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Histogram Stacking for Reliable Spectrum Sensing in Cognitive Radio

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Abstract: Cognitive Radio(CR), the radio of secondary users requires a reliable spectrum sensing to detect spectrum holes for a non-interfering secondary transmission. But, factors like uncertainties in noise, multipath fading, shadowing and Low Signal to Noise Ratio (SNR) of the detected signal put a limit on the robustness of reliable detection of primary signal. In this paper, we consider a multiple antennas spectrum sensing in CR system and we propose a power spectral density (PSD) based histogram stacking method, which can even detect weak signals with very high noise levels.

Key words: Cognitive Radio Networks · Multiple Antenna Spectrum sensing · Power Spectral Density · Histogram stacking

INTRODUCTION

The today's communication world requires a large spectrum to satisfy the need of increasing service providers. A user, who has the license to use the allotted frequency band is called the primary user. The secondary users do not have their own spectrum; they are waiting (or) looking for a free spectrum, if any. The recent spectrum surveys show that the spectrum below 3GHz has already been completely distributed. Spectrum is a natural resource and there is no way for spectrum to be increased. It can only be efficiently utilized. Even though, it looks like, the spectrum bands are highly congested and there is a scarcity of spectrum for new users, 70% of the licensed spectrums are underutilized at both time and location which are called spectrum holes ([1, 2]). This is shown in Fig. 1. This under utilization of the spectrum is more in TV channels, the so-called TV white spaces.

CR should be capable of sensing the spectral environment and uses the spectral holes if any, without causing interference to the primary transmission [3, 4]. Reliable spectrum sensing is an important task of a cognitive radio since it enables the CR to adapt to the available spectral hole. Importance of spectrum sensing can be understood from it is being considered for inclusion of IEEE 802.22 standards.

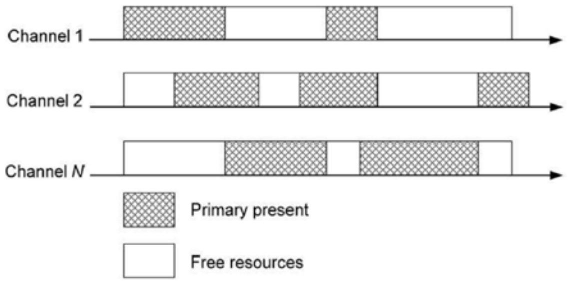

Fig. 1: Channel allocation and Spectrum Holes [4]

There are many techniques like Energy Detection[5], Cyclostationary feature detection[6], Matched filter detection and wavelet based sensing to sense whether the channel is free from secondary transmission or not.

Main Issues: Due to low SNR, Channel uncertainty and noise uncertainty, there are possibilities for misdetection and false alarm. If the system decides that the channel is free when it is actually used by the primary user, it is called misdetection. Misdetection may lead to serious primary interference issues. If the system detects a signal when the channel is actually free, it is called false alarm. This may again lead to underutilization of the channel.

The primary signal that received may be a faded signal due to multipath and it may be shadowed by obstacles like tall buildings, trees, towers, etc. Hence, a

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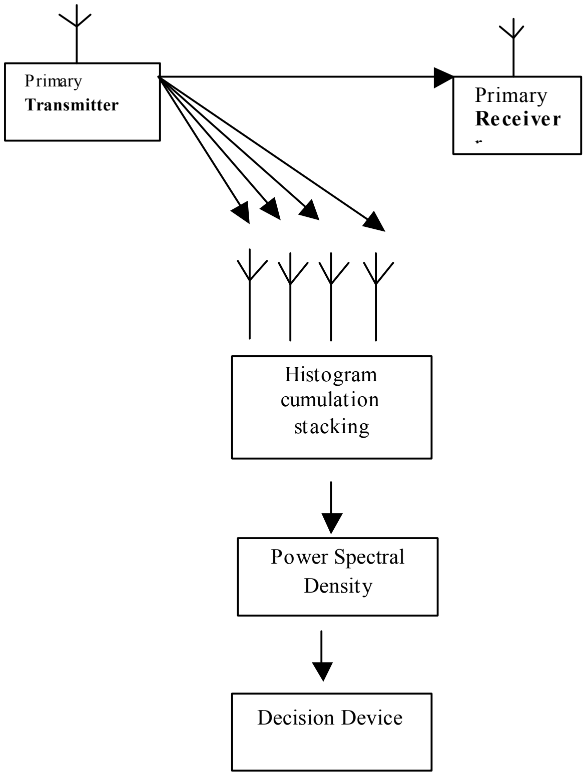

