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Performance Evaluation of Spectrum Sensing Techniques in Cognitive Radio Network

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Abstract: *Cognitive radio (CR) is a promising technique that offers a solution to the spectrum scarcity problem by dynamically exploiting the underutilization of the spectrum among the bands. There are numerous procedures to detect spectrum using CRs like energy detection (ED), matched filter detection (MFD), cyclostationary feature detection (CFD), waveform based detection (WBD) and so on. In this paper, the most popular techniques i.e. ED, MFD and CFD and their comparative analysis are discussed. Investigation is done by discussing theoretical aspect of the spectrum sensing techniques that are based on primary transmitter detection and receiver operating characteristics (ROC) of "Energy based detection", "Matched filter detection" and "Cyclostationary feature detection" in AWGN and we also validate ROC at different SNRs and* evaluated for their detection performance. This analysis shows that CFD shows better results among the three *techniques as discussed.*

Keywords: *Cognitive Radio; Energy detection; Matched filter detection, Cyclostationary feature detection.*

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I. Introduction

Cognitive radio (CR) is a cutting edge technology for wireless communications and requires the design of novel spectrum sensing schemes which have a high degree of reliability, even at low SNR [1]. The CR paradigm allows a set of unlicensed or secondary users to opportunistically access unused spectrum bands licensed to primary users, thus radically improving the efficiency of spectrum usage. These systems can powerfully distribute range to numerous clients, subsequently facilitating system congestion.CR innovation permits unlicensed users, also called cognitive users (CUs), to misuse the spectrum vacancies whenever with no or constrained additional impedance at the licensed users. Typically, cognitive radios make arranges with a specific end goal to better recognize spectrum sensing, maintain a strategic distance from resultant impedance, and thusly, amplify their revenues [2]. One of the primary difficulties in cognitive radio systems is the high vitality utilization, which may restrain their execution particularly in battery-controlled terminals. In spectrum sensing, a CU detects the spectrum with a specific end goal to distinguish the movement of the authorized users.

II. Spectrum Sensing In Cognitive Radio

Spectrum sensing is a radio process for determining whether a signal is present across a specified RF bandwidth. It is the capacity to gauge, sense and know about the parameters identified with the radio channel qualities, accessibility of range and transmit power, obstruction and clamor, radio's working condition [3]. This process has many applications and usages, including dynamic spectrum access networks, which are designed to maximize spectrum efficiency and capacity within congested wireless transmission environments. Dynamic spectrum access temporarily utilizes spectral white spaces in order to transmit data means that if a licensed (primary) user is allocated a predetermined frequency to operate on, an unlicensed (secondary) user can temporarily "borrow" the unoccupied spectrum for transmission. In a system consisting of many primary users and secondary users, the secondary users need to be able to jump into and utilize the unused spectrum of the primary users as it becomes available [4,5]. In order to accomplish this action, spectrum sensing techniques are employed to avoid spectral collisions. Practically speaking, the unlicensed clients, likewise called secondary users (SUs), need to ceaselessly screen the exercises of the authorized users, additionally called Primary Users (PUs), to discover the spectrum holes (SHs), which is characterized as the spectrum bands that can be utilized by the SUs without meddling with the PUs. This procedure is called spectrum sensing [10,11].

III. Spectrum Sensing Techniques

One of the key objectives of the cognitive radio is the detection of the spectrum. It is to find the spectrum holes in the radio environment for users of CR. The detection techniques that are mostly used in the case of detection non-cooperative are the following:

- Energy based detection method
- Matched filter detection method
- Cyclostationary features detection method

A. Energy based detection method: Energy identification is ideal for distinguishing free and indistinguishably disseminated signals at high signal to noise ratio (SNR) , however not ideal for recognizing corresponded signals [6]. It computers the energy of the received signal in a definite frequency band to a threshold value (γ) which is characterized by the SNR, to decide the signal is present or not.

