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Analysis and Design of Cyclostationary Feature Detection in Cognitive Radio Network

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Abstract - The increased demand for remote applications necessitates a significant increase in bandwidth. This creates a barrier between the expanding demand for wireless spectrum and the limited number of wireless resources available. The radio spectrum has traditionally been assigned in a predetermined or statistical manner. The spectrum is not fully utilized in this type of allocation. As a result, the spectrum is underutilized. To ensure that unused spectrum is adequately utilized, it should be dynamically allocated. This research is focused on spectrum sensing based on cyclostationary feature detection for accurate, rapid, and efficient main signal detection. When secondary users fail to recognize the white space, it either causes substantial interference with the prime user or prevents the unoccupied band from being reused. There are numerous strategies for detecting the unoccupied band, the most basic of which is energy detection, which is inefficient. Spectrum sensing based on cyclostationary feature detection (CFD) needs to take advantage of the modulated signal's second order periodicity. For the performance evaluation of cyclostationary feature detection, simulation factors such as P_d, P_{fa} and P_{md} were used.

Index Terms—Cognitive Radio (CR), Primary User (PU), Secondary User (SU), Cyclostationary feature detection (CFD), Signal-to-Noise Ratio (SNR), Probability of False Alarm (P_{fa}), Probability of Miss-Detection (P_{md}), Probability of Detection (P_d),Cooperative Communication (CC), Spectrum Sensing (SS), Additive White Gaussian Noise (AWGN).

I. INTRODUCTION

CR is a relatively new technology that opportunistically reuses spectrum to greatly increase its availability [1]. The simplest approach for detecting the vacant band is energy sensing, although it is ineffective. [2, 3]. Other spectrum sensing approaches include CFD and MFD (see Figure 1). Despite the fact that MFD has the most excellent detection performance, it does necessitate earlier awareness of the primary information, such as packet format, which is a disadvantage.

CFD can be employed for accurate SS by utilising the second order periodicity found in most modulated signals [5, 6]. CFD sensing has been proposed in the past and is a more consistent form of SS at low SNR when integrated with other methodologies such as neural networks. This CFD effectively utilises a modulated signal's second order repetition, such as a sinusoidal waveform. [4]

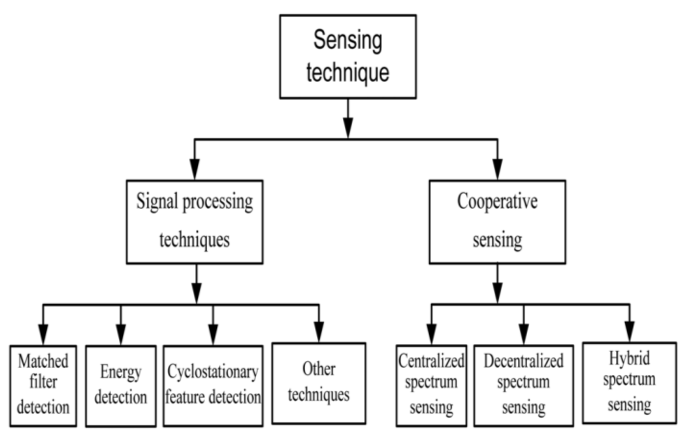

Fig 1: diagram of different Spectrum Sensing Techniques in CRN

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II. PROPOSED METHOD

The principal user is identified using the cyclostationary characteristic, which is the periodicity of the received signal. To achieve this, the cyclic autocorrelation function (CAF) of the received signal is mostly utilised. CAF is also described using the Cyclic Spectrum Density (CSD) function. The fundamental frequency of a transmitted signal is equal to the cyclic frequency. CSD is used to show the peaks of the received signal. There is no peak, according to H_0 hypothesis. Modulated signals include sine waves, hopping sequences, cyclic prefixes, and pulse trains, among others. [7, 8, 9]

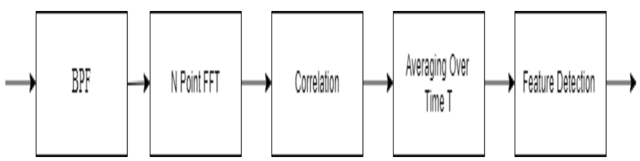

Fig 2: Block Diagram of CFD

Figure 2 depicts the cyclostationary feature detection block diagram. The input signal is received by BPF, which is then designed to evaluate the energy around the associated band before being sent to FFT. The signal is now FFT, and the correlation block correlates the signal before passing it to the integrator. The Integrator block's output is then evaluated to a threshold. This evaluation is used to determine whether the PU signal is present or not.

