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Analysis of Spectrum Sensing Techniques in Cognitive Radio

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Abstract

Today the need for flexible wireless communication is of utmost importance because the growth of wireless networks shows the trend that in future it will be the collaboration of mobile systems and internet technologies that will offer several varieties of services to the consumer. So spectrum becomes the most important resource for these services but today's spectrum policy is the biggest hurdle in the advancement of the technology. The existing spectrum policy leads to inefficient usage of radio spectrum. To overcome this problem Cognitive radio turns out to be one of the efficient technologies as a solution. Spectrum sensing is the most important and the very first step of cognitive radio technology. Spectrum sensing assists in detecting the unutilized radio spectrum bands also known as spectrum holes for the purpose of secondary usage of the same. In this paper the three basic spectrum sensing technique's operations have been compared to find out the best in the practical scenarios.

Keywords: Mobile Learning, Cognitive Science, Cooperative relay Communication.

1. Introduction

As we know that the frequency spectrum is limited but the increasing demand for the same because of emerging applications for mobile users has lead to the scarcity of available spectrum. Traditionally a license is provided to the service providers to have access of spectrum which is not evenly utilized by them leading to this problem of scarcity of RF spectrum.

The traditional licensing scheme limits the frequency spectrum's use and results in low utilization of it. Due to this spectrum licensing scheme, spectrum holes arises. Spectrum holes are frequency bands which are allocated to but in some location and at sometimes not utilized by licensed users and hence give an opportunity to secondary unlicensed user to use it.

In order to increase the efficiency of available spectrum, above mentioned restrictions needs to be modified. Hence the idea of cognitive radio [1] was introduced, with goal to provide adaptability to wireless transmission through dynamic spectrum access as well as enhancing the utilization of the frequency spectrum [2]. Therefore from above discussion the essential features of cognitive radio can be drawn which are like continuous awareness, dynamic frequency selection, frequency negotiation and agility. The whole functioning of cognitive radio can be explained through cognitive cycle which is given in figure 1.

Hence from the cognitive cycle it is very clear that there are 3 main tasks [3]:

1. Radio scene analysis, which takes care of estimation of interference temperature and detects spectrum holes. This step is also termed as Spectrum Sensing.
2. Channel identification which takes care of estimation of channel state information (CSI). This step is also termed as spectrum analysis.
3. Transmit power control and dynamic spectrum management. This step is also termed as spectrum decision.

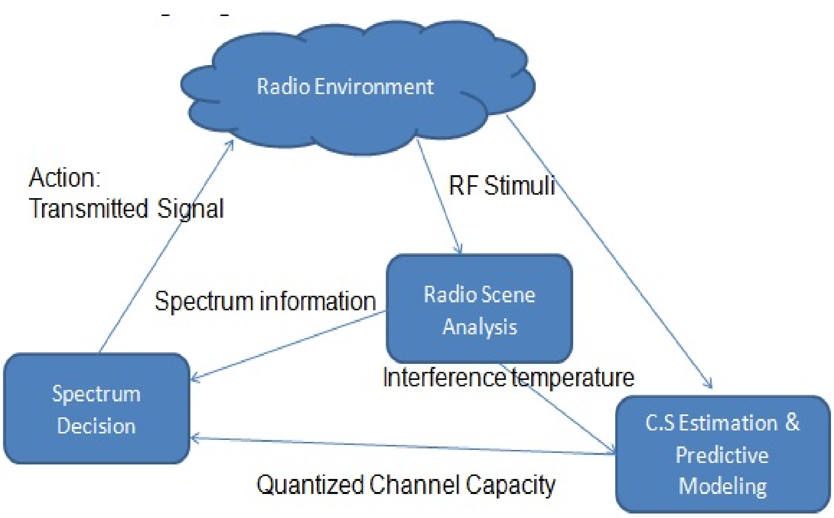

Fig. 1: Cognitive cycle.

This paper is targeted at addressing the performance analysis of the three main spectrum sensing techniques under the non-cooperative category. The techniques which have been discussed in the paper are Matched Filter detection, Energy detection and Cyclostationary feature detection.

