Comparative Performance Analysis of Non-Cooperative Spectrum

Ankita Arora[1], Lokesh Kumar[2]

[1]Dept. of Computer Science Rohtak Institute of Engineering and Management, Rohtak, Haryana, India
[2]Assistant Professor & HOD, Dept. of Computer Science & Engineering, Rohtak Institute of Engineering& Management, Rohtak, Haryana, India

ABSTRACT

Cognitive Radio (CR) is a wireless system that communicates in an efficient and reliable manner by sensing the environment. The main challenge in any cognitive radio system is to maximize secondary user's throughput while limiting interference imposed on licensed users.CR has to automatically analyses its radio spectrum environment to identify temporarily vacant spectrum and use it by adapting to the environment by changing its transmission parameters. This paper presents a comparative performance analysis of three broad non cooperative SS techniques i.e. energy detection, cyclostationary detection and matched filter detection.

Keywords: Cognitive Radio, Spectrum Sensing, Non-co-operative spectrum, Software Defined Radio.

1. INTRODUCTION

Cognitive Radio (CR) is a wireless system that communicates in an efficient and reliable manner by sensing the environment. CR is built on Software Defined Radio (SDR). To ensure interference free operation, secondary user(opportunistic user/ cognitive user) sense regularly allocated frequency band and reliably detect the presence of primary user (licensed user). This process is known as Spectrum Sensing (SS). A vast use and enormous applications of wireless services has made a considerable use of spectrum. This results into increase in number of users requiring access of wireless system and services but wireless spectrum is limited. This leads to spectrum scarcity. The real problem is not spectrum scarcity but inefficient spectrum utilization. This poor spectrum utilization is termed as spectrum hole. This indicates that spectrum scarcity is nothing but only a false belief. inefficient spectrum utilization like utilization of public safety band (410-470 MHz) and unlicensed band (2.4 GHz) is only 16.6% and 1.5% respectively [1] To address this problem Spectrum Policy Task Force (SPTF) prepared a report under guidance of Federal Communications Commission (FCC) [2]. A possible solution to these problem has been provided if licensed spectrum is made available to unlicensed users provided there is no interference with licensed users. This can solve almost all spectrum scarcity problems, and this solution can be achieved via intelligent radio system called CR. The main objective is to effectively utilize the current available spectrum without affecting the primary users.

2. Spectrum Sensing

Spectrum Sensing is one of the most important step in cognitive cycle. The objective of spectrum sensing is to detect the presence of transmissions from the primary users. SS problem is similar to signal detection in noisy environment. Analytically, this can be given by binary hypothesis test as shown in Figure 2.10 [19].

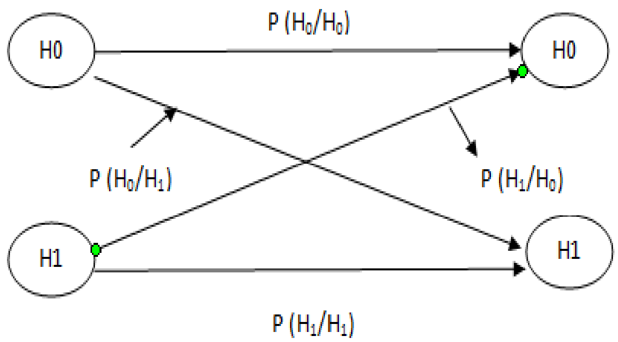
$$y(t) = \begin{cases} w(t) & H_0 \\ s(t) + w(t) & H_1 \end{cases}, \qquad (2.1)$$