Let as predictable complex sine signal s(t) that has been routed through an AWGN channel and can be written as: [10,11,18]

$$s(t) = A\cos(2\pi F_0 t + \theta) \tag{1}$$

"In which, A = Amplitude of input signal, f_0 = Frequency. θ = early Phase".

Transmission of s(t) via an AWGN with a mean of zero results to x(t) = s(t) + n(t). Thus, the Mean function of x(t) will be

$$M_x(t) = E[x(t)] \tag{2}$$

$$M_x(t) = E[s(t) + n(t)] \tag{3}$$

$$M_x(t) = E[s(t)] \tag{4}$$

"In the equation, x(t) = Received information, s(t) = Transmitted Input information, E = Expectation operator, Mx(t) = Mean function of x(t) and also a Periodic function with period T_0".

As talk about earlier, a modulated signal x(t) is called a periodic or cyclostationary signal in the broad sense if its mean and autocorrelation demonstrate periodicity as shown below. [16]

i.e. $$M_x(t) = M_x(t + T_0) \tag{5}$$

Similarly, the auto-correlation function of x(t) is also periodic with period T_0.i e

$$R_x(t,u) = R_x(t + T_{0,} u + T_{0,}) \tag{6}$$

Replacing t and u in autocorrelation equation with (t+τ/2) and (t-τ/2), express in Fourier series is as follows:

$$R_x\left(t + \frac{\tau}{2}, T - \frac{\tau}{2}\right) = R_x\left(t + \frac{\tau}{2} + T_0, T - \frac{\tau}{2} + T_0\right) \tag{7}$$

And $$R_x\left(t + \frac{\tau}{2}, T - \frac{\tau}{2}\right) = \sum_\alpha R_x^\alpha(\tau) e^{j2\pi\alpha t} \tag{8}$$

"Where, R_x^α = Cyclic Autocorrelation function, α - Cyclic frequency".

The receiver's cycle frequency is now considered to be known. The cyclic autocorrelation can be computed on the basis:

$$R_x^\alpha(\tau) = \frac{1}{T}\int_{-\frac{1}{T}}^{+\frac{1}{T}} R_x\left(t + \frac{\tau}{2}, T - \frac{\tau}{2}\right) e^{-j2\pi\alpha t}\, dt \tag{9}$$

The Cyclic Spectral Density (CSD) function is defined as the Fourier transform of the cyclic autocorrelation function, obtained by

$$S_x^\alpha(f) = \int_{-\infty}^{+\infty} R_x^\alpha(\tau)\, e^{-j2\pi f\tau}\, d\tau \tag{10}$$

CSD is also named as Spectral Correlation Function (SCF). And

$$S_x^\alpha(f) = \int_{-\infty}^{+\infty}\left[\frac{1}{T}\int_{-\frac{1}{T}}^{+\frac{1}{T}} R_x\left(t + \frac{\tau}{2}, T - \frac{\tau}{2}\right) e^{-j2\pi\alpha t}\, dt\right] d\tau \tag{11}$$

The standardized correlation between two spectral components of x(t) at frequencies (f + α/2) and (f -α/2) during an interval of length Δt can be used to calculate SCF. Taking all of this into account, SCF can be expressed as

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$$S_x^{\alpha}(f) = \lim_{T\to\infty}\left[\lim_{\Delta t\to\infty}\frac{1}{\Delta t}\int_{-\Delta t}^{+\Delta t}\frac{1}{T}X_T\left(t, f+\frac{\alpha}{2}\right)X_T^*\left(t, f+\frac{\alpha}{2}\right)dt\right], \quad (12)$$

Where, finite time Fourier transforms is

$$X_T(t,u) = \int_{t-\frac{T}{2}}^{t+\frac{T}{2}} x(u)e^{-j2\pi u}\ du \quad (13)$$

Here, the PSD is a special form of spectral correlation function for α = 0, where α is cyclic frequency. [12, 14]

CFD, on the other hand, necessitates a vast processing capacity and lengthy observation intervals, making it challenging to execute. Furthermore, it is unable to detect the nature of communication, limiting CR's flexibility.