Fig. 2: Multiple antenna based histogram stacking

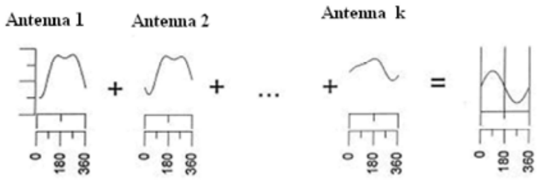

Fig. 3: Histogram stacking for averaging the signal [9]

single receiver will not give a reliable solution for spectrum sensing. Both, multipath fading and shadowing depends upon the receiver’s location. To fight these effects, cooperative spectrum sensing is proposed by many authors; in which different users can share their sensing results to cooperatively improve the detection sensitivity. This technique allows the secondary users to use less sensitive detectors, which is cost effective and thus reduces hardware complexity [6, 7].

But, there are few drawbacks in cooperative spectrum sensing also. To take a final decision on spectrum sensing, the local measures of individual secondary users have to be collected through a common channel, which increases the communication overhead. Moreover, Multipath fading and shadowing correlates with spatial distance between different secondary users which reduces the diversity gain [8, 9]. In cooperative spectrum sensing, there is a possibility of repudiation attack by the malicious secondary user, which may lead to serious primary user interference problem. When large number secondary user is interested in transmission, then there will be a secondary interference.

To overcome the Low SNR Problem and noise uncertainty, histogram stacking is suggested which is described in section 3 and the proposed system has multiple antennas, which provides multiple measurements of the signal and gives a reliable solution over multipath fading and shadowing[10]. Spectrum sensing is done by using the power spectral density of the received signal and it is explained in section 4.

Histogram Stacking and Spectrum Sensing: We propose multiple antenna CR sensors, which require no prior knowledge about the primary user. All these sensing hardware is integrated into the Master via WLAN. The received signals from diverse antennas will be taken continuously and the received signal is analyzed at the Master using histogram stacking and power spectral density as explained below. This method is well suited for signal detection when the SNR of the signal is very low, especially during disasters like tsunami, earthquake and flood.

Histogram cumulation stacking has been widely used in earth and natural sciences to detect weak signals in a noisy environment [9]. The same procedure is adopted with slight modifications for spectrum sensing. The signal received may contain high amount of noise, which first appears as a white noise. 1° histogram of signal received by each antenna is created and is connected to the master system via WLAN (Fig. 2). As illustrated in Fig. 3, ln the master system they are stacked, which results in an averaging of signal. Once the shape of the histogram for a particular time period is established, the power spectral density can be calculated to confirm the signal presence.

Let us consider a primary signal x(t) which is centered about fc and bandwidth B.

If y(t)=w(t) : for Ho i.e., there is no signal present and the band is free.

If y(t)=x(t)+w(t) : for H1 i.e., there is a noisy signal present and the band is occupied by the primary user.

Histogram stacking is applied to the time locked signals which results in averaging of signals. Ideally, averaging of signals results in SNR improvement.

The noise is assumed to be an Additive White Gaussian Noise (AWGN) with zero mean and a variance σ2. The signal to noise ratio of ‘n’ antenna outputs is given by equation (1),

☻ (1)

Thus, SNR increases square root number of antennas used for measurements. Generally, the sensing time depends on the Signal to noise ratio. This improved SNR reduces the sensing time.

During histogram stacking, the signal is converted into discrete time signal.

y(n)=w(n) : for Ho
y(n)=x(n)+w(n) : for H1

Power spectral density of a signal can be obtained by taking the DFT of its autocorrelation.

Sxx(f) = ☻ (2)

where, $Rxx(n) = Lim_{N\rightarrow\infty}\frac{1}{N}\sum$

For a noisy signal

$Sxx\ (f) = \sum_{k=-\circ}^{\infty}$

where, $Rww\ (n) = Lim_{N\rightarrow\infty}\frac{1}{N}\sum_{n=0}^{N}$

= ☻

$Sxx\ (f) = \sum_{k=-\infty}^{\infty} R_{xx}(k)e^{-i2\pi kf} +$

= ☻ (3)

and Sww (f) = ☻ = ☻ (4)

Equation (4) shows that the white noise has constant, flat power spectral density. Whereas, the signal has equal power in a fixed width (B), which is centered about a particular frequency (fc) (Equation(3).

Let the power spectral density is S and performance evaluation of the system using Probability of detection is,

Pd = P (S> ☻ (5)

The performance of the detector can be described by the receiver operating characteristic curve (ROC) which can be given as,

ROC(a) = ☻

Where,

Pmd = 1- Pd = 1-P(S>☻ (6)

Pfa= P(S<☻ (7)

RESULTS AND DISCUSSIONS

The proposed system was simulated using matlab and the performance was evaluated. By increasing the number of antennas, the improvement in SNR has been studied. We show the improvement in the results, compared to the existing hard fusion cooperative spectrum sensing (AND, OR and Majority Rule). For a multiple antenna system with n=4, Fig. 4 compares the power spectral density of a raw signal and the histogram stacked signal for an SNR of -5dB. Generally, power spectral density of a signal has a strong peak at the center frequency and noise has a constant power spectral density [10, 11].

We test the effect of histogram stacking on the probability of detection and Receiver operating characteristics (Figure 5). Receiver operating characteristics was studied using equation (8) and equation (9),

$$Pfa = \frac{1}{2}[1 - erf\left[\frac{No}{\sqrt[2]{2\sigma_N{}^2}}\right]] \qquad (8)$$

$$Pd = \frac{1}{2}[1 - erf[erf^{-1}(1-2P_{fa}) - \sqrt[2]{\frac{n\frac{1}{2}x}{2}}]] \qquad (9)$$

It is noted that there is a significant improvement in the ROC curve with increasing number of antennas, as the noise uncertainty will not affect the power spectral density. For the same reason, setting the threshold is also not a problem, compared to the energy detection method [12].

Fig. 6 shows the improvement in SNR for different number of antennas. For Pf=0.1 and SNR=9dB, the probability of detection for an individual antenna is 0.7638 whereas, the probability detection for four antennas with histogram staking method is 0.9391.

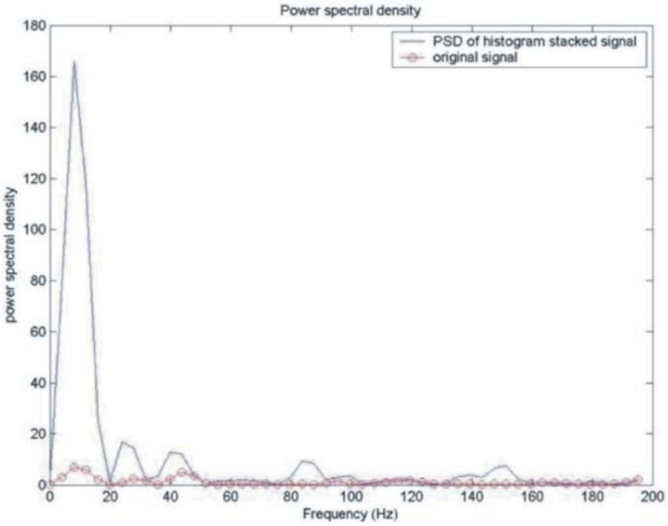

Fig. 4: PSD of raw signal and histogram stacked signal for n=4

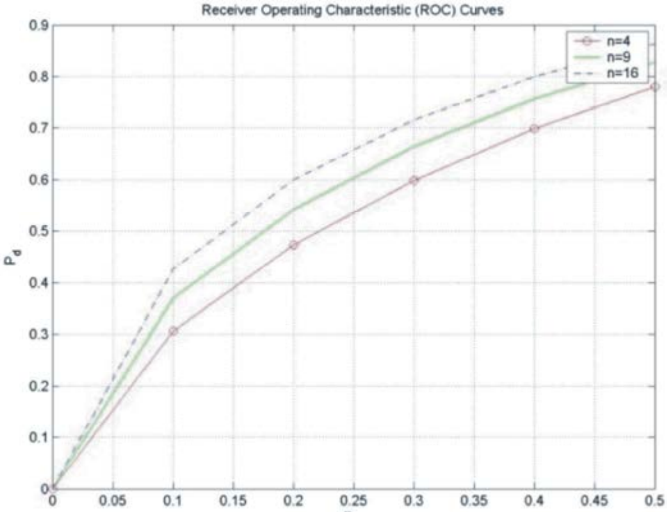

Fig. 5: Receiver operating characteristics

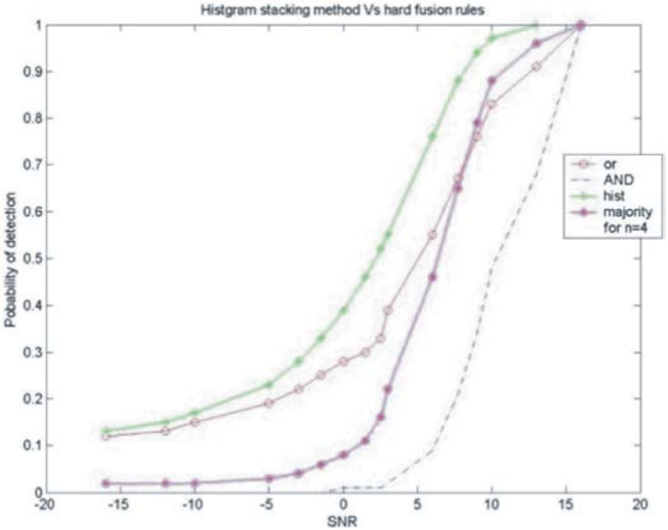

Fig. 6: Histogram stacking vs. hard fusion techniques

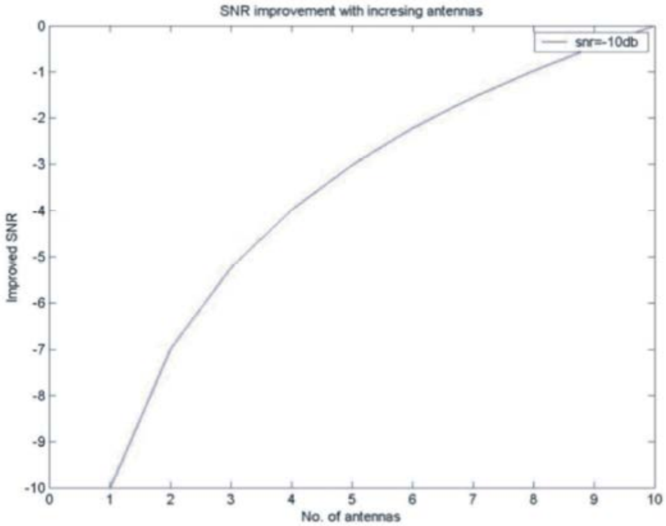

Fig. 7: No. of Antennas vs. Improvement in SNR

The proposed system shows a significant performance improvement compared to the hard fusion cooperative spectrum sensing techniques like AND rule, OR rule and majority rule (Fig..7).

CONCLUSION

In this paper, we proposed a multiple antenna power spectral density based histogram stacking method for spectrum sensing and the improvement in SNR and ROC curve were shown. We also prove that this method is robust to noise uncertainty. It is also verified that setting a threshold is also simple as it is solely depends upon the power spectral density of white noise.

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