2. Spectrum Sensing

One of the most important steps of cognitive cycle is spectrum sensing. The objective of spectrum sensing is to detect the presence of transmissions from primary users. Mainly, there are three types of spectrum sensing; non-cooperative sensing, cooperative sensing and interference based sensing as shown in figure 2.

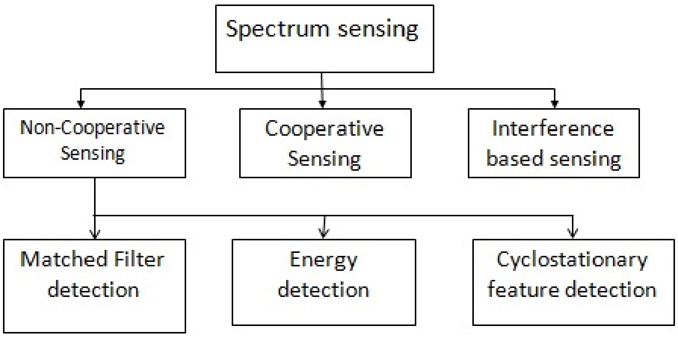

Fig. 2: Spectrum Sensing Techniques.

In this paper we are limiting ourselves to the non-cooperative sensing only.

2.1 Matched Filter Detection

A matched filter is a linear filter which maximizes the output signal to noise ratio for a given input signal. Matched filter detection technique is applied when primary user's a priori knowledge is known. In matched filter operation the unknown signal is convolved with the filter's impulse response which is the mirror and time shifted version of the primary user signal [4]. Mathematically, matched filter operation can be expressed as:

$$Y(n) = \sum_{k=-\infty}^{\infty} h(n-k)x(k) \tag{1}$$

The block diagram for the matched filter detector is given in figure 3.

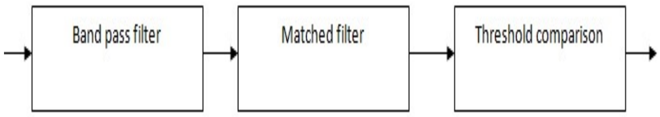

Fig. 3: Block Diagram for Matched Filter Detection [11]

2.2 Energy Detection

Energy detection is the simplest sensing technique because it does not require any a priori knowledge of the primary user signal. In this detection the primary user is detected based on the sensed energy. The block diagram description of the same is given in figure 4. In this method, the received signal is passed through band pass filter and the band limited signal is then integrated over a time interval. The time integrated signal is then compared with the predefined threshold to determine the presence of primary signal. The hypothesis test for the signal identification can be expressed as [4]:

$$H_1: x(n) = s(n) + w(n) \quad (2)$$
$$H_0: x(n) = w(n) \quad (3)$$

where s (n) is the signal transmitted by the primary users, x (n) is the signal received by the secondary users, w (n) is the additive white Gaussian noise. Hypothesis H_0 represents the absence of primary user whereas H_1 represents the presence of primary user. The mathematical expression for the calculation of energy is given as:

$$\sum_{n=0}^{N} |x(n)|^2 \quad (4)$$

Now the energy is compared to the threshold for checking which hypothesis is true using the following mentioned expressions.

$$E>\lambda: H_1 \quad (5)$$
$$E<\lambda: H_0 \quad (6)$$

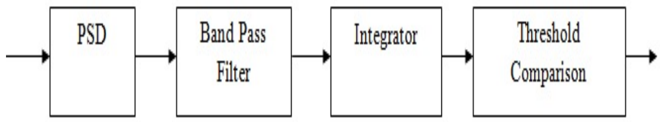

Fig. 4: Block Diagram of Energy Detection [11]

2.3 Cyclostationary Feature Detection

The transmitted signal from the primary users has a periodic pattern. This periodic pattern is known as cyclostationarity and is used to detect the presence of a licensed user [4]. If the autocorrelation of a signal is a periodic function, then the signal is called cyclostationary signal. When the autocorrelation function is expanded in terms of Fourier series co-efficient it comes out that the function is only dependent on frequency. The spectral components of a cyclostationary process are completely uncorrelated to each other. The Fourier series expansion is called cyclic auto-correlation function (CAF) and the related frequency is called cyclic frequency. The cyclic spectral density (CSD) is calculated by taking the Fourier transform of the CAF and it represents the density of the correlation between two spectral components that are separated by a quantity equal to the cyclic frequency. This periodic pattern is very helpful in distinguishing the primary user from the noise [5], [6], [7].