III. DESIGN METHODOLOGY

This section presented numerical expression for P_{fa}, P_d and P_{md} for the CFD respectively.

In CFD technique according to the Central Limit Theorem [17], the probability distribution function (PDF) of $M_X(t)$ T for both hypothesis H_0 and H_1 can be approximated by Gaussian distributions.

$$P_{M_x(t)T}(T:H_0) = C_N\ \left(0, \frac{\sigma_W^2}{2N+1}\right) \quad (14)$$

$$P_{M_x(t)T}(T:H_1) = C_N\ \left(\mu, \frac{\sigma_W^2}{2N+1}\right) \quad (15)$$

"Where, C_N (,) = Circularly symmetric complex Gaussian distribution,μ = Mean, σ_W^2 = Noise variance".

$$M_x(t) = \lim_{T\to\infty} M_x(t)_T \quad (16)$$

so, for a particular threshold λ, an approximate expression for the P_{fa} of CFD can be obtained as [16].

$$P_{fa} = P_r(\frac{H_1}{H_0} \quad (17)$$

$$P_{fa} = \exp\left(\frac{-\lambda^2}{2\sigma_A^2}\right) \quad (18)$$

"Where, λ = Threshold assessment. Exp ( ) = Exponential function".

$$\sigma_A^2 = \frac{\sigma_W^2}{2N+1} \quad (19)$$

Now, the P_d of PU for the CFD method can be considered by the given equations

$$P_d = P_r(\frac{H_1}{H_1} \quad (20)$$

$$P_d = Q\left(\frac{\sqrt{2\gamma}}{\sigma_W}, \frac{\lambda}{\sigma_A}\right) \quad (21)$$

"Where, γ = Signal to noise ratio. Q (,) = Generalized Marcum Q-function. σ_w^2 = Noise variance".

$$P_{md=}1 - P_d \quad (22)$$

Hence, the P_{md} for CFD method can be calculated using equations (21, 22) as follows

$$P_{md} = 1 - Q\left(\frac{\sqrt{2\gamma}}{\sigma_W}, \frac{\lambda}{\sigma_A}\right) \quad (23)$$

"The plot between P_d and P_{fa} is termed as the receiver operating characteristics (ROC). ROC is the probability of the sensing algorithm (here the sensing algorithm is CFD method) claiming that the primary signal is present. Thus the P_d increases with increasing value of P_{fa}. Also P_{md} decreases with increasing value of P_{fa}". [12, 15]

IV. SIMULATION AND RESULTS

A frame model is used to detect the spectrum in a desirable environment, and a CFD mechanism is used to allow numerous users to access a single spectrum. This entails following a series of steps.

Step 1: Set parameters like sample S and SNR. It is essential to receive a spectrum of random variables.

Step 2: Spectrum detection by CFD technique.

Step 3: take a decision by fusion centre either PU present or absent.

Step 4: The performance of CFD is evaluated according to the simulation parameters such as such as Pd, Pfa, with respect to SNR.

"Radio in which communication systems are aware of their environment and internal state and can make decisions about their radio operating behavior based on that information and predefined objectives. The environmental information may or may not include location information related to communication systems." [18]

