A Spectrum Sensing Method for Cognitive Radio Networks Using Dispersion Detection

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Abstract: Spectrum sensing techniques are used to identify the frequency spectrum in cognitive radio(CR) and software defined radio (SDR). The main aim of this project is to utilize the available frequency bands effectively for CR and SDR. Different detection techniques are currently available for the secondary users to use the frequency band of the primary users. From the research, the efficiency of the spectrum sensing technique increases only if its complexity is increased and if its complexity is decreased then its efficiency decreases. so, a new technique is proposed in this paper based on dispersion to balance both complexity and efficiency.

Keywords : cognitive radio, dispersion detection, spectrum sensing, detection probability, false alarm probability

I. INTRODUCTION

In modern era, the communication between two devices or machines have become wireless. Today, in smart industry automation, the machines are connected and controlled by wireless. today due to increase in wireless devices and machines, there is shortage of frequency bands. to meet the needs of wireless users, communication system needs higher data rate with large channel capacity[1]. Mitola.J [2] proposed a concept of cognitive radio (CR) in 1998, an extension of software defined radio (SDR). In 2011, an official standard for CR is published by IEEE.

Cognitive radio utilizes the available spectrum efficiently. CR has primary and secondary users. The primary users (PU) are licensed users and the secondary users (SU) are unlicensed users. The secondary users depend up on primary user's frequency band. The available spectrum hole and used spectrum is identified as in figure 1.

The spectrum sensing method performance can be calculated using two main metrics they are 1) Detection probability where the probability that a CR can correctly decides that the spectrum is busy or free when the primary transmission is taking place or not. 2) False alarm probability is where the CR makes a wrong decision that the spectrum is occupied while it is actually not.

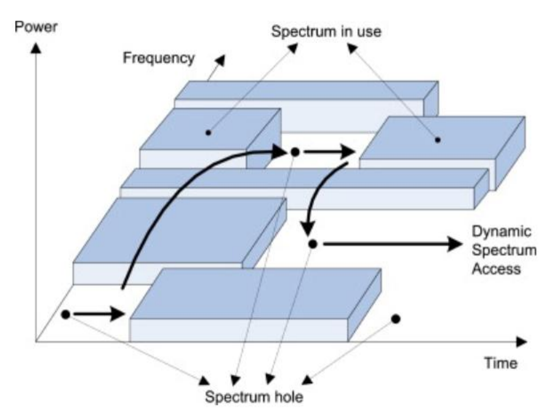

Fig. 1. Spectral opportunity for secondary user

II. LITERATURE SURVEY

Today various techniques are available in practice to detect white space in spectrum for

CR. Generally, the sensing techniques are classified into following categories[4].

A. Energy Detection Technique

Hypothesis model for transmitter detection is defined in [5] that is, the signal received is detected by the CR (secondary) user is (equation 1)

$$x(k) = \begin{cases} n(k), H_0 \\ s(k) + n(k), H_1 \end{cases} \quad (1)$$

s(k) - Transmitted signal of primary user

n(k) - Additive white Gaussian noise (AWGN) and

h - Amplitude gain of the channel.

H0 represents the Primary user absent H1 represents the primary user is present

The main advantage of this technique is, it is doesn’t require any previous knowledge about primary user i.e. semi-blind spectrum sensing technique. The input signal obtained cannot be differentiated between noise and signal power. The performance of this technique is susceptible to uncertainty in noise power. This technique provides low accuracy and low complexity with low SNR values. This method consumes more time to provide good results. The sensing in energy using adaptive threshold provides much better performance at lower SNR region [14]. The energy is calculated as (equation 2)

E=|x(n)|2 (2)

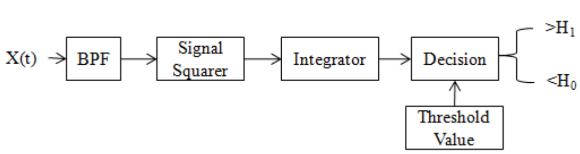

Fig. 2. Block diagram of an Energy Detection Technique

B. Matched Filter Detection

The SNR obtained from the matched filter is very high (Fig. 3). This technique is difficult to implement because it requires carrier at receiver which increases the cost. This technique requires the previous knowledge about the user.[17]