A received signal x (t) is considered to be cyclostationary if it's mean and auto correlation shows periodicity as [8]:

$$m_x(t+T_0) = m_x(t) \quad (6)$$
$$R_x(t+T_0, u+T_0) = R_x(t, u) \quad (7)$$

where the period of mean and auto correlation is T_0. If t and u are replaced in the autocorrelation equation with $t+\tau/2$ and $t-\tau/2$, then

$$R_x(t+\tau/2, t-\tau/2) = \sum R_x^{\alpha}(\tau) e^{j2\pi\alpha t} \quad (8)$$

where R_x^α represents the Cyclic Autocorrelation Function (CAF) and α denotes the cyclic frequency. Cyclic frequency is presumed to be a known parameter to the receiver. CAF is calculated as:

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

Cyclic spectral density (CSD) is obtained as:

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

The signals transmitted by the primary users are generally coupled with cyclic prefix, spreading codes, etc which result in the periodicity of their statistics like mean and auto correlation. When the CSD for such signals is calculated, it helps in highlighting such periodicities. Fourier transform of the correlated signal results in the peak at frequencies which are specific to a signal and searching for these peaks helps in determining the presence of the primary user whereas noise is random in nature and it does not exhibit such periodicities hence it doesn't get highlighted when its correlation is done. The block diagrammatic explanation of this detector is shown in figure 5.

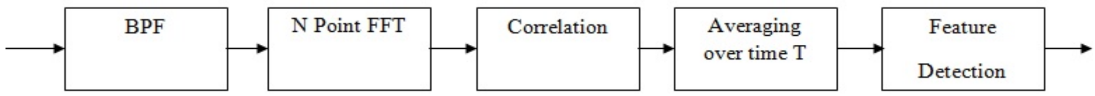

Fig. 5: Block diagram for cyclostationary feature detection [10]

The three techniques discussed above can be summarized in table 1 [9].

Table 1: Comparison Of Sensing Techniques.

Sensing Approach	Advantage	Disadvantage
Matched filter detection	Optimal performance and low cost	Prior knowledge of PU's signal is required
Energy detection	No prior knowledge required and low cost	Cannot work in low SNR; cannot distinguish primary and other secondary users
Cyclostationary detection	Robust in low SNR and interference	Partial information of primary user is required; high computation cost

3. Results & Analysis

The simulations for analysing the above discussed techniques were done on MATLAB. The main target of these simulations was to compare the operation performance of the three. The performance metrics considered in the paper are probability of detection and probability of false alarm. The simulation parameters are tabulated in table 3. The primary signal considered in the simulation is Digital Video Broadcast - Terrestrial (DVB-T) signal at 90MHz [10]. The DVB-T signal parameters are mentioned in table 2.

Table 2: DVB-T Parameters

Transmission Mode	**2K, 8K**
Number of useful sub-carriers	1705,6817
Number of TPS pilots	17,68
Radio Frequency (MHz)	45~860
Guard Interval	1/ 4, 1/8, 1/16, 1/32
Bandwidth	6, 7, 8
Elementary period	7/48, 7/56, 7/64
Channel model	Rayleigh, Ricean
Require BER	2x10-4

Table 3: Simulation Parameters.

Parameters	**Values**
Mode	2K
Elementary period (T)	7/64 µs
Number of carriers (K)	1705
Minimum carrier number	0
Maximum carrier number	1704
Duration (Tu)	224µs
Carrier Spacing (1/ Tu)	4464 Hz
Carrier Spacing between Kmin & Kmax (K-1)/TU	7.61 Hz
Guard interval	¼
Duration of guard interval (Δ)	56µs
Duration of symbol section (TU)	224µs
Total symbol duration (Δ+TU)	(56+224)µs=280µs