Let y(n) is the received signal by CR, x(n) is the transmitted signal and w(n) represents the additive white gaussian noise (AWGN) with zero mean and variance σ_{ω}^2 where n is the sample index. In the case of energy detector the decision metric can be formulates as

$$D = \sum_{n=0}^{N} |y(n)|^2$$

where N is the extent of the perception vector. The inhabitance choice of a band can be acquired by looking at the choice metric D against a fixed threshold λ. It is analysed as a binary hypothesis model:

$$y(n) = \begin{cases} w(n) & H_0 \\ x(n) + w(n) & H_1 \end{cases}$$

H0 corresponds to the absence of primary signal in scanned frequency band while H1 indicates that the spectrum is occupied. The execution of the detection algorithm can be compressed with two probabilities namely detection probabilities (Pd) and false alarm probabilities (Pf). In terms of hypothesis it is defined as Pd=P(signal is detected|H1)=P(D>λ|H1) and Pf= P(signal is detected|H0)=P(D>λ|H0)

Pf should be kept as little as conceivable keeping in mind to counteract underutilization of transmission openings. The decision threshold (λ) can be settled for finding an ideal harmony amongst Pd and Pf. The noise power can be figured, yet the flag control is difficult to evaluate as it changes relying upon continuous transmission attributes and the separation between the CR and PU. In practice, λ is chosen to get a specific false alarm rate. Hence, knowledge of noise variance is adequate for choice of a threshold. The identification execution relies upon the instability of the noise.

The detection probability Pd and false alarm probability Pf in a non-fading channel can be derived using the cumulative distribution functions of the central and non-central chi square distributions. In the absence of coherent detection, the signal samples x(n) can be modeled as a Gaussian random process with variance σ_x^2. The noise sample w(n) is assumed to be additive white Gaussian noise (AWGN) with zero mean and variance σ_w^2. So y(n) is also a Gaussian random process. By central limit theorem, the test statistic can be approximated as a Gaussian distribution.

$$H_0: \quad D \sim \text{Normal}(N\sigma_w^2, 2N\sigma_w^4)$$
$$H_1: \quad D \sim \text{Normal}(N(\sigma_w^2 + \sigma_x^2), 2N(\sigma_w^2 + \sigma_x^2)^2)$$

The decision statistics $T > \gamma$ decide the signal is present and $T < \gamma$ decide the signal is absent. Then Pd and Pf can be evaluated as

$$P_d = P(T > \gamma | H_1) = Q\left(\frac{\gamma - N(\sigma_w^2 + \sigma_x^2)^2}{\sqrt{2N(\sigma_w^2 + \sigma_x^2)^2}}\right)$$

$$P_f = P(T > \gamma | H_0) = Q\left(\frac{\gamma - N\sigma_w^2}{\sqrt{2N\sigma_w^4}}\right)$$

The detection performance depends on the uncertainty of the noise. Noise in most communication systems is an aggregation of various independent sources including not only thermal noise, but also interferences due to nearby unintended emissions. So the assumption that the noise is a Gaussian random process is always appropriate. Further, the variance of the noise could vary over time and it cannot be estimated exactly.

B. Matched filter detection method: Matched filter (MF) is intended to boost the yield SNR for a given input flag. MF detection is connected when the optional utilized has earlier information of the residing user. In matched filter operation convolution of the obscure flag is finished with the channel whose motivation reaction is time moved and reflected regarding the coveted flag. The articulation for matched filter is communicated as:

$$y(m) = \sum_{k=-\infty}^{\infty} x(k)h(m-k)$$

Where, x is the obscure flag and h is the impulse response of matched filter that is matched to the reference flag is convolved with it for maximizing the SNR.
Matched filter detection is applicable only in cases where the cognitive users know the data from the primary user. The implementation of matched filter spectrum sensing algorithm is given in the fig 1.

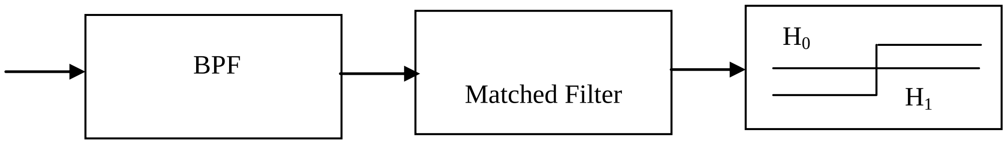

Fig 1: Block diagram of matched filter detection

The above figure shows the beginning of the input signal passes during a band-pass filter; this will determine the energy approximately the correlated band, then output signal of BPF is convolved with the match filter whose desire answer is similar as the suggestion signal. The matched filtered output value is evaluated to a threshold for detecting the presence (H1) or absence (H0) of primary user [7].