where,

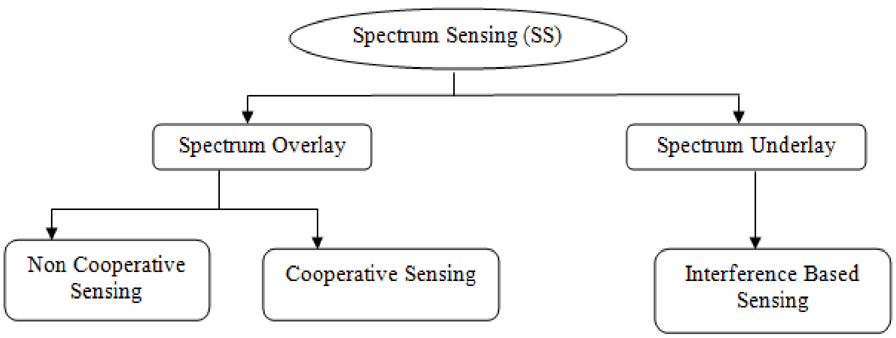
y(t) is received sample analysed at every t

w(t) is noise (not necessarily AWGN)

s(t) is desired signal network wants to detect



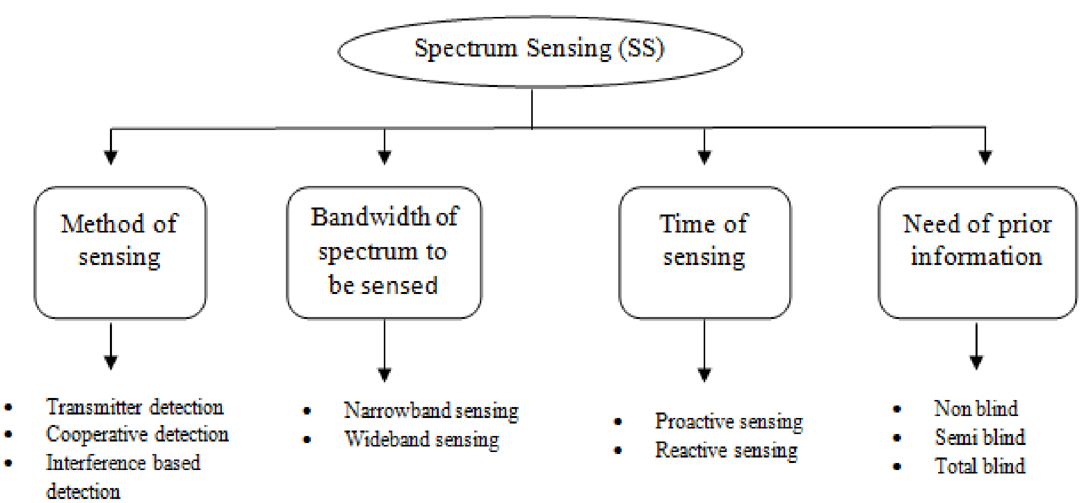
There are basically two approaches based upon which decision about the presence of PU can be made, these are spectrum overlay and spectrum underlay.



In spectrum overlay approach SU can opportunistically use licensed spectrum only when there is no PU transmission is detected i.e. spectrum is free. On the basis of number of CR require to make decision spectrum overlay scheme is further divided into two schemes. These are non-cooperative detection and cooperative detection. Here, we are limiting ourselves to non-co-operative sensing. Transmitter detection is same as non-cooperative sensing. Based on the priori information required to detect PU, SS methods can be classified in three classes.

- Non-blind schemes require knowledge about both i.e. PU and noise floor.
- Semi-blind schemes require information about noise floor to detect a white space in given frequency band.
- Blind, no information regarding to PU signal and noise is required.

SS techniques can be classified on the basis of how to send. Following figure shows.



3. NON-COOPERATIVE SENSING

There are two fold functions of SS, first to determine presence and absence of signal and second, to differentiate PU signal from SU signals. Performance parameters are measured in term of detection P_d and probability of false alarm P_f, respectively.

