A SURVEY OF SPECTRUM SENSING TECHNIQUES FOR COGNITIVE RADIO NETWORKS

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ABSTRACT

Spectrum sensing is a challenging issue in cognitive radio (CR) environment. As a result, it has been reborn as a very active innovative area in recent years. Although various spectrum sensing techniques have been proposed, their strength at very low signal-to-noise ratio (SNR) and unsure noise interference in wireless networks. If we see frequency usage graph, it is viewed that spectrum utilization is concentrated at some portion while some of frequency bands are left unutilized. So these sensing methods include the detection of primary user (PU) transmission on preassigned frequency band.

In this paper, a survey of spectrum sensing techniques for cognitive radio based network is presented first afterward the co operative spectrum sensing concept and its various forms are discussed for robust spectrum sensing. The various sensing technologies i.e. energy detection, cyclostationary detection, waveform based detection and matched filter detection can be used for signal detection applications without requiring the knowledge of signal. It is proved mathematically that under some circumstances the proposed sensing methods are robust to unsure impulsive noise and interference.

Keywords - Cognitive Radio, Cooperative Sensing, Dynamic Spectrum Access, Multi-dimensional, Radio Identification, Spectrum Sensing etc

I. INTRODUCTION

Today's wireless networks are synchronized by a fixed spectrum allocation policy, i.e. the spectrum is synchronized by governmental agencies and is allocated to license holders or services on a long term basis for huge geographical regions. In addition, a huge portion of the allocated spectrum is used sporadically as illustrated in Figure 1.1, where the signal strength distribution over a huge portion of the wireless spectrum is shown in Figure 1.1. The spectrum usage is concentrated on certain portions of the spectrum while a significant amount of the spectrum remains unutilized. Although the fixed spectrum allocation policy generally served well in the past, there is a striking increase in the access to the limited spectrum for mobile services in the recent years. This increase is straining the effectiveness of the traditional spectrum policies.

The restricted available spectrum band and the inadequacy in the spectrum usage require a new communication prototype to make use of the existing wireless spectrum band opportunistically. The dynamic spectrum access is proposed to resolve these current spectrum inadequacy troubles during wireless communication. Dynamic spectrum access network is also called as NeXt Generation (xG) program use to realize the policy based intelligent radios known as cognitive radios (CR) [1]. Next Generation (xG) wireless communication networks, also called as Dynamic Spectrum Access Networks (DSAN) as well as cognitive radio networks will afford high bandwidth to mobile users via various wireless architectures and dynamic spectrum access techniques. The incompetent usage of the existing spectrum band can be enhanced through opportunistic access to the licensed bands without snooping with the existing users. The next generation wireless networks however require several innovative challenges due to the wide range of accessible spectrum band as well as miscellaneous Quality-of-Service (QoS) requirements of applications [2]. These deference's must be captured and used vigorously as mobile terminals roam between wireless architectures and along the accessible spectrum band.

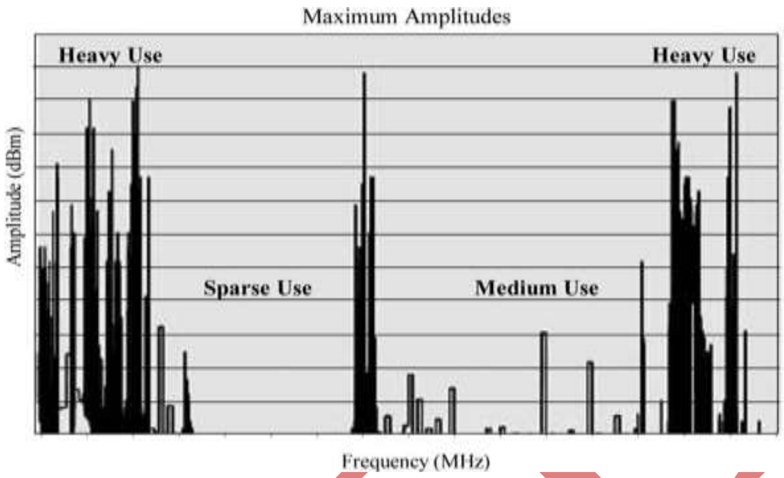

Fig. 1.1: Spectrum Utilization

1.1 Need of Spectrum Allocation

Spectrum band allocation is essential in order to make sure interference free operation for each radio network. Each frequency band is shared between various radio networks but the sharing is possible only with the use of related systems or networks [3]. Sharing is also achievable by way of geographical partitioning, time-sharing and through technical solutions like smart antenna and intelligent radio system.