C. Cyclostationary features detection method: The CFD is the most appropriate choice as compared with the ED and MFD techniques. As the MFD technique requires the prior knowledge about the licensed user's wave but for the ED it is not necessary to have a prior knowledge of the primary user wave. The ED technique is simplest but it is highly sensitive with the changing noise levels. The primary modulated waveforms with the patterns are also characterized as Cyclostationary feature like pulse trains, hoping sequences, and the sine waves. The cognitive radio can detect any specific modulated random signal in a stochastic noisy environment by exploiting the mean and the auto correlation periodic characteristics of the primary waveform. This technique is more effective in an environment where the levels of noise are uncertain. The noise uncertainty is because of the spectral correlation function of the AWGN channel is zero due to the stationary property [8].
The absence or presence of the PU signal can be identified by calculating the spectral correlation of the PU signal at the Cyclostationary detector. The output of the CFD is compared with the predefined threshold value to determine the presence or absence of the PU's signal. The block diagram of Cyclostationary feature detector is shown in fig 2.

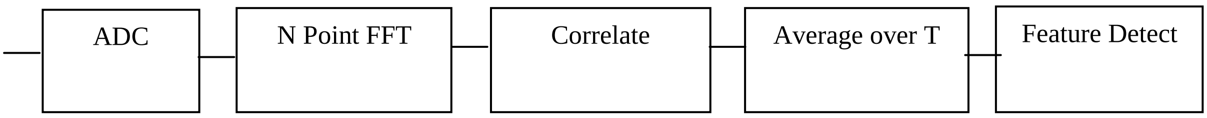

Fig 3: Block diagram of Cyclostationary feature detection

Cyclostationary can be a perfect probabilistic approach to model wireless man-made signals where certain periodicity comes from coding, modulation, multiplexing, sampling etc. Cyclostationary can also be observed in nature-originated signals, such as in climatology, atmospheric, or biomedicine signals, due to their rhythmic or seasonal behavior. Stationary processes exhibit a time-invariant mean and autocorrelation function, whereas a cyclostationary process has a time periodical probability distribution function. In addition, a cyclostationary process exhibits the so-called spectral correlation property. Spectral correlation means that the signal and its frequency shifted version are correlated. A random process is known as Cyclostationary if its mean and autocorrelation fluctuate periodically in time. In the perspective of stationary signals, wide-sense stationary refers to time-invariant moments whereas strict-sense stationary refers to time-invariant probability distribution function. A stationary random process is cyclostationary in strict sense if its probability distribution function is periodic in time. Wide-sense cyclostationarity means that the mean and the autocorrelation function of the signal are periodic. Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation, which is not found in stationary noise and interference.

IV. SIMULATION RESULTS

In this section, a simulation study is performed to approve the explanatory outcomes introduced in the past segments. The performance of spectrum sensing technique is illustrated by the receiver operating characteristics (ROC) curve which is a plot of Pd vs Pf or Pd vs Pm [9,12].