Mathematically,

$$P_d = P_r(\text{PU Signal detected}/H1)$$

$$P_f = P_r(\text{PU Signal is detected}|H0)$$

$$P_m = 1 - P_d = Pr(\text{PU Signal is not detected}|H1)$$

Probability of missed detection P_m. P_m indicates the probability of not detecting PU signal provided H1 hypothesis. If P_f and P_m are high, probability of making wrong decision increase and performance of SS technique degrades, as high P_f corresponds to poor spectrum utilization/exploitation by CR and high P_m results in increased interference with PU signal. Methods present in literature based upon non cooperative detection:-

- Energy Detection
- Matched Filter Detection,
- Cyclostationary Detection

ENERGY DETECTION

In this method energy of received signal is compared with predetermined threshold to make decision about spectrum occupancy. [3,4]. Energy detection decide among two hypotheses H0 and H1 by comparing T(y) with predefined threshold voltage λ as

$$T(y) \geq \lambda \qquad \Rightarrow H1$$
$$T(y) < \lambda \qquad \Rightarrow H0$$

If threshold λ is low, P_f increases which result into poor spectrum utilization and a higher value of λ leads to higher P_m which in turn cause increase interference with PU signal. Hence always exist a trade-off between P_f and P_m.

Advantages of Energy Detection

- Easy to implement.
- Low computation complexities.
- Knowledge about only noise power is required to set threshold i.e. semi blind scheme.
- Detection is independent of transmission from PU.

Disadvantages of Energy Detection

- Based upon assumptions i.e. static environment scenario.
- Uncertainty in threshold setting.
- Performance depends on accuracy in noise floor measurement.
- Highly susceptibility to uncertain noise.
- Doesn't make differentiation between modulated signal, noise and interferences.
- Spread spectrum signals detection is not possible in energy detection.
- Performance degrades under deep fade.
- Below SNR walls detection is not possible.

CYCLOSTAIONARY FEATURE DETECTION

Signals to be transmitted is coupled with high frequency carrier, spreading sequence or hoping sequence etc. to exploit built in periodicity of PU signal. This make signal cyclostationary, cyclostationary means certain statistical properties of signals repeats itself after a period of time. [5,6].

Advantages of Cyclostationary feature detection

- Able to differentiate between types of signals i.e. PU from noise and interference.
- Able to differentiate among PU signals from different transmitter.
- Reliable and robust detection in noise uncertainty.
- Hidden terminal problem likely to occur less.
- Good performance in low SNR.

Disadvantages of Cyclostationary feature detection

- Higher computational complexities.
- Higher sensing time.

MATCHED FILTER DETECTION

Matched filter detection [7] is an optimal approach as it offers maximized SNR at output. The output of matched filter is compared with a predefined threshold to decide PU is active or inactive. It require prior knowledge (such as modulation type and order, pulse shaping, packet format) of PU signal for effective demodulation of PU signal. To store such information memory is required.

4. MAJOR CHALLENGES IN NON-CO-OPERATIVE SENSING

- Sensitivity of detection: To detect low power PU signal high sensitivity is required. [8]
- High degree of flexibility : In dynamic environment parameters are keep on changing, so to cope up with changing dimensions high degree of flexibility required
- Uncertainty of PU and hidden PU problem: In most of cases PU location is unknown and SU may lie within or outside coverage area of PU. But sometime PU signal is not detected by SU because of these conditions is referred uncertainty of PU and hidden PU problem.
- Limited sensing constraints: sensing should be done considering all dimensions to exploit spectrum opportunity efficiently.
- Presence of another secondary network: this effect detection capability in two ways. First, SU might be identified as PU signal and second, PU signal may hide PU signal by masking. Hence, degrades detection ability of SU.

5. SYSTEM MODEL

Basic system model for SS is presented in form of binary hypothesis i.e. either PU is present or absent.

- Hypothesis H1 i.e. when PU signal is active.

$$y(n) = s(n) + w(n) \tag{3.1}$$

Where y(n) is received signal at SU, s(n) is transmitted signal by PU and w(n) corresponds to white noise.

- Hypothesis H0 i.e. when PU signal is inactive.

$$y(n) = w(n) \tag{3.2}$$

PROBABILITY OF INTEREST IN SS

- Probability of detection (P_d)
- Probability of false alarm (P_f)
- Probability of miss detection (P_m)

Operation of CR system should ensure two things

- There should be no interference with PU.
- It should maximize utilization of free frequency band.

To ensure first condition P_d should be as high as possible and for second condition P_f should be as low as possible.