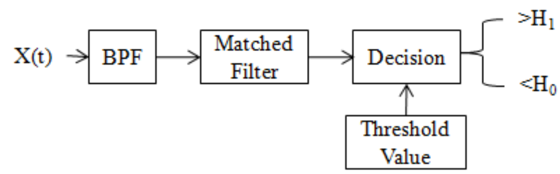

Fig. 3. Block diagram of matched filter detection

C. Cyclostationary Feature Detection

This technique doesn’t require previous knowledge about the primary user (Fig. 4). This technique is better under noise environment for detecting the primary signals. This detection technique produces complexity while there by it takes longer observation time for sensing. Some of the drawbacks in transmitter detection technique is receiver uncertainty problem, shadowing problem, Hidden node problem. This method has information about licensed user but no information about the primary receiver. The cognitive radio can’t identify the low power signals [15-16,18]. The cyclostationary feature detection is given by (equation 3)

$$S_{yy}^{a} = \sum_{\tau=-\infty}^{\infty} R_{yy}^{a}(\tau) e^{-j2\pi f} \quad (3)$$

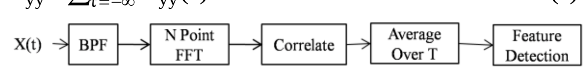

Fig. 4. Block diagram of a Cyclostationary feature detection

Interference temperature method (Fig. 5) works under ultra-wideband (UWB) technology. The secondary user coexists with the primary user and at lower power it can be transmitted. This method is restricted by the interference temperature level to not cause any interference to the primary user [6].

$$T_1(f_c, B) = \frac{P_1(f_c, B)}{KB} \quad (4)$$

$P_1(f_c, B)$ is the average interference power limit in Watts centered at critical frequency (equation 4).

Mounir Ghogho et.al proposed [7] a Locally optimum detection technique of random signals under weakly correlated models over fading channels (i.e. Rayleigh fading environment) is considered here. The theoretical average probabilities obtained from the estimated correlation between noise samples is different from real correlation. The probability of detection is superior over the existing transmitter detection method (i.e. Energy detection) with complexities in noise.

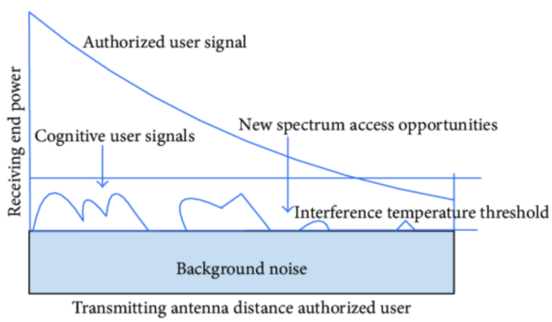

Fig. 5. Interference temperature model

Waleed Ejaz et al proposed [8] a Fuzzy based technique (Fig. 6) produces a 'SOFT' linguistics like (H-High, L-low, M-Medium) system variables and can have more values in the interval [0,1] instead of a binary system decision to detect the presence of a primary users or not. The description of L, M, H represents PU is not present (assigned input is 0), the PU can be present or absent (assigned input is 0.5), the PU is present (assigned input is 1). Fuzzy based technique provides better output under low SNR values than other basic detection techniques with a drawback of increase in computation time.

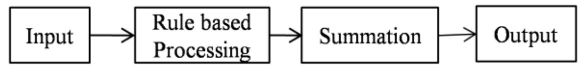

Fig. 6. Block Diagram for Fuzzy Based Technique

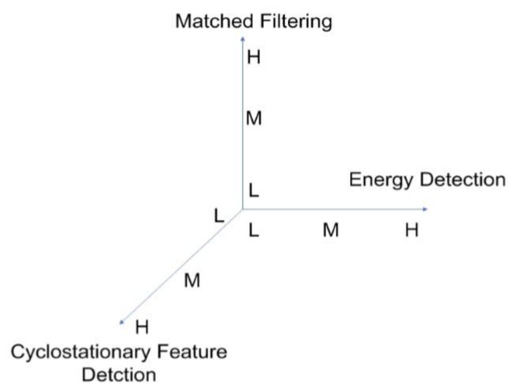

Fig. 7. Description of fuzzy based logic

Subhashree et al. proposed [9] a method that uses generic algorithm and differential evolution algorithm to minimize the probability of error. The differential evolution provides better solutions and fewer evaluations to solve optimization problems. It takes less time for computing the differential evolution then generic algorithm.