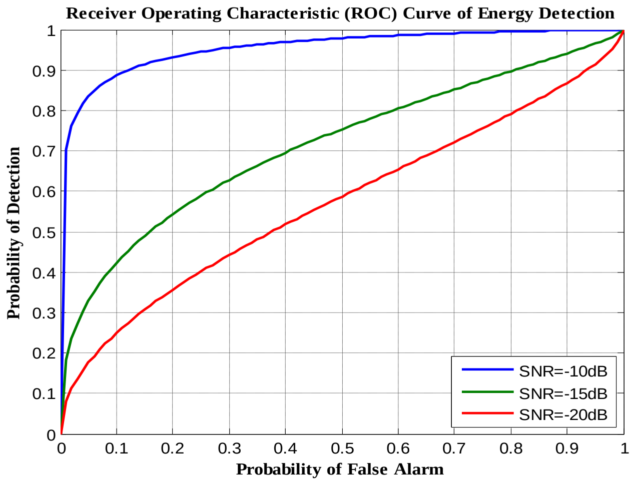

Fig. 3: *ROC curve of energy detection method under different values of SNR*

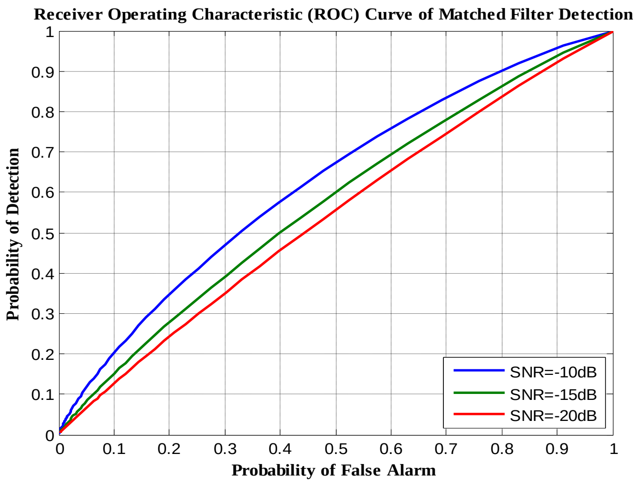

Fig. 4: *ROC curve of MFD method under different values of SNR*

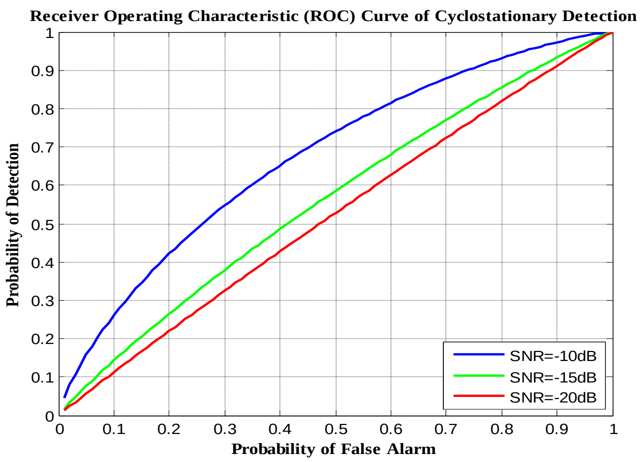

Fig. 5: *ROC curve of CFD method under different values of SNR*

The above figure 3,4 and 5 illustrates the ROC curves i.e. Pd versus Pf of ED,MFD and CFD based spectrum sensing for different values of SNR and it can be interpreted from the figure that the performance of energy detector improves with increase in SNR and increase in probability of false alarm respectively which is quantified in Table 1.

TABLE 1: Improvement of P_d with increase in SNR at different P_f

	Spectrum Sensing Method	SNR	Probability of false alarm (Pf)				
			0.1	0.3	0.5	0.7	0.9
Probability of detection (Pd)	ED	-10dB	0.88	0.95	0.97	0.98	0.99
	MFD		0.20	0.46	0.67	0.83	0.95
	CFD		0.26	0.54	0.73	0.87	0.97
	ED	-15dB	0.42	0.62	0.75	0.85	0.94
	MFD		0.15	0.39	0.59	0.78	0.93
	CFD		0.14	0.37	0.58	0.77	0.93
	ED	-20dB	0.24	0.44	0.58	0.72	0.86
	MFD		0.12	0.35	0.55	0.74	0.92
	CFD		0.11	0.32	0.52	0.72	0.91

From the above table it is shows that for 5dB increase in signal to noise ratio the probability of detection (at SNR=-15dB) is increase up to 0.52 times as compared to probability of detection (at SNR=-10dB) in AWGN channel for energy based detection spectrum sensing and in case of MFD and CFD the improvement is 0.25 times and 0.21 times respectively.

V. Conclusion

Cyclostationary spectrum sensing gives better results when contrasted with ED technique at low Signal to Noise Ratios (SNR's). However, It is substantially more requesting computationally and is more unpredictable than ED spectrum sensing method. It demonstrates the better detection performance as compared with the matched filter and energy detection techniques. As it yield good performance even at lower SNR of -40dB. It does not depend on the noise uncertainty. Matched filter technique shows better performance as compare the energy detection technique. Simulations results show that, energy detection technique gives excellent detection of the PU at higher SNR. Moreover, it is a simplest detecting algorithm that does not depend on the noise uncertainty. Similarly, Cyclostationary feature detection and matched filter detection also shows the best detection results at higher SNR values of 20dB or above. It is seen that, performance of all three techniques varies as the SNR values decreases. Energy detection technique performance degrades at lower SNR. Although it does not depends on the noise uncertainty but it also can not differentiate between the original signal and noise.

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