- **ENERGY DETECTION**

Block diagram for energy detection is represented as in Figure

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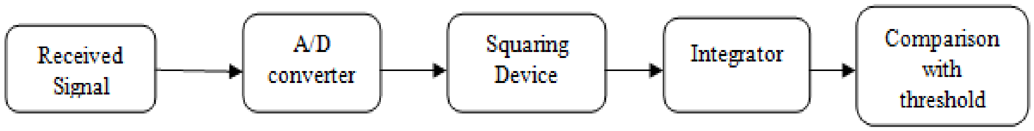


Consider τ be the sensing time, f_s be sampling frequency and N be the number of samples.
Input signal y(t) is passed through A/D converter to get y(n) signal. [9,10].
Test statistics for energy detector is given as

$$T(y) = \frac{1}{N}\sum_{n=1}^{N}\left|s(n)+w(n)=y(n)\right|^{2}, \qquad (3.3)$$

T(y) represent energy of received signal y(n).
Hypothesis H0: in this case test statistics T(y) is considered to be a random variable with Probability Density Function (PDF) $p_0(x)$ having chi-square distribution. For real valued signal degree of freedom is N where's for complex valued signals it is 2N. Let threshold value be λ, P_f is given by [11]

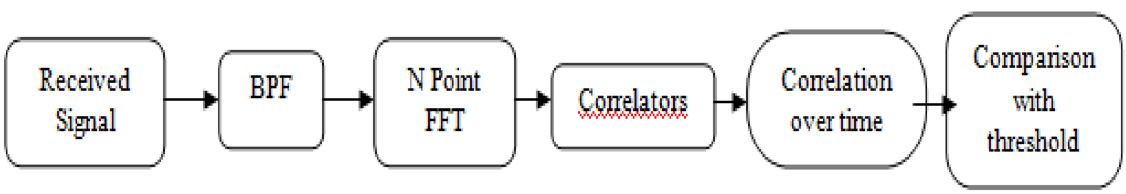
$$P_f(\lambda,\tau) = \Pr(T(y) > \lambda \mid H_0) = \int_{\lambda}^{\infty} p_0(x)dx, \qquad (3.4)$$

Hypothesis H1: in this case test statistics T(y) is considered to be random variable with PDF $p_1(x)$. For threshold λ detection probability is given as [11]

$$P_d(\lambda,\tau) = [\Pr(T(y) > \lambda \mid H_1] = \int_{\lambda}^{\infty} p_1(x)/PDF(H_1)dx, \qquad (3.8)$$

- **CYCLOSTATIONARY DETECTION**

In cyclostationary detection inherent periodicity of received signal is used to differentiate between noise and PU signal. Cyclostationary means properties of signals like mean Auto Correlation Function (ACF) etc. repeats itself after a certain fixed interval. Block diagram of cyclostationary detector is represented as in Figure



Input signal is passed through Band Pass Filter (BPF) of appropriate pass band to have a desired frequency band signal. BPF is also used for measuring energy around related frequency band, for that Fast Fourier Transform (FFT) of signal is computed. Assuming a complex deterministic sinusoidal PU signal s(t) passed through AWGN channel,

$$s(t) = A\cos(2\pi ft + \theta) \qquad (3.13)$$

Where, A= Amplitude of PU signal,

f = frequency of signal and

θ = Phase of PU signal (Initial).

The mean value corresponding to y(t) will be, where y(t)=s(t)+w(t).

$$M_y(t) = E[y(t)],$$

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$$M_y(t) = E[s(t)]. \qquad (3.14)$$

w(t) is Gaussian noise with zero mean and variance σ_w^2. $M_y(t)$ represent mean of y(t) and is periodic with time period T=1/f, provided signal is periodic with frequency f.