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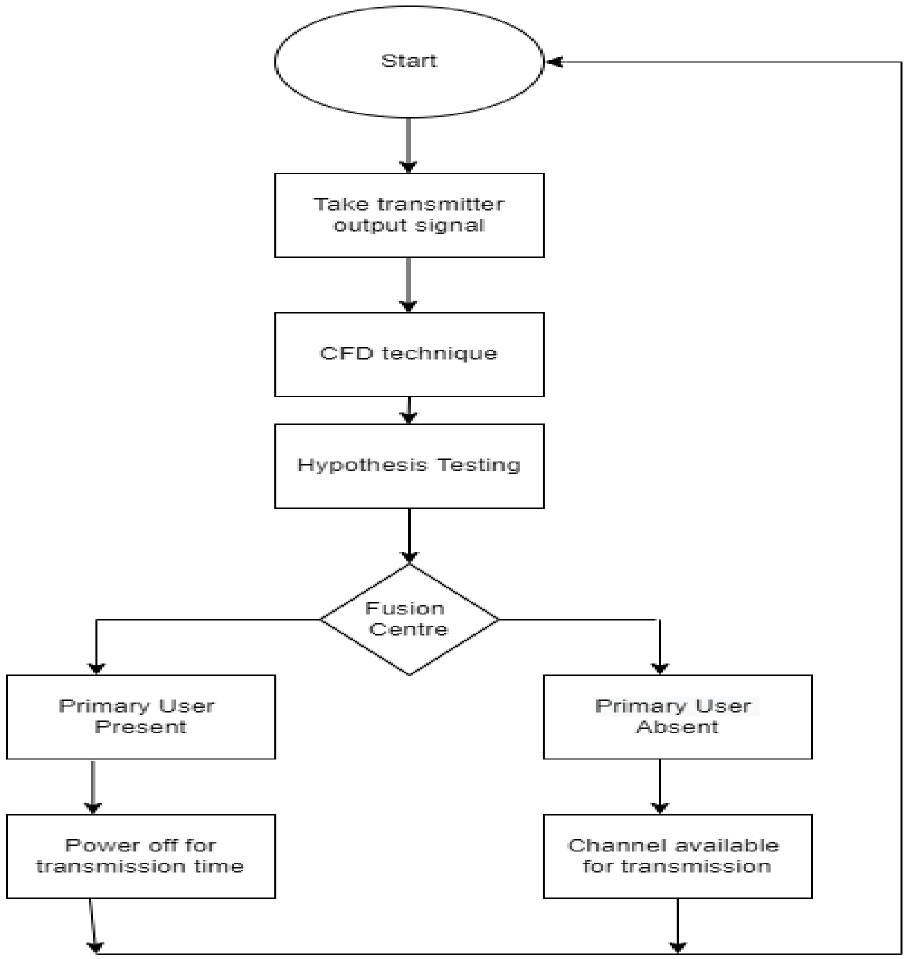

Fig 3: Flow Chart of CFD Technique

Figure 4 shows that the curves between P_d Vs P_{fa} of CFD over AWGN, Rayleigh and Rician fading channels. Figure 5 demonstrate the ROC curves between P_{md} Vs P_{fa} of CFD over AWGN, Rayleigh and Rician fading channels. Figure 6 displays the ROC curves between P_{md} Vs number of secondary user. Figure 7 depicts that the ROC curves between P_d Vs number of secondary user. Finally A comparative analysis of obtained values related to different parameters represented by graphs in fig 8,9,10.

V. CONCLUSION

The cyclostationary feature detection approach is the most reliable and successful method for spectrum sensing. Even though this method adds to the system's complexity, it is well worth the risk because its noise immunity is far superior to existing systems. The CFD method for estimate and the spectral autocorrelation function methodology for spectrum analysis are provided in this paper. According to a simulation, CFD is best for signal detection with low SNR.

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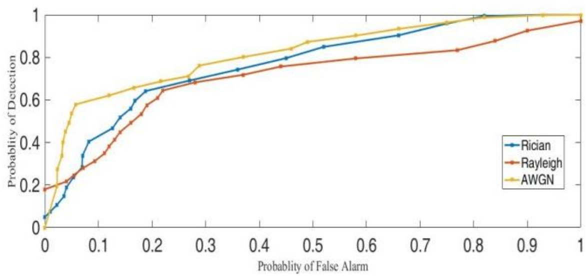


Fig 4: ROC curves between P_d Vs P_{fa} of CFD over AWGN, Rayleigh and Rician fading channels.