Chen et al. proposed [10] a method to avoid interference and spectrum efficiency problem. The major drawback is sensing efficiency problem (i.e. decreasing the transmitting opportunities)

Kortun et al prposed [11] a Eigen value-based detection which is closely equivalent to covariance detection. This detection technique is simplified to provide a better performance for the probability of detection. The Eigen value-based detection is analyzed using matrix theory. Several variations for eigen value test statistics is given by

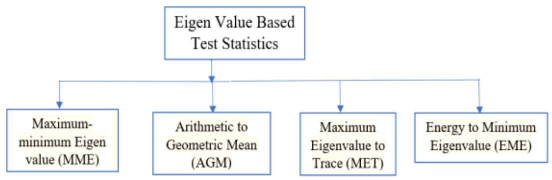

Fig. 8. Block Diagram for Eigen Value Based Test Statistics

Zhao proposed [12] a Wavelet based detection technique which is used for performing multi resolution analysis in signal space. Discrete wavelet transform is also proposed for the separation of frequency spectrum. A general wavelet transform is given by

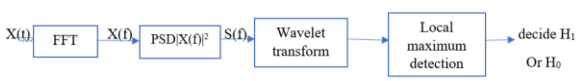

Fig. 8. Block Diagram for Wavelet Based Detection

Wang proposed [13] a PSD which is used for detection of spectrum holes. It is also used for modulation of incoming input signals at different channel with different carrier frequencies. It can also be calculated from different channels in the network and therefore the calculated power and threshold value is compared to find the presence of the primary users.

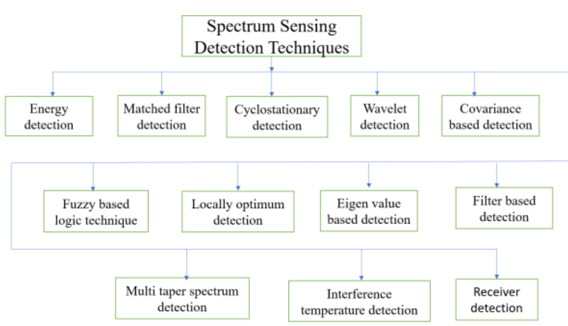

Fig. 9. Block Diagram for different Spectrum Sensing Detection Techniques

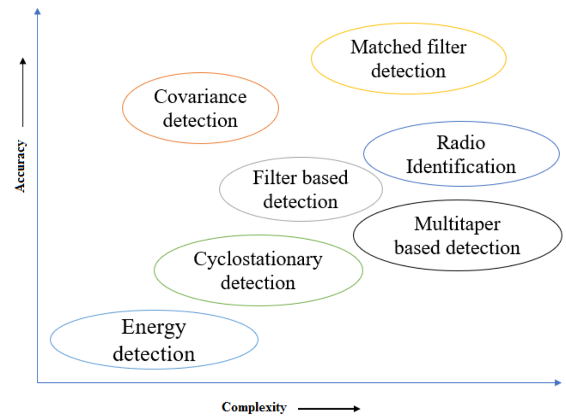

Fig. 10. Performance for Different Detection Techniques

III. DISPERSION DETECTION METHOD

Dispersion is a measure which gives an idea about the scattering of the values. Some of the different measures of dispersion are Range, Mean deviation, Variance and Coefficient of variance

A. THE SIGNAL MODEL

Dispersion detection can differentiate the power and noise of the signal which is a drawback of interference feature detection and energy detection. The proposed technique is used for avoiding uncertainty of noise power. The dispersion detection attempts on 1) noise samples are not dependent and hence not correlated 2) samples of reasonable information carrying signals are correlated. The flow of dispersion detection technique is given in fig 5. Consider M antennas utilized. be the discrete time sample received signal form Mth antenna. The statistical dispersion matrix of the discrete time sample received signal with binary hypotheses is defined as (equation 7)

$$x(k)=\begin{cases} n(k), H_0 \\ s(k)+n(k), H_1 \end{cases} \tag{7}$$

i.e., the received signal x(k) = [x1(k), x2(k), ... xn(k)] consists only of Independent and identically distributed (IID) with zero mean additive white gaussian noise (AWGN)

$$n(k)=[n_1(k), n_2(k)......n_M(k)]$$

$$n(k)\cong N(0,\sigma^2{}_n\, I_M) \quad (8)$$

The dispersion detection of received signal is given by

$$R_x = E[x(k)\,x^T(k)] \quad (9)$$

Then,

$$R_x = \begin{cases} \sigma^2{}_n\, I_M & , H_o \\ Rs + \sigma^2{}_n\, I_M & , H_1 \end{cases} \quad (9)$$

x(k) is a multivariate random vector with general properties

$$x(k) \approx \begin{cases} N(0,\sigma^2{}_n\, I_M) & , H_0 \\ N(0, R_s\, \sigma^2{}_n\, I_M) & , H_1 \end{cases} \quad (10)$$

If the PU signal is not present Rx then the slanting elements are zeros. If PU signal is present then the non-diagonal elements should be related to signal and power which should not be affected by correlation.

$$T=\frac{T_1}{T_2} \quad (11)$$

T1 represents non-diagonal elements and T2 represents diagonal elements i.e. power signal where,

$$T_1 = \sum_{p\neq q;\, p,q=1}^{M} |R_x(p,q)| \quad (12)$$

and

$$T_2 = \sum_{p=1}^{M} |R_x(p,p)| \quad (13)$$

B. STATISTICAL DISPERSION DETECTION

The sample dispersion estimates are calculated based on the obtained received signal (Equations 14 to 22)

$$\hat{R}_x = \frac{1}{k}\sum_{k=1}^{k} x(k)\,x^T(k) \quad (14)$$

The test dispersion is given by

$$\hat{T}=\frac{T_1}{T_2} \quad (15)$$

Where,

$$\hat{T}_1 = \sum_{p\neq q;\, p,q=1}^{M} |R_x(p,q)| \quad (16)$$

and

$$\hat{T}_2 = \sum_{p=1}^{M} |R_x(p,p)| \quad (17)$$

The decision threshold is given by

$$\text{decision} = \begin{cases} H_0, \hat{T} < \lambda \\ H_1, \hat{T} > \lambda \end{cases} \quad (18)$$

The Pd and Pf is given by

$$P_f = P_r(\hat{T} > \lambda \mid H_0) \quad (19)$$

$$P_d = P_r(\hat{T} > \lambda \mid H_1) \quad (20)$$

The probability of false alarm and the probability of detection is given by

$$P_d = 1 - F_{\hat{T}|H_1}(\lambda) \quad (21)$$

$$P_f = 1 - F_{\hat{T}|H_0}(\lambda) \quad (22)$$

C. THE DECISION THRESHOLD

For a good detection technique, a high Pd and low Pf should be achieved. The choice of threshold is a compromise between Pd and Pf . The threshold is chosen such that a certain value of false alarm probability Pf is achieved. The threshold selection can be based on either theoretical derivation or computer simulation.

1) Threshold selection based on computer simulation

Initially, Pf value is set and a threshold '□' is found to meet the required Pf . A AWGN is generated as the input signal and the threshold is adjusted to meet the required Pf .

2) Threshold selection based on theoretical derivation

To find the statistical distribution of T1(Ns)/T2(Ns), the threshold associated with these probabilities are derived as follows (Equations 23 to 36)

$$\mu_{\hat{T}|H_0} = (M^2 - M)\sqrt{\frac{2}{K\pi}}\sigma^2{}_n \qquad (23)$$

$$\mu_{\hat{T}|H_0} = M\sigma^2{}_n \qquad (24)$$

$$\sigma^2{}_{\hat{T}_2|H_0} = \frac{1}{K}(M_2 - M)\left(2 - \frac{4}{n}\right)\sigma^4{}_n \qquad (25)$$

$$\sigma^2{}_{\hat{T}_2|H_0} = \frac{2M}{K}\sigma^4{}_n \qquad (26)$$

$$\rho_{\hat{T}_1\hat{T}_2|H_0} = \frac{E[\hat{T}_1\hat{T}_2 \mid H_0] - \mu_{\hat{T}_1|H_0}\mu_{\hat{T}_2|H_0}}{\sigma_{\hat{T}_1|H_0}\sigma_{\hat{T}_2|H_0}} \qquad (27)$$

In practical estimation the K value should be always larger than M. so it will be reasonable to calculate the false alarm probability.

$$\xi_u(\lambda) \mid H_0 = \frac{\lambda\mu\hat{T}_2 - \mu\hat{T}_1}{\sqrt{(\alpha_{11} - \xi\alpha_{21})^2 + (\lambda - \zeta)^2\sigma^2\hat{T}_2}} \mid H_0 \qquad (28)$$

The decision threshold for the false alarm probability is given by

$$\xi_u(\lambda) \mid H_0 = \varphi^{-10}(P_f) \qquad (29)$$

The quadratic equation for decision threshold is given by

$$A\lambda^2 + B\lambda + C = 0 \qquad (30)$$

where

$$A = M^2 - \frac{2M}{K}(\varphi^{-1} - (P_f))^2 \qquad (31)$$

$$B = 2 \qquad (32)$$

$$(M^3 - M^2)\left(\frac{2\sqrt{2}}{K\pi}e^{-k/4} + \sqrt{\frac{2}{k\pi}} \times \left(\varphi\left(-\sqrt{\frac{K}{2}}\right) - \varphi\left(\sqrt{\frac{K}{2}}\right) - 1\right)\right)$$

$$\times\left(\varphi^{-1}(P_f)\right)^2 - 2(M^3 - M^2)\sqrt{\frac{2}{K\pi}} \qquad (33)$$

$$C = \left(M^3 - M^2\right)\frac{2}{K\pi} - \frac{1 - \rho^2{}_{\hat{T}_1\hat{T}_2|H_0} + 2\rho^4{}_{\hat{T}_1\hat{T}_2|H_0}}{1 + \rho^2{}_{\hat{T}_1\hat{T}_2|H_0}}$$

$$\times \frac{1}{K}\left(M^2 - M\right)\left(2 - \frac{4}{\pi}\right) \qquad (34)$$

The decision threshold is given by for false alarm probability less than equal to 0.5.

$$\lambda = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \qquad (35)$$

The decision threshold is given by for false alarm probability greater to 0.5.

$$\lambda = \frac{-B - \sqrt{B^2 - 4AC}}{2A} \qquad (36)$$

The decision threshold is independent of noise. Hence dispersion detection is nonsensitive for noise uncertainty.

IV. SIMULATION RESULTS

In this section, the probability of detection Pd for different SNR (Signal to Noise Ratio) is analyzed for different ρ. The M and K values are selected as M=2, M=3, M=4, M=5, M=10, M=20. The number of samples analyzed is 1000. The figure shows the detection probability for ρ is 0.1 to 0.9. By increasing the M values the detection performance is improved with the antenna correlation and by increasing the number of antennas.

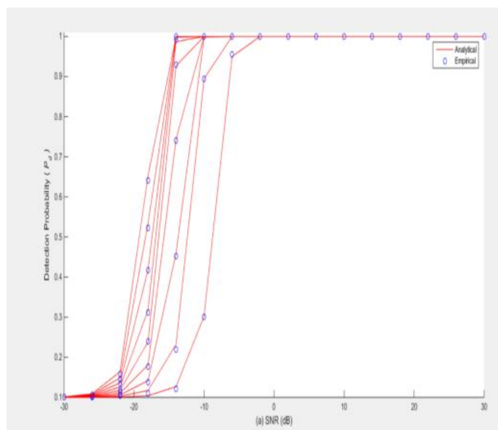

Fig. 11. detection probability vs. SNR (M=2, K=1000)

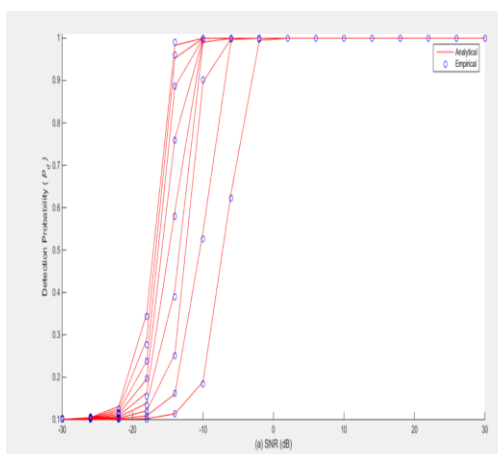

Fig. 12. detection probability vs. SNR (M=3, K=1000)

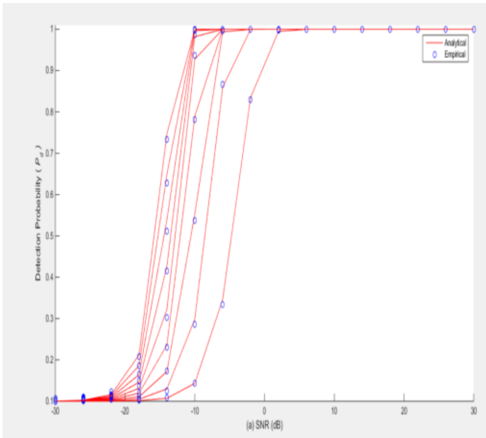

Fig. 13. detection probability vs. SNR (M=4, K=1000)

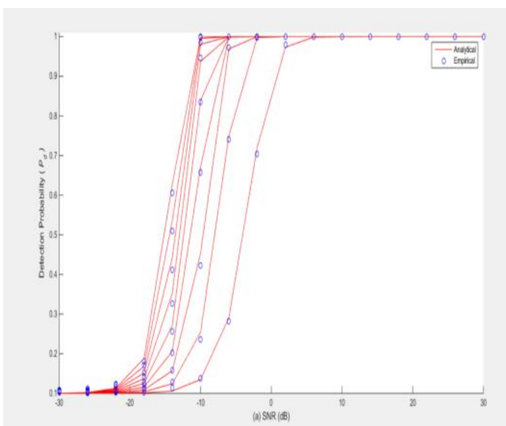

Fig. 14. detection probability vs. SNR (M=5, K=1000)

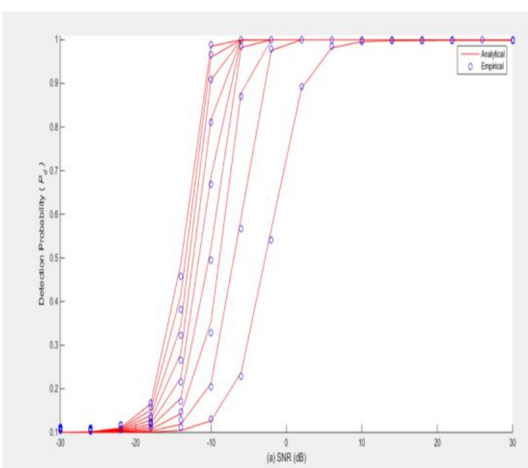

Fig. 15. detection probability vs. SNR (M=10, K=1000)

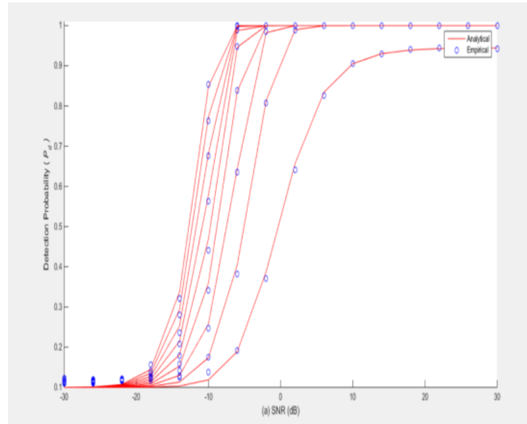

Fig. 16. detection probability vs. SNR (M=20, K=1000)

V. CONCLUSION

To efficiently use RF spectrum in CR, Dispersion detection method is introduced. This method effectively detects the white and grey spaces in the RF spectrum even in high SNR.

The spectrum sensing for CR based on dispersion detection is compared with analytical and empirical value. The result obtained is matched well with analytical and empirical value.

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