The important features provided by cognitive radio are -

- Spectrum Sensing – CR constantly sense the radio environment and find out unallocated frequency bands to be used by CR environment.
- Spectrum Management – CR verify data rate and transmission mode before using unallocated spectrum band in order to gain best accessible band according to user necessity spectrum characteristics.
- Spectrum Mobility – If CR user discovers primary user in its spectrum band then CR must give up spectrum to licensed user for interference free network.
- Spectrum Sharing – CR have functionality to offer difficult scheduling mechanism for simultaneous CR users.

1.2 Characteristics of Radio Frequency Spectrum

Radio frequency spectrum is an inadequate natural resource used for wireless communication. The word 'Spectrum' is basically refers to a collection of different types of electromagnetic radiations of different wavelengths. In India, the radio frequencies are randomly confined between 9 kHz to 3000 GHz and are being used for 40 different types of services like fixed communication, cellular communication, television broadcasting service, radio navigation service, fixed and mobile satellite system, aeronautical satellite service and radio navigational satellite service. Some of the important and typical characteristics of the radio frequency spectrum are as below.

1. Radio frequency spectrum does not respect international geographical boundaries as it is spread over a large terrestrial area.

2. Use of radio frequency spectrum is susceptible to overlapping interference and requires the application of complex engineering tools to ensure interference free operation of various wireless networks.

3. Unlike other natural resources, the radio frequency spectrum is not enthusiastic upon its usage. It is also accountable to be exhausted if it is not used optimally and capably. Radio frequency spectrum band usage is therefore to be collective between the various radio services and must be used capably, optimally and economically in traditionalism with the provisions of national and international laws [4].

II. SPECTRUM SENSING TECHNIQUES FOR COGNITIVE RADIO

Generally spectrum sensing techniques are classified in three types' i.e. transmitter detection, receiver detection and interference temperature detection. In transmitter detection cognitive radio sense the waveform from primary transmitter which transmits at any given time [5]. Hypothesis model given for transmitter detection techniques are:

$$H1: \quad x(n) = s(n) + w(n) \tag{1}$$

$$H0: \quad x(n) = w(n) \tag{2}$$

Where,

'$s(n)$' = Signal transmitted by the primary users.

'$x(n)$' = Signal received by the secondary users.

'$w(n)$'= Additive white Gaussian noise with variances σ^2_{w}.

Hypothesis H0: Absence of primary user (PU)

H1: Existence of primary user (PU)

This hypothesis model is used to realize following spectrum sensing techniques in following subsections:

a) Energy Detection

b) Waveform Based Detection

c) Cyclostationary Feature Detection

d) Matched Filter Detection

2.1 Energy Detection

The recognition of unidentified deterministic signals despoiled by the additive white Gaussian noise (AWGN), an energy detection (ED) technique is derived which is called conventional energy detector. In this sensing technique receiver does not have prior information about the primary user (PU) only the value of white Gaussian noise is known. By evaluating the energy of received signal, received signal can sense without difficulty. Energy detection technique is simple and can be realize capably because the receiver does not require any prior information to detect the PU signal. The block diagram for energy detection technique is shown in the Figure 2.1

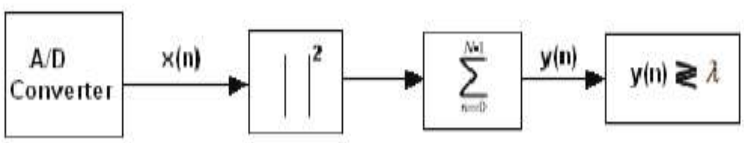

Fig 2.1: Energy Detection Technique

Input signal is received by A/D converter then output of A/D converter x(n) is given to square law circuit and fed to summation block. The output of summation/Integrator y(n) is compared to a pre-defined threshold . This comparison is used to discover the presence or absence of the PU signal. The threshold value can set to be fixed or variable, based on channel conditions. The computation of energy of input received signal is done as follows:

$$E = \sum_{n=0}^{N} |x(n)|^2 \tag{3}$$

Where,

x (n) = Input received signal.

E = Calculating the Energy of received input signal or some time denoted by y(n).