According to CLT, PDF of mean value for hypothesis H_0 and H_1 can be approximated to Gaussian distribution and given as

$$P_{M_y}(H_0) = C_N\left(0, \frac{\sigma_w^2}{2N+1}\right) \quad (3.23)$$

$$P_{M_y}(H_1) = C_N\left(\mu, \frac{\sigma_w^2}{2N+1}\right) \quad (3.24)$$

Where C_N (,) = Circularly symmetric complex Gaussian distribution,

μ = mean value of transmitted signal,

σ_w^2 = Noise variance and

M_y = Mean value of received signal

For a particular value of threshold λ, P_f, P_d and P_m can be represented as [11]

False alarm Probability

$$P_f = \Pr\langle H1 | H0 \rangle,$$

$$P_f = \exp\left(\frac{-\lambda^2}{2\sigma_A^2}\right).$$

$$\sigma_A^2 = \frac{\sigma_w^2}{(2N+1)},$$

where λ is threshold value.
Detection Probability

$$P_f = \Pr\langle H1 | H1 \rangle$$

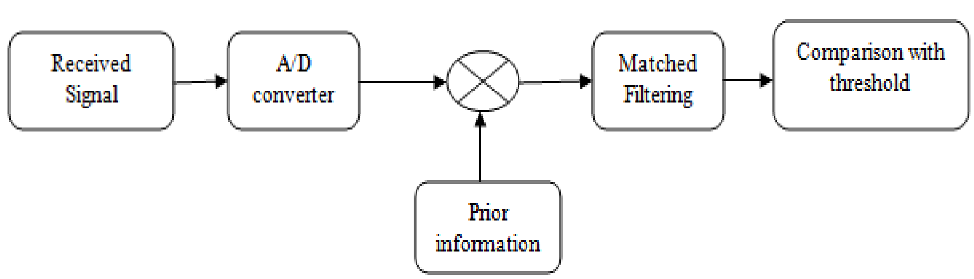
$$P_d = Q\left(\frac{\sqrt{2\gamma}}{\sigma w}, \frac{\lambda}{\sigma_A}\right) \quad (3.26)$$

Where, Q(,) = Generalized Marcum Q function
Miss detection probability

$$P_m = 1 - P_d = 1 - Q\left(\frac{\sqrt{2\gamma}}{\sigma w}, \frac{\lambda}{\sigma_A}\right) \quad (3.27)$$

- **MATCHED FILTER DETECTION**

This is an optimal detection scheme but it requires prior information about PU signal such as preamble, signalling for synchronization, pilot pattern for channel estimation etc
Block diagram for matched filter detector is represented as



Input signal s(t) is passed through A/D converter to get discrete time signal s(n). This signal further multiplied with prior information s*(n). [12]

$$T(y) = \sum_{n=0}^{N-1} s(n) \times s^*(n) \qquad (3.28)$$

Where s*(n) is prior information
False alarm probability

$$P_f = \Pr\langle H1|H0\rangle = \Pr[T(y) > \lambda|H0]$$

$$P_f = \exp\left(\frac{-\lambda^2}{E\sigma_w^2}\right)$$

where λ = threshold value,
E = PU signal power
Detection probability

$$P_d = \Pr\langle H1|H1\rangle = \Pr[T(y) > \lambda|H1]$$

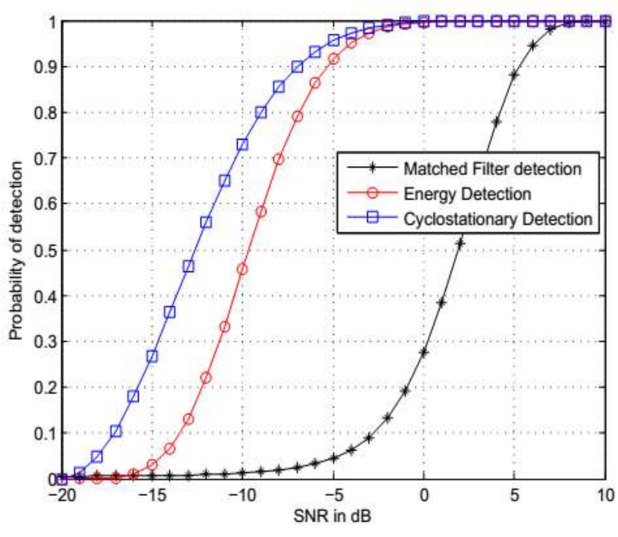
$$P_d = Q\left(\sqrt{\frac{2E}{\sigma_w^2}}, \sqrt{\frac{2\lambda^2}{E\sigma_w^2}}\right) \qquad (3.30)$$

