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SPECTRUM SENSING ANALYSIS USING PSD BASED ENTROPY DETECTION OF DVB-T SIGNAL

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ABSTRACT

Spectrum Sensing plays an important role incorporating intelligence into Cognitive Radio Networks. There are many sensing algorithms proposed in the literature evaluating the detection performance. However, most of them show less recognition accuracy in noisy environment. Due to inaccurate estimation of noise power, it is difficult to sense the primary user signal in the radio frequency band. In this work, a detector is proposed based on the power spectral density of entropy computed in the frequency domain. The SNR wall obtained in the proposed method had an improvement of 6 dB for DVB-T signal compared with the published results. Further, many Monte Carlo simulations were carried under Rayleigh fading and Rician fading channels with Additive White Guassian Noise. Simulation results show the robustness of the proposed method with the noise uncertainty.

Index terms: cognitive radio, energy detection, additive white guassian noise (AWGN), DVB-T.

I. INTRODUCTION

Cognitive Radio is an emerging technique to increase the effective usage of the spectrum. Due to the rapid development in number of wireless devices and gadgets, there is a scarcity in radio frequency band. This leaded to the spectrum sensing concept of identifying the unused spectrum holes. Spectrum sensing can be defined as the ability to detect the presence or absence of a licensed user in the channel. And the most challenging task is to sense in very low SNR regime.

There are several sensing techniques that have been proposed in the literature [1]. Some of them are Energy detection, Cyclo-stationary detection, Entropy detection, Matched filtering. Each method of sensing has its own merits and demerits. If there is any prior information about the signal, then it is easy to correlate the signal. Matched filtering gives productive results using the known characteristics of the signal like pilot sequence, period, and frame size. Not all the times, this method seems to be appropriate. Cyclo-stationary detection is another method that exploits the cyclic features of the signal. It gives better detection results even in the presence of noise uncertainty but with high number of computations and longer sensing time. While the Energy detection is the simplest blind sensing method which do not rely on any information about the primary user signal, but highly sensitive to noise. Considering all these factors in this paper, we investigate entropy detection technique to mitigate the effects of noise interference. In paper [2], a frequency domain entropy based detector is proposed and is proved to be efficient in presence of noise uncertainty. In this paper, its performance is slightly improved by computing the absolute power spectral density of the received signal without increasing the sensing time.

According to 802.22 WRAN standards [3], the unused TV broadcast channels can be used for point to multipoint (P-MP) service. These TV channels address the rural, remote and low population areas with performance same as urban and suburban areas. The WRAN system consists of one base station and one or more CPE (customer premise equipment) radios. The frequency bands may vary over different government bodies. But the range of the system is 33 km to 100 km. The European television broadcasting signal, DVB-T (Digital Video Broadcasting-Terrestrial) is used as the primary user signal here [4].

The received signal is passed through Rayleigh fading and Rician fading channels with Additive White Gaussian Noise. The Fourier transform of the faded signal is first calculated and then its power spectral density is computed. The histogram of these values is divided into L bins and their probability in each bin is estimated. Finally the entropy of the random variable is calculated based on Shannon theorem. The test statistics is compared with threshold to detect the presence of the signal. If the received signal has more information, the entropy is reduced. The threshold is derived using differential entropy in the frequency domain [2], [5]. It depends on the probability of false alarm value and noise power assumed.

The rest of the paper is organized as follows: Section II discusses about the earlier work on entropy detection. Section III describes the proposed method. Section IV presents the simulation results for different cases of fading and noise uncertainty and finally Section V closes with conclusions.

2. EARLIER WORK

In paper [6], Entropy detection is proposed in time domain using matched filter. A likelihood ratio test is used to estimate the entropy of a 4-PAM modulated signal. The estimated entropy of signal for both the classical and Bayesian framework were presented.

In paper [2], [5], entropy is estimated in frequency domain. It has been proved that the entropy of

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noise is constant when number of bins L is fixed. A performance improvement of 4 to 6 dB SNR is achieved compared to cyclo-stationary and energy detection.

In this paper, we investigate entropy of power spectrum to improve the SNR in frequency domain. The received DVB-T signal is sensed with an appropriate detection rate.

3. SPECTRUM SENSING MODEL

In the present communications scenario, the analog samples are converted into digital samples [d (0), d (1), ...d (N-1)]. Using Hypothesis testing [7], the decision is evaluated using a function of available data. There are only two possible hypothesis-one being only noise present and other signal and noise both present. This problem is modeled as

$$H_0 : y(n) = w(n)$$
$$H_1 : y(n) = s(n) + w(n) \quad (1)$$

n = 0, 1, 2….N-1

where H0 is null hypothesis having only noise component w(n) and H1 is true hypothesis having both signal s(n) and noise w(n) components. y(n) is the received signal which follows guassian distribution.

Assumptions:

- The noise is additive white guassian noise (AWGN) with zero mean and variance 1. ($N(0, \sigma_n^2)$)
- The mean of the received signal is μ_s and variance is $\sigma_s^2 + \sigma_n^2$.

The uncertainty of a random variable can be predicted by the information Entropy. Using Shannon entropy, the information contained in the message can be estimated. It has been observed that the Entropy in time domain gives a constant output irrespective of the SNR value [5]. Therefore, we choose frequency domain for detecting the signal.

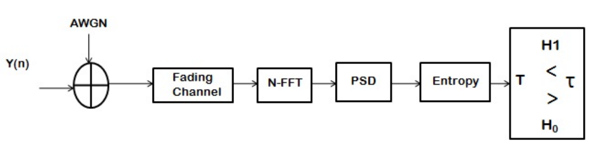

Figure-1. Block diagram of Entropy detection.

A. Proposed detector

The basic block diagram of the proposed detector is shown in Figure-1. The Discrete Fourier transform of hypothesis (1) is given as

$$Y(k) = W(k) \quad (2)$$

$$Y(k) = S(k) + W(k)$$

where k is the DFT length equal to number of samples N, $Y(k)$, $S(k)$ and $W(k)$ are the frequency spectrum representation of received signal and noise components of primary user signal. The complex spectrum $Y(k)$ can be represented as

$$Y(k) = \sum_{n=0}^{N-1} y(n) \exp\left(-j\frac{2\pi}{N}kn\right) \quad (3)$$

$$Y(k) = Y_r(k) + jY_i(k) \quad (4)$$

$$|Y(k)| = \sqrt{Y_r(k)^2 + Y_i(k)^2} \quad (5)$$

In paper [2], [5], the above spectrum magnitude is used for detection of primary user signal. The entropy detection based on spectrum magnitude is proved to be efficient to the noise uncertainty. In this paper, the power spectral density of the signal is evaluated to improve the detection rate. The power spectral density of the received signal can be expressed as [9]

$$P(k) = \frac{|Y(k)|^2}{N} \quad (6)$$

The Shannon entropy of information is used as a measure to estimate the randomness of a signal which is expressed as

$$E(y) = -\sum_{i=1}^{N} p_i \log p_i \quad (7)$$

where p_i is the probability of vector space and L is the number of bins. The spectral values are divided into L bins and the probability is computed. Let r_i be the total number of occurrences in the i[th] bin. The probability p_i is estimated using histogram method.

$$p_i = \frac{r_i}{N}$$

The test statistic can be determined by substituting in (7),

$$E(y) = -\sum_{i=1}^{L} \frac{r_i}{N} \log_2 \frac{r_i}{N} \quad (8)$$

The received signal in time domain follows guassian distribution where as the spectrum follows rayleigh distribution. By proposition1 stated in [2], [5], the threshold for entropy detection is derived using differential entropy as

$$H_L(y) = \ln\frac{L}{\sqrt{2}} + \frac{\gamma}{2} + 1 \quad (9)$$

where γ is a Euler mascheroni constant = 0.5772. Using equation (8) the entropy is calculated to derive the test statistic, given as

$$T_s(y) = -\sum_{i=1}^{L} \frac{r_i}{N} \log_2 \frac{r_i}{N} \begin{cases} \le \tau : H_0 \\ > \tau : H_1 \end{cases} \quad (10)$$

where τ is the threshold for detection which is evaluated by probability of false alarm P_{fa}. The theoretical entropy of AWGN is H_L as mean and variance σ_n^2. The detection threshold is expressed as [5]

$$\tau = H_L(Y) + Q^{-1}(1 - P_{fa})\sigma_n \quad (11)$$

where Q^{-1} is a complementary Q function.

4. RESULTS AND DISCUSSIONS

The detection performance of the proposed scheme is evaluated for DVB-T signal. The primary signal used for transmission is DVB-T signal following the standards specified in ref [4], [10]. In this standard, a set of OFDM coding pulses are used in the transmission. The DVB-T broadcasting signal includes finite-duration symbols of OFDM [8]. There are three specifications pertained to the signal namely bandwidth, mode and cyclic prefix length. The carrier frequency is 4.8 MHz. The bandwidth of the signal may vary from 6 MHz to 8 MHz. There are two modes either 2k or 8k mode deciding the number of subcarriers used in coded OFDM modulation. The 2k mode assumes 2048 and 8k mode assumes 8192 subcarriers. A cyclic prefix is commonly used in the modulation to reduce interference.

The length of cyclic prefix used in OFDM is 1/4, 1/8, 1/16, 1/32. We used 2k mode for our simulations. The number of Monte Carlo simulations is 10000. The probability of false alarm is set to 0.1. SNR is varied from -30 dB to 0 dB. The results were shown for both Rayleigh fading channel and Rician fading channel with AWGN. The number of samples used for simulation are N = 5000. The nominal noise uncertainty assumed is 0.5 dBw and 1 dBw [8]. The number of bins are L =10.

A. Rayleigh fading channel with AWGN

Rayleigh fading channel models the multipath propagation of signals at the receiver. This fading is applicable when there is no dominating line of sight component [11]. Figure-2 compares the detection performance of energy detection, entropy in frequency domain and power spectral density of entropy under Rayleigh fading channel for the same number of samples N = 5000. The SNR wall is defined as the minimum signal to noise ratio below which the detection is not possible. The SNR wall for energy detection is -10.6 dB without the application of noise uncertainty. The results of the published method and the proposed method are compared. The SNR wall of the proposed method is -25 dB without noise, when compared to -18.8 dB for the published method of entropy detection in frequency domain [2]. The proposed method is even tested with noise power of 0.5 dBw and 1 dBw yielding -18.2 dB and -16.4 dB, which shows the sturdiness against noise uncertainty. From simulations, it is clear that there is a significant improvement of 5 to 6 dB in the proposed method.

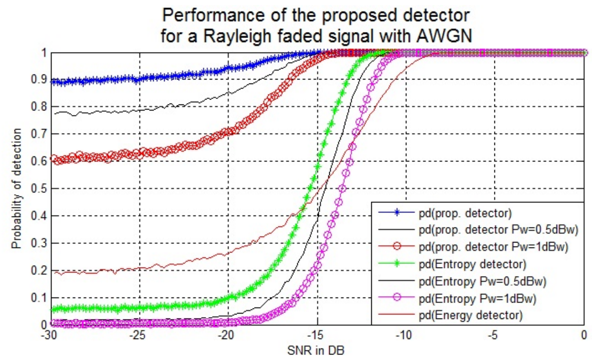

Figure-2. Probability of detection of Rayleigh fading with and without noise uncertainty.

B. Rician fading with AWGN

Rician fading channel is used to simulate the atmospheric disturbances caused due to multipath and line of sight components [11]. The performance of the proposed method is tested under rician fading with AWGN. Figure-3 shows the results of the proposed method, entropy and the energy detection when the primary user signal is passed through the rician fading channel. The entropy detector detects the DVB-T signal at an SNR of -21.6 dB without noise uncertainty. When a noise power of $P_w = 0.5$ dBw and $P_w = 1$ dBw are applied, the SNR reduces by 0.4 dB and 0.8 dB. On the other hand, the proposed method detects the DVB-T signal successfully at an SNR of -23.4 dB without noise, -19 dB and -17.4 dB with noise of 0.5 dBw and 1 dBw respectively. From the simulations of Rayleigh and Rician fading channels, there is a 1.6 dB difference in the detection rate.

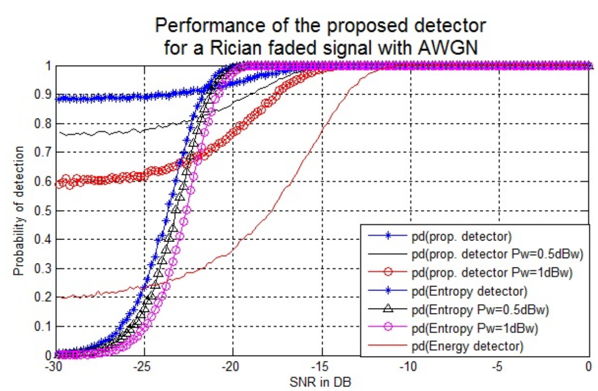

Figure-3. Probability of detection of Rician fading with and without noise uncertainty.

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Table-1. SNR wall comparison in the proposed and published methods.

	Method	Rayleigh fading channel			Rician fading channel		
		$P_{w\,1}= 0$	$P_w = 0.5$	$P_w = 1$	$P_w = 0$	$P_w = 0.5$	$P_w = 1$
Published Methods	Energy detection	-10.6 dB	-	-	-13.4 dB	-	-
	Entropy detection	-19 dB	-	-	-21.6 dB	-	-
Proposed Method	PSD of Entropy	-25 dB	-18.2 dB	-16.4 dB	-23.4 dB	-19 dB	-17.4 dB

$P_w{}^1$ means noise power

Table-1 compares the lowest SNR regime of the published and proposed results. In Entropy detection, the lowest SNR at which the primary user signal is detected is -19 dB without noise uncertainty. There is a 6 dB significant improvement in the proposed method.

When a noise uncertainty of 0.5 dBw and 1 dBw is applied, the detection performance deteriorates. Still the signal is detected at -18.2 dB and -16.4 dB SNR. In the proposed method, a probability of detection of 0.97 is attained at an SNR of -25 dB. The results show that the proposed power spectral density method achieves better results than Entropy detection in frequency domain.

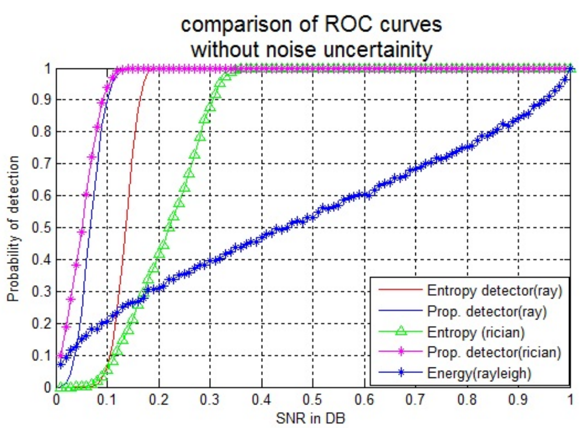

Figure-4. Comparison of different methods at SNR=-25dB.

5. CONCLUSIONS

1. The randomness of the DVB-T signal is explored to increase the sensing performance of the primary user signals in the cognitive radio networks.
2. The SNR wall achieved for the primary user signal in the published literature using Energy detection [12] is -10.6 dB and -19.6 dB using Entropy detection of SSB signal [5]. The proposed algorithm using PSD of entropy method yielded high SNR value of -25 dB which is 6 dB better than the published method for Rayleigh faded DVB-T signal.
3. Using the Rician fading channel, the literature shows -13.4 dB SNR wall for Energy detection method and -21.6 dB for Entropy detection method of SSB signal, where as the proposed method shows -23.4 dB which is 1.6 dB on higher side.
4. The sensing performance for high noise power of 0.5 dBw and 1dBw is also successful for DVB-T signal using the proposed algorithm.

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