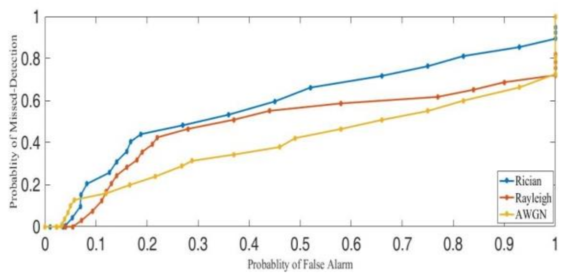
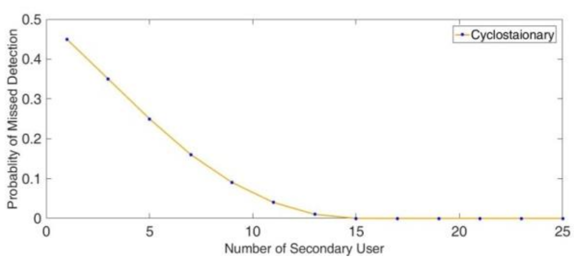


Fig 5: ROC curves between P_{md} Vs P_{fa} of CFD over AWGN, Rayleigh and Rician fading channels.



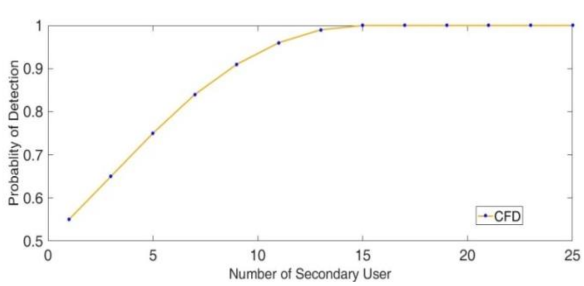


Fig 7: ROC curves between P_d Vs number of secondary user

Fig 6: ROC curves between P_{md} Vs number of secondary user

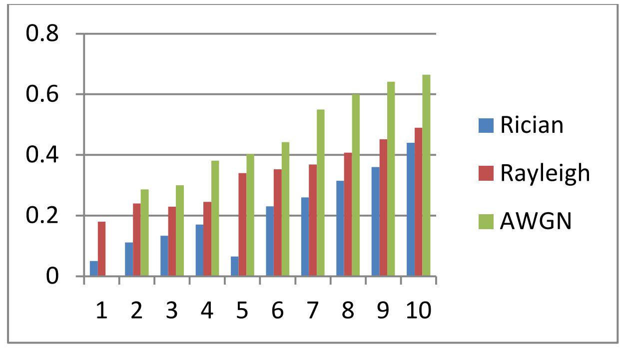


Fig 8: P_d for different channels

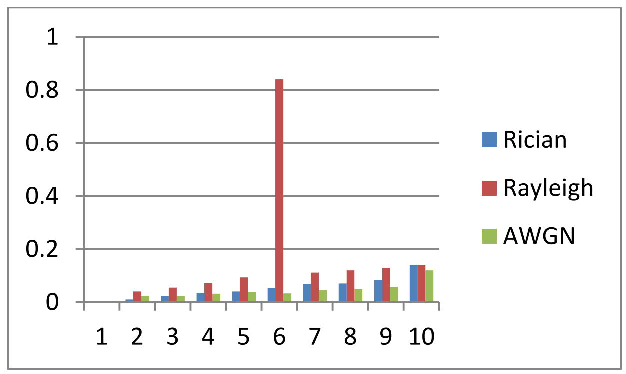


Fig 9: P_{fa} for different channels

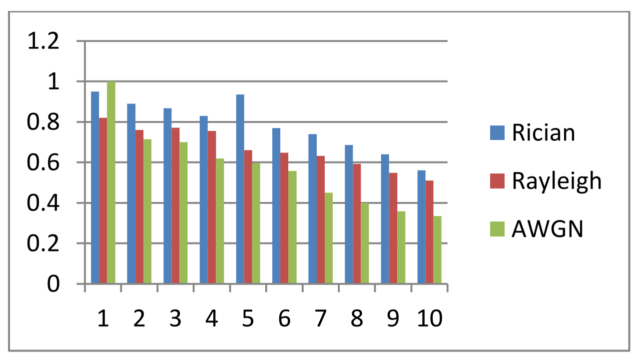


Fig 10: P_m for different channels

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