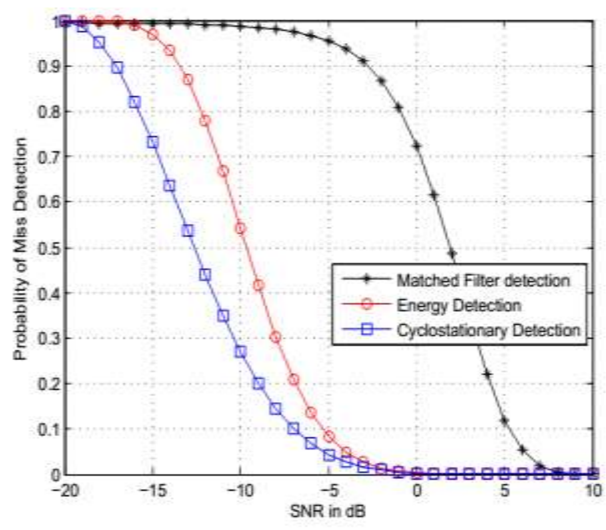
Miss detection probability

$$P_m = 1 - Q\left(\sqrt{\frac{2E}{\sigma_w^2}}, \sqrt{\frac{2\lambda^2}{E\sigma_w^2}}\right) \qquad (3.32)$$

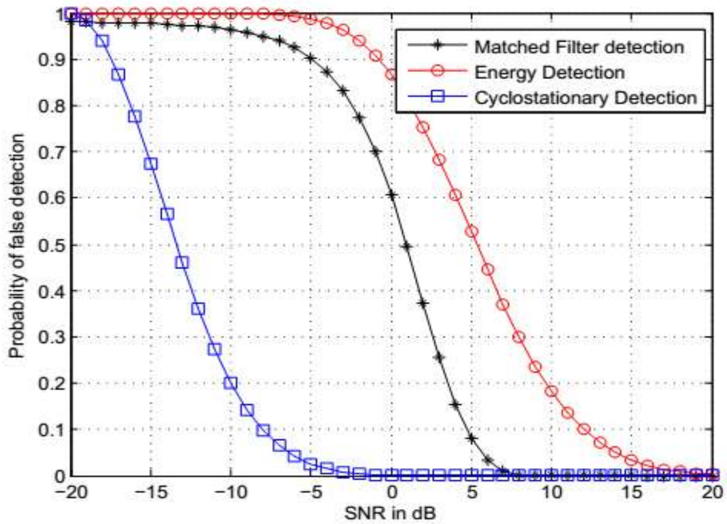
6. RESULTS

Energy detection, cyclostationary detection and matched filter detection are three most important SS techniques in literature. Simulation is done using MATLAB 2013a for number of samples = 1000, λ=.5 and SNR variations range from -20 to +10 in dB. Comparative performance of energy detection, matched filter detection and cyclostationary detection in terms of P_d





At -18 dB, cyclostationary detection is only scheme that can detect signal with low probability as in this scheme decision statistics is based upon noise rejection property of spectrum. Comparative analysis of three detection schemes in terms of P_f. Performance of energy detection scheme is worst in terms of P_f as it is a complete blind scheme i.e. it does not require any prior information.



CONCLUSION

Simulation results illustrated that, cyclostationary detection outperforms energy detection and matched filter detection under low SNR because of its ability to differentiate between PU signal and noise signal. Cyclostationary detection performs better than other schemes under low SNR and matched filtering operation maximize SNR at any value of detection probability.

FUTURE SCOPE

Various challenges encountered in SS techniques. This research work can be extended into numerous ways, some of them are listed below.

- Performance comparison among **user mobility**.
- Performance comparison under imperfect **channel estimation** (i.e. diversity detection and fading).
- Performance comparison in **correlated and non-identical diversity.**

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