Energy detection technique has few limitations like, at low SNR does not perform well, cannot distinguish between signal and interference and does not work for the spread Spectrum techniques. Further, the performance of energy detection suffers in the case when power of the noise is unknown decided the value of threshold based on noise power which varies continuously depending upon the temperature, obstruction and other special effects so unchanging threshold is the problem [6]. During the probability of false alarm input signal x (n) will be,

$$x(n) = \omega(n) \quad ; H0$$

From equation (1) and (3), the received signal y (n) can be written as,

$$E = \sum_{n=0}^{N} |\omega(n)|^2 \tag{4}$$

Under H_0 hypothesis, the distribution of the energy detector output becomes a chi-square pdf with N degrees of freedom thus the pdf of the energy detector output can be derived as follows:

$$f_{E0}(x) = \frac{1}{\sigma\omega^{(2N/2)} * 2^{(N/2)} * \Gamma(N/2)} x^{\left(\frac{N}{2}-1\right)} e^{-\left(\frac{x-\mu}{2\omega\sigma^2}\right)}, \qquad x \geq 0\,, \tag{5}$$

$$P_f = \frac{1}{\sigma\omega^{(2N/2)} * 2^{(N/2)} * \Gamma(N/2)} \int_{\lambda}^{\infty} x^{\left(\frac{N}{2}-1\right)} e^{-\left(\frac{x}{2\omega\sigma^2}\right)} dx \tag{6}$$

After solving above equation, the final expression for probability of false alarm can be written as,

$$P_f = \frac{\Gamma\left(N/2, \left(\frac{\lambda}{2\omega\sigma^2}\right)\right)}{\Gamma(N/2)} \tag{7}$$

Where,

λ =Threshold value.

Γ(,) =Upper partial gamma function.

$\Gamma(a,x) = \int_{x}^{\infty} t^{(a-1)} e^{(-t)} dt$.

Γ() = Gamma function

$$\Gamma(a) = \int_x^{\infty} t^{(a-1)} e^{(-t)}\, dt$$

It is experimental that the sensing performance of energy-detector degrades considerably under Rayleigh fading.

2.2 Waveform Based Detection

Recognized patterns are frequently used in wireless communication systems to facilitate synchronization or for other communication purposes. In the occurrence of a recognized pattern the spectrum sensing or detection can be performed by correlating the received signal with a recognized copy of itself. This sensing technique is only relevant to systems with recognized signal patterns and it is known as waveform-based sensing (WBS) or coherent sensing [7] .

The waveform based sensing technique is well performed than energy detection (ED) spectrum sensing in consistency and convergence time. In addition, it is shown that the performance of the sensing algorithm increases as the duration of the recognized signal pattern increases [8]. Using the same model given in the waveform-based sensing metric can be obtained as

$$M = R_e \sum_{n=1}^{N} y(n)\, s(n) \quad (8)$$

In the absence of the primary user's (PU) signal, the metric value will be,

$$M = R_e \sum_{n=1}^{N} w(n)\, s(n) \quad (9)$$

Similarly, in the presence of a primary user's signal the sensing metric becomes

$$M = \sum_{n=1}^{N} |s(n)| + R_e \sum_{n=1}^{N} w(n)\, s(n) \quad (10)$$

The measurement result shows that waveform-based sensing requires less sensing time; however it is vulnerable to synchronization errors.

2.3 Cyclostationary Feature Detection

In this sensing technique CR can differentiate between noise and user signal by analyzing its periodicity and signal power. Cyclostationary feature detection is a much optimized technique that can easily separate out the noise signal from the user signal. Using a spectral correlation function it is achievable to separate noise signal if PU signal is present. Cyclostationary feature detection is distinguished between noise and received signal makes it better than energy detection (ED) and matched filter detection (MFD). It performs very well for superior noise on channels. The block diagram for the cyclostationary feature detection is shown in Figure 2.2.

Here, input signal established by Band pass filter (BPF) and is used to compute the energy around the associated band and then output of BPF is given to FFT for computing the signal received and then fed to the correlation block to correlate the signal and get ahead of integrator. The output from the Integrator block is then compared to a threshold [9]. This comparison is used to determine the existence or absence of the primary user signal.

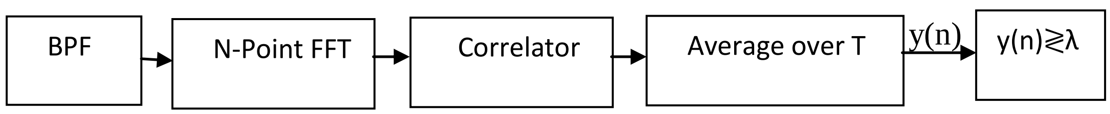

Fig 2.2: Cyclostationary Feature Detection

By considering a deterministic complex sine signal s(t) and passed it through an Additive white Gaussian noise (AWGN) channel which may be expressed as :

$$s(t) = A\cos(2\pi f0 + \theta) \quad (11)$$

Where,

A = Amplitude of input signal.

f_0 = Frequency.

ϴ= Initial Phase.

Transmission of s (t) through an AWGN, which having zero mean and results to x (t) = s (t) + n (t).
Thus, