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Entropy based Spectrum Sensing in Cognitive Radio Networks

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Abstract: Spectrum sensing is one of the important tasks of Cognitive Radio Networks (CRN). Though many spectrum sensing techniques are available, sensitivity to noise uncertainty is the basic limitation for these techniques. In this paper, an improved entropy based detection technique in frequency domain is proposed. This work investigates the detection performance using Renyi and Tsallis entropy methods in both single node as well as multi node scenario. Simulations were carried out using QPSK and OFDM signals. The performance is evaluated by considering fading channels like Rician, Rayleigh and Nakagami-m fading. The proposed method could achieve 3 dB improvement compared to the Shannon entropy technique, with and without fading channels. The results have shown that Renyi entropy outperforms Tsallis entropy with significant improvement in SNR wall.

Keywords: Cognitive radio, entropy detection, Shannon entropy, Renyi entropy, fading channels.

I. INTRODUCTION

The demand for radio spectrum is increasing due to increase in the use of wireless communication and its applications. But the available spectrum is limited and it is very costly. In many countries, government allocates spectrum to licensed users. But recent measurements have shown that the licensed spectrum is rarely utilized continuously across time and space [1]. Some frequency bands are overcrowded while others are under-utilized. Cognitive Radio (CR) is a possible solution to this spectrum congestion problem which uses the spectrum holes that are not accommodated by the licensed users (also called primary users) [2].

A Cognitive Radio searches and uses unoccupied spectrum bands that are already licensed to a Primary User. The Federal Communications Commission (FCC) allocated the television band to start the CR processes which is mentioned in its Spectrum Policy Task Force (SPTF) report [3]. The IEEE 802.22 working group developed an air interface for the secondary users to access the TV spectrum. Spectrum sensing is one of the important tasks of Cognitive Radio.

There are different spectrum sensing methods which include matched filtering, energy detection, cyclostationary detection and covariance detection. Matched filtering method provides good results, but it requires prior knowledge of the signal characteristics. Energy detection does not require any prior information about the signal, but it is limited by high sensitivity to noise uncertainty. Cyclostationary detection involves complex computations.

In this paper, we investigate entropy based detection technique to overcome the effect of noise uncertainty. In paper [4], [5], entropy is estimated by using Shannon entropy technique. In this paper, we compare and analyze the results using three entropy detection techniques which are Shannon, Renyi and Tsallis entropy. The SNR wall is evaluated in the presence of fading channels like Rician, Rayleigh and Nakagami-m fading. Here, QPSK and OFDM signals are used as primary user signals. Simulations are carried out for both the signals in single node and multi node scenario.

The received signal is passed through Rician, Rayleigh and Nakagami-m fading channels with Gaussian noise. The Fourier transform is applied to this signal and then histogram based probability density function is computed. The probability space is partitioned into L bins. The entropy is evaluated using Shannon entropy, Renyi and Tsallis entropy. The threshold value is determined using differential entropy [4], [5]. Finally, the derived test statistic is compared with the threshold value to detect the presence of primary user signal. To further increase the sensing capability, co-operative sensing is implemented using hard fusion rules such as logical AND and logical OR rule.

This paper is organized as follows. Section 2 presents the earlier work on entropy detection. In Section 3, the spectrum sensing methodology of proposed work is described. Section 4 presents the simulation results of different entropy techniques under fading conditions in case of QPSK and OFDM signals. Finally, Conclusions are drawn in Section 5.

II. EARLIER WORK

In paper [4], [5], Shannon entropy is estimated in frequency domain. They show a performance improvement of 6 dB and 5 dB when compared to energy detectors and cyclostationary detectors in low SNR region. In paper [5], it is proved that noise is constant and time-domain based entropy detections are inappropriate for signal detection.

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In this paper, we investigate the performance using Renyi and Tsallis entropy and evaluate the results in the presence of fading channels. Hard fusion rules are used for multi node detection.

III. SPECTRUM SENSING METHODOLOGY

Let [x(0), x(1),……x(N-1)] be discrete samples of primary user signal. Spectrum sensing can formularized as two hypotheses [6], one indicating the presence of noise and the other indicating the presence of primary signal with noise. This can be expressed as

$$\begin{aligned} H_0 &: x(n) = w(n), \\ H_1 &: x(n) = s(n) + w(n), \end{aligned} \qquad (1)$$

n=0, 1, 2,…..N-1.

Here H_0 is the null hypothesis which indicates presence of only noise signal w(n) and H_1 is the alternative hypothesis which indicates the presence of primary user signal s(n) and noise signal w(n). The received signal x(n) follows Gaussian distribution.

Following assumptions are made:

- The noise is additive white Gaussian noise (AWGN) with zero mean and variance 1.
- The mean of the received signal is μ_s and variance is σ_s^2.

It is proved in paper [4] that entropy estimation in time domain gives constant output in case of noise signal as well as primary signal. Hence, we use entropy estimation in frequency domain.

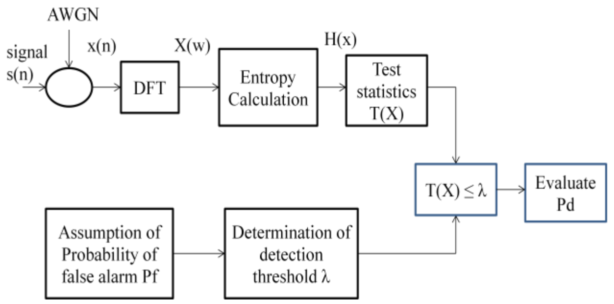

Fig1. Block Diagram of Entropy Detection in frequency domain

A. Proposed Detector

Fig 1 shows the basic block diagram of the proposed detector. After applying Discrete Fourier Transform (DFT) to the hypothesis (1), we get

$$\begin{aligned} \vec{X}(k) &= \vec{W}(k) \\ \vec{X}(k) &= \vec{S}(k) + \vec{W}(k) \end{aligned} \qquad (2)$$

where $\vec{X}(k)$, $\vec{S}(k)$ and $\vec{W}(k)$ are the frequency spectrum representation of received signal, primary signal and noise respectively.

In this paper entropy is estimated using histogram method. The histogram of the received signal X(k) is obtained by dividing the range of values of X_i into L bins. The Shannon entropy is expressed as

$$S = -\sum_{i=1}^{n} p_i \log_2 p_i \qquad (3)$$

where p_i is the probability of the frequency of occurrences in the ith bin and is given as

$$p_i = \frac{m_i}{N} \qquad (4)$$

By substituting this in (3), we get the test statistic

$$T(X) = \sum_{i=1}^{L} \frac{m_i}{N} \log \frac{m_i}{N} \qquad (5)$$

The detection threshold λ is determined as [5]

$$\lambda = H_L(Y) + Q^{-1}(1 - P_f) \qquad (6)$$

where Q^{-1} is complementary Q function, P_f is the probability of false alarm.

The differential entropy in (6) is expressed as

$$H_L(Y) = \ln \frac{L}{C1\sqrt{2}} + \frac{\gamma}{2} + 1 \qquad (7)$$

where γ is the Euler-Mascheroni constant.

The test statistic in (5) is then compared with the detection threshold λ in (6). If $T < \lambda$ detection is decided as H_1 otherwise it is H_0. The same procedure is implemented for Renyi and Tsallis entropy methods. The SNR wall is evaluated in all the three methods.

The Renyi entropy is defined as

$$I_\alpha = \frac{1}{1-\alpha} \log\Big(\sum_{i=1}^{n} p_i^{\alpha}\Big) \qquad (8)$$

By substituting p_i from (4) in (8), we get the test statistic for Renyi entropy.

The Tsallis entropy is defined as

$$S_\alpha = \frac{1}{\alpha - 1}\Big(1 - \sum_{i=1}^{n} p_i^{\alpha}\Big) \qquad (9)$$

By substituting p_i from (4) in (9), we get the test statistic for Tsallis entropy.

In case of multi node detection, hard fusion rules such as AND, OR are used.

The logical AND-rule is expressed as

$$P_{d,AND} = P_{d,i}^{\;N} \qquad (10)$$

where $P_{d,i}$ is the probability of detection for each individual CR user and N is the number of users sensing the primary user.

The logical OR-rule is expressed as

$$P_{d,OR} = 1 - (1 - P_{d,i})^N \qquad (11)$$

IV. SIMULATION RESULTS

The detection performance of the proposed scheme is evaluated for both QPSK and OFDM signals as primary signals. The number of samples used for simulation is 5000. The probability of false alarm (P_f) is set to 0.1. The nominal noise uncertainty assumed is -90 dBmw. The number of bins are L=5. The numbers of Monte Carlo simulations carried out are 1000. In case of QPSK signal, the carrier frequency (f_c) is 40 KHz and sampling frequency (f_s) is 100 KHz. In case of OFDM signal, the numbers of subcarriers used are 32. The encoded polynomial is [171,133]. 16 QAM modulation is used here. A cyclic prefix is commonly used in the modulation to reduce interference.

SNR wall is the key factor evaluated in all the graphs. The SNR wall is defined as the minimum signal to noise ratio below which the detection is not possible [8]. The results of the published method and the proposed method are compared and shown for Rician fading, Rayleigh fading and Nakagami-m fading channels with AWGN. For Nakagami-m fading channel, the shape factor, m is assumed to be 1 and the parameter ω which controls the spread of the distribution is assumed to be 3. All the simulations have been carried out in two phases, one for single node CR and the other for multi node CR.

A. Single Node

In single node simulations, only one SNR range is considered and it is varied from -25 dB to 5 dB.

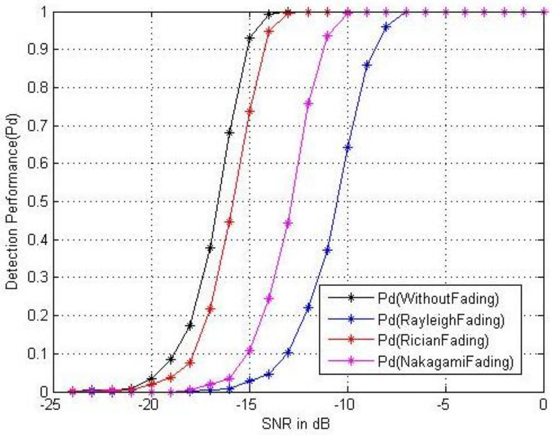

Fig2. SNR vs P_d for Shannon entropy of QPSK signal

Fig 2. shows the probability of detection, Pd on the Y axis in response to Signal to noise ration, SNR on the X axis. The probability of detection of Primary User is evaluated without fading and in the presence of Rician fading, Rayleigh fading and Nakagami-m fading for single node. The entropy is evaluated using (3) and the input signal is QPSK signal. The SNR wall detected without fading is observed as -15 dB. The SNR wall with Rician fading is -14 dB, which is almost near to the value obtained without fading. Similarly, the SNR wall values for Nakagami and Rayleigh fadings are -11 dB and -8 dB respectively.

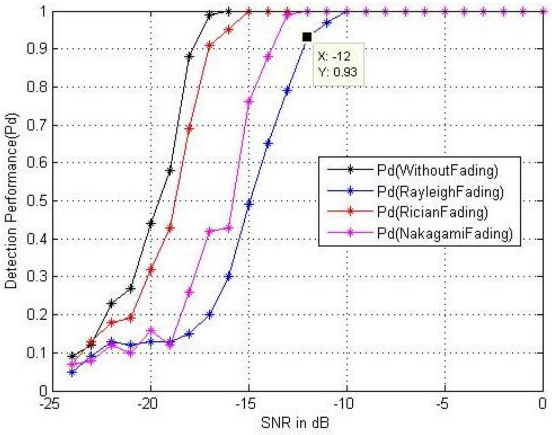

Fig 3. SNR vs P_d for Renyi entropy of QPSK signal

In Fig 3., entropy is evaluated using (8). The SNR wall for QPSK signal without fading is observed as -17 dB. The SNR wall values for Rician, Nakagami-m and Rayleigh fadings are -16 dB, -14 dB and -12 dB respectively. It can be noticed that there is 2 dB improvement in case of Renyi entropy when compard to Shannon entropy.

The SNR walls for all the three entropies for conditions without fading and in the presence of Rician, Rayleigh and Nakagami-m fading are tabulated in table I.

Table I shows results for both QPSK and OFDM signals. The table compares the lowest SNR regime of the published and proposed results. In Shannon entropy detection, the lowest SNR at which primary user signal is detected is -15dB for QPSK signal without fading.

For the same conditions in Renyi entropy detection, the SNR wall detected is -17dB and in Tsallis entropy detection, the value is detected as -13dB. It is observed that there is a significant improvement of about 2dB in the SNR wall with Renyi tropy detection. It is also observed that the performance drops in the presence of Nakagami and Rayleigh fadings for all the three methods.

TABLE I
SNR WALL COMPARISON IN THE PROPOSED AND PUBLISHED METHODS FOR SINGLE NODE

	Method	**Signal**	**Without Fading**	**Rician Fading**	**Nakagami Fading**	**Rayleigh Fading**
Published Method	Shannon Entropy	QPSK	-15dB	-14dB	-11dB	-8dB
		OFDM	-7dB	-5dB	-3dB	----
Proposed Method	Renyi Entropy	QPSK	-17dB	-17dB	-14dB	-12dB
		OFDM	-9dB	-8dB	-6dB	----
	Tsallis Entropy	QPSK	-13dB	-12dB	-9dB	-4dB
		OFDM	-5dB	-3dB	-1dB	----

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B. Multi Node

Multi node simulations are carried out using Logical AND and logical OR rule using (10), (11). In multi node simulations, three nodes are considered with SNR ranges varied from -26 dB to -2 dB, -26.5 dB to -2.5 dB and -27.5 dB to -3.5 dB in case of QPSK signal and -20 dB to 4 dB, -20.5 dB to 3.5 dB and -21.5dB to 2.5 dB in case of OFDM signal.

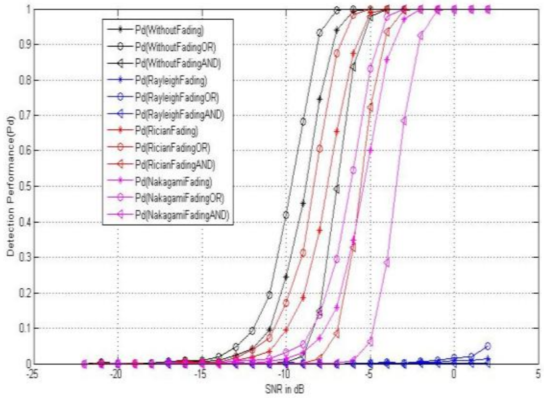

Fig4. SNR vs P_d for Shannon entropy with multi node

Fig 4 shows probability of detection for Shannon entropy. Here the input signal is OFDM. In this case the SNR wall without fading is observed to be –5 dB using AND rule and -8 dB using OR rule. For Rician and Nakagami fadings, the SNR wall is -4 dB and -2 dB using AND rule and -6 dB and -4 dB using OR rule respectively. These values are tabulated in Table 6.3. With OFDM signal also we observe that the SNR wall factor has significant rise when evaluated using logical OR rule.

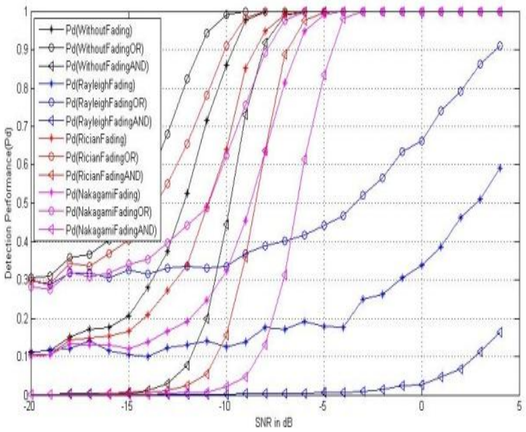

Fig 4. Comparison of P_d of Renyi entropy in multi node

Fig 4 shows the probability of detection for Renyi entropy with OFDM signal using multi node. In this case the SNR wall without fading is observed to be –8 dB using AND rule and -11 dB using OR rule. For Rician and Nakagami fadings, the SNR wall is -7 dB and -4 dB using AND rule and -9 dB and -7 dB using OR rule respectively. It is noticed that the SNR wall has significant rise when evaluated using logical OR rule.

Table II shows results of published and proposed methods for multi node. For a single node with Shannon entropy detection without fading, the SNR wall is observed to be -15dB for QPSK signal. In case of multi node, by considering the same conditions and applying Logical OR rule, the SNR wall is observed to be -16 dB. A marginal increase of 1dB is observed in all the three methods when logical OR rule is applied for detection. Hence, we can see that performance improves using cooperative sensing.

TABLE II SNR WALL COMPARISON FOR MULTI NODE SCENARIO

	Method	**Signal**	**Logic Rule**	**Without Fading**	**Rician Fading**	**Nakagami Fading**	**Rayleigh Fading**
Published Method	Shannon Entropy	QPSK	AND	-13dB	-12dB	-9dB	-7dB
			OR	-16dB	-15dB	-12dB	-9dB
		OFDM	AND	-5dB	-4dB	-2dB	----
			OR	-8dB	-6dB	-4dB	----
Proposed Method	Renyi Entropy	QPSK	AND	-15dB	-14dB	-12dB	-10dB
			OR	-19dB	-18dB	-15dB	-13dB
		OFDM	AND	-8dB	-7dB	-4dB	----
			OR	-11dB	-9dB	7dB	4dB
	Tsallis Entropy	QPSK	AND	-11dB	-10dB	-7dB	-2dB
			OR	-13dB	-12dB	-9dB	-5dB
		OFDM	AND	-3dB	-2dB	0dB	----
			OR	-5dB	-4dB	-2dB	----

V. CONCLUSIONS

This paper presents a Renyi entropy based spectrum sensing in CRNs. In the proposed method, the primary user signal has been sensed in the presence of all the three fading channels namely, Rician, Rayleigh and Nakagami Fading. The SNR wall for both QPSK and OFDM signals using the proposed method gave at least 2 dB improvement in both with fading and without fading channel conditions. For the QPSK signal, the best SNR wall obtained is -17dB with Renyi entropy for single node and for the OFDM signal, the best SNR wall obtained is -9 dB. In the multi node scenario, the hard decision fusion techniques, were successfully implemented under fading, which gave a 3 dB improvement in detection. The Renyi entropy method outperforms the Tsallis method with significant improvement in SNR wall.

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