesian detector to maximize the spectrum utilization

2. System Design

In this paper we have referred the mathematical model of Shoukang Zheng [3], For spectrum sensing two Hypothesis are present,

$\mathcal{H}_0$: the PU is absent

$\mathcal{H}_1$: the PU is present.

And there are two important design parameters for spectrum sensing

i) Probability of detection (P_D): the probability that SU accurately detects the presence of active primary signals
ii) Probability of false alarm (P_F): the probability that SU falsely detects primary signals when PU is in fact absent.

Now the spectrum utilisation can be defined as

$$P(\mathcal{H}_0)(1 - P_F) + P(\mathcal{H}_1)P_D \quad (1)$$

and normalized SU throughput is

$$P(\mathcal{H}_0)(1 - P_F), \quad (2)$$

Here $P\ (\mathcal{H}_1)P_D$ is PU throughput when there are primary signals and the SUs detect the presence of the primary signals.

To determine whether the spectrum is being used by the primary user, the detection statistic T_D is compared with a predetermined threshold ϵ. Probability of false alarm P_F is the probability that the hypothesis test chooses $\mathcal{H}_1$ while it is in fact$\mathcal{H}_0$:

$$P_F = P\ (T_D > \epsilon|\ \mathcal{H}_0). \quad (3)$$

Probability of detection P_D is the probability that the test correctly decides $\mathcal{H}_1$ when it is $\mathcal{H}_1$:

$$P_D = P\ (T_D > \epsilon|\ \mathcal{H}_1). \quad (4)$$

A. Signal Model

Here time-slotted primary signals where N primary signal samples are used to detect the existence of PU signals is considered. The PU symbol duration is T which is known to the SU and the received signal $r(t)$ is sampled at a rate of $1/T$ at the secondary receiver. For MPSK modulated primary signals, the received signal of k-th symbol at the CR detector, $r(k)$ is given in [4].

$$r(k) = \begin{cases} n(k)\ \mathcal{H}_0 \\ he^{j\varphi_n(k)} + n(k)\ \mathcal{H}_1 \end{cases} \quad (5)$$

Where $n(k) = n_c(k) + jn_s(k)$ is a complex AWGN signal with variance $N0$, $n_c(k)$ and $n_s(k)$ are respectively the real and imaginary part of n(k), $\varphi_n(k) = 2n\pi/M$, $n = 0, 1, \cdot\ ,M - 1$ with equi-probability, h is the propagation channel that is assumed to be constant within the sensing period. Denote $\boldsymbol{r}$ = [$r(0)\ r(1)\ \cdot\ \cdot\ \cdot\ r(N - 1)$]. Assume that the SU receiver has no information with regards to the transmitted signals by the PU and $\varphi_n(k)$, $k = 0, 1,... ,N - 1$ are independent and identically distributed (i.i.d.) and independent of the Gaussian noise.

The detection statistics of energy detector (ED) can be defined as the average energy of observed samples as

$$T_{ED} = \frac{1}{N}\sum_{k=1}^{N}|r(k)|^2 \quad (6)$$

The likelihood ratio test (LRT) of the hypotheses $\mathcal{H}_0$ and $\mathcal{H}_1$ can be defined as

$$T_{LRT}(r) = \frac{p(r[\mathcal{H}_1)}{p(r[\mathcal{H}_0)} \quad (7)$$

B. Optimal Detector Structure

The probability density function (PDF) of received signals over N symbol duration for hypothesis of $H0$ is denoted as p(**r**|H0) [5], which can be written as

$$p(r|\mathcal{H}0) = \prod_{k=0}^{N-1}\frac{e^{-|r(k)|^2/N_0}}{\pi N_0}$$

Since the noise signals n(k), k=0,….,N-1 are independent. The PDF of received signals is

$$p(r|\mathcal{H}1) = \prod_{k=0}^{N-1}\sum_{\varphi_n(k)} p(r(k)|\mathcal{H}1, \varphi_n(k))\, p\, \varphi_n(k)$$

the structure of the optimal detector (BD) for MPSK signals becomes:

$$T_{BD} = \frac{1}{N}\sum_{k=0}^{N-1} ln\left(\sum_{n=0}^{M/2-1} cosh\left(v_n(k)\right)\right) \gtrless \gamma + ln\frac{M}{2} + \frac{\ln\epsilon}{N}$$

The above equation is complicated to use, we will simplify it in below section

C. Suboptimal Detector (ABD) Structure

The theoretical analysis (detection performance and threshold) for the suboptimal detector to detect complex MPSK (M = 2 and M > 2) in low SNR regime and comparison with the results for real BPSK primary signals.

a. Approximation in the Low SNR Regime

We study the approximation of our proposed detector for MPSK modulated primary signals in the low SNR regime. When $x \to 0, \cosh(x) \approx 1 + \frac{x^2}{2} and\ \ln(1 + x) \approx x$ we can obtain:

$$\sum_{k=0}^{N-1} ln\left(\sum_{n=0}^{\frac{M}{2}-1} \cosh(v_n(k))\right)$$

Through approximation, the detector structure becomes:

$$T_{L-ABD-1} = \frac{1}{N}\sum_{k=0}^{N-1}|r(k)|^2 \gtrless \frac{N_0}{\gamma}\left(\gamma + \frac{\ln\epsilon}{N}\right)$$

b. Approximation in the High SNR Regime

We consider the high SNR regime in this section. When $x \gg 0, cosh(x) \approx \frac{e^x}{2}$ or when $x \ll 0, cosh(x) \approx \frac{e^{-x}}{2}$
The detector structure becomes

$$T_{H-ABD} = \sum_{k=0}^{N-1}\left(ln\left(\sum_{n=0}^{M/2-1} e^{\frac{2}{N_0}\Re[r(k)h^* e^{-j\varphi n\ (k)}]}\right)\right)$$

$$\gtrless \gamma + lnM$$

It employs the sum of received signal magnitudes to detect the presence of primary signals in the high SNR regime, which shows that energy detector is not optimal in high SNR regime.

1. False Alarm Probability

The false alarm probability, is

$$P_F = P\left(T_{L-ABD-1} > \frac{N_0}{2}\left(\gamma + \frac{\ln \epsilon}{N}\right) | \mathcal{H}0\right)$$
$$= Q\left(\frac{\frac{N_0}{\gamma}\left(\gamma + \frac{\ln \epsilon}{N}\right) - \mu}{\sigma}\right)$$
$$= Q\left(\frac{\ln \epsilon}{r\sqrt{N}}\right)$$

2. Detection Probability

The detection probability is

$$P_D = P\left(T_{L-ABD-1} > \frac{N_0}{2}\left(\gamma + \frac{\ln \epsilon}{N}\right) | \mathcal{H}1\right)$$
$$= Q\left(\frac{\frac{N_0}{\gamma}\left(\gamma + \frac{\ln \epsilon}{N}\right) - \mu}{\sigma}\right)$$
$$= Q\left(\frac{\ln \epsilon - N\gamma^2}{r\sqrt{N(1+2\gamma)}}\right)$$

3. Advantages

- Useful for high-rate, emerging wireless communication systems such as WiMAX.
- Spectral efficiency.
- Utilization of spectrum.

4. Result

Using Matlab software we plot P_D *and* P_F versus SNR for L ABD- 2 for 8PSK signals in fig.3 to 4, with the number of samples set to 5,000 when the SNR is low., Figs. 5 and 6 illustrate the theoretical results of P_F and P_D based on the $Q(\cdot)$ function expressions, For 10 samples and 20 million simulation runs the results for the high SNR regime are illustrated in Figs. 7 and 8 for 8PSK signals. BD/H-ABD has a better performance in terms of spectrum utilization and secondary users' throughput, as shown in Figs. 9 and 10.

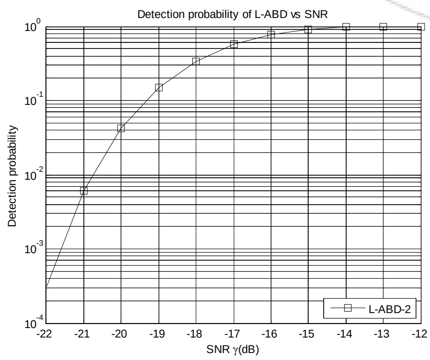

Figure 3: Detection probabilities of L-ABD-2 vs. SNR(dB) for 8PSK modulated primary signals

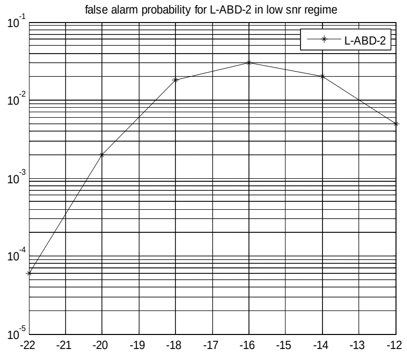

Figure 4: false alarm probabilities of 6 L-ABD-2 vs SNR(dB) for 8PSK modulated primary signals

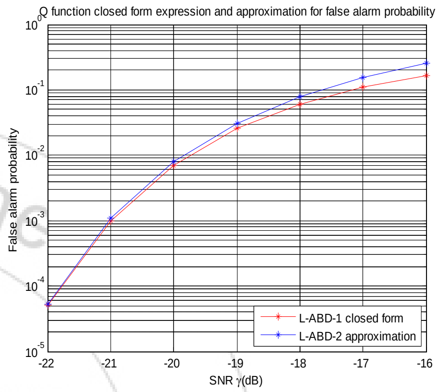

Figure 5: Q function closed form expression and its approximation for false alarm probability of L-ABD-1 vs SNR(dB) for 8PSK modulated primary signals over AWGN

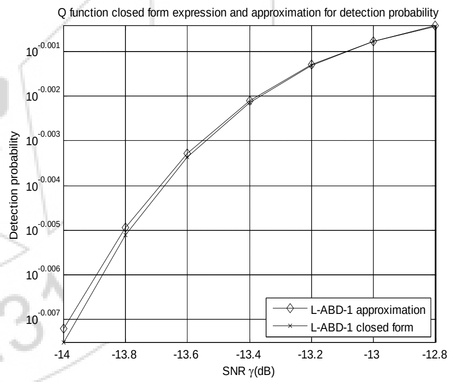

Figure 6: Theoretical results based on Q function closed form expression and its approximation for detection probability of L-ABD-1 vs. SNR (dB) for 8PSK modulated primary signals

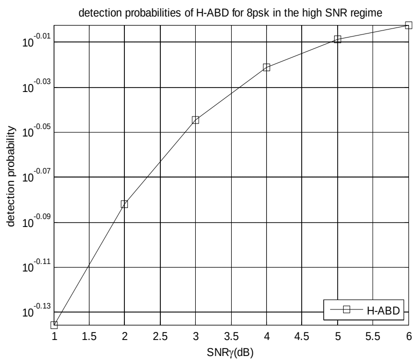

Figure 7: Detection probability of H-ABD vs. SNR (dB) for 8PSK modulated primary signals

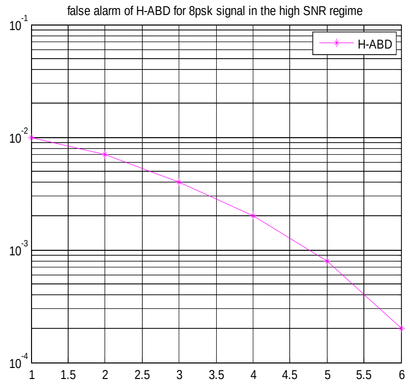

Figure 8: False alarm probability of H-ABD vs. SNR (dB) for 8PSK modulated primary signals over AWGN channel

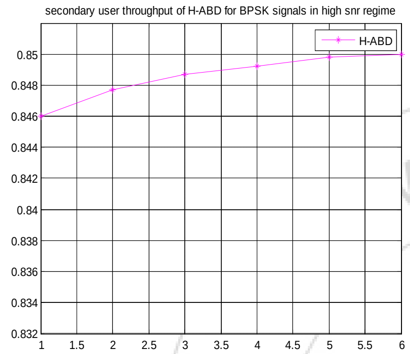

Figure 9: Secondary user throughput of H-ABD for BPSK signals in High snr regime

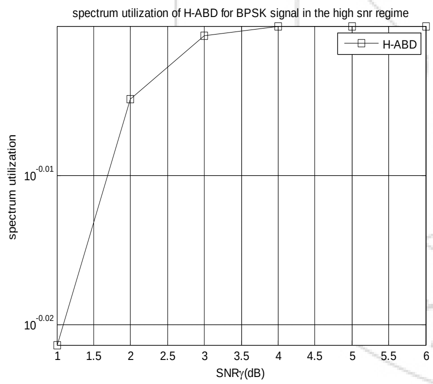

Figure 10: Spectrum utilization of H-ABD vs. SNR (db) for BPSK modulated primary signals over AWGN channels

5. Conclusion

The proposed Bayesian detector has the performance similar to the energy detector that is designed to maximize the spectrum utilization, for complex MPSK signals in the low SNR regime. But they are different in high SNR regime, where Bayesian detector has a better performance in terms of spectrum utilization and secondary users‘ throughput.

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