The simulation results for both the metrics is shown in figure 6 and figure 7 respectively. From the figure 6 we can observe that cyclostationary detector can achieve 100% detection at near about -8db SNR whereas to achieve such detection energy detector needs to have around 8 db of SNR and matched filter detector can achieve the same detection performance at near about 15db SNR. So from the figure we conclude that cyclostationary detector proposed here out performs the other two major detectors by a large margin as it performs extremely well at lower SNR, which is the most important aspect of DVB-T primary signal as per the IEEE 802.22 standards of cognitive radio. Figure 7, shows the probability of false detection as a function of SNR. Here we can observe that the probability of false detection for energy detector increases with the decrease in SNR i.e. as the SNR goes negative the false detection probability increases for the energy detector, for matched filter also follows the similar path though the detection probability for both these detectors approaches to minimum at 14db and 8 db SNR respectively. Now when the cyclostationary detector is observed it has the probability of false detection almost zero i.e. negligible in comparison to the other two detectors. So even on this parameter the cyclostationary detector out performs the other two major detectors.

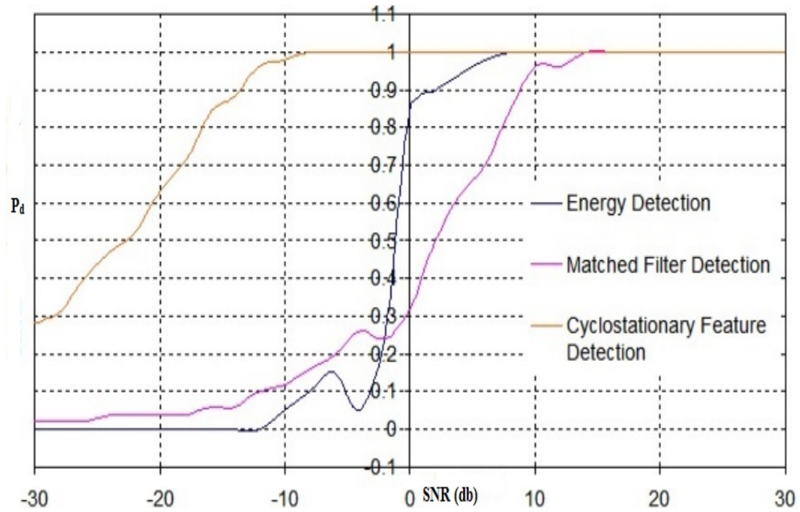

Fig. 6: Probability of Detection.

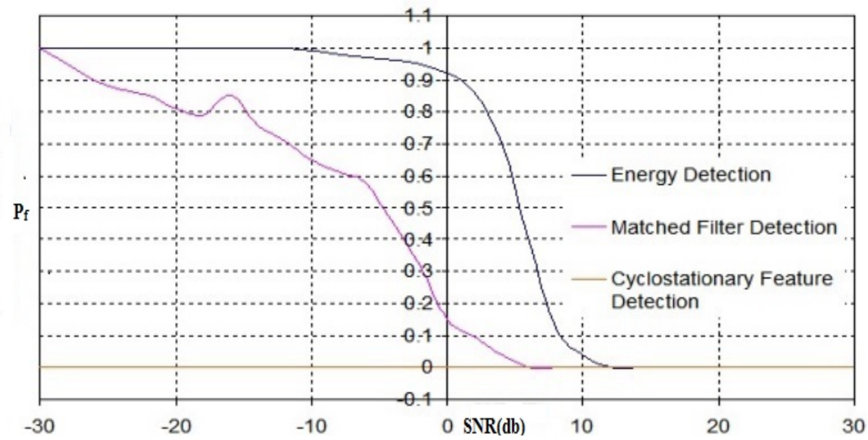

Fig. 7: Probability of False Alarm.

4. Conclusion

In the paper, the three major sensing techniques were compared for their performance on detection of DVB-T signal with probability of detection and probability of false alarm as performance metrics. The advantages and disadvantages of all the detectors have been tabulated as well. The results obtained after the simulation shows that energy detection begins its operation at -7db SNR whereas the matched filter detection is better than the energy detection which begins its operation at far below SNR than energy detector. But the cyclostationary detector is far better than the two because it performs very well even below -30db SNR. When considering probability of false alarm even then the cyclostationary detector shows better performance at lower SNR with negligible false alarm probability. So from the above discussions it can be concluded that if the mathematical complexity can be compromised then the cyclostationary feature detector is the best sensing detection technique for cognitive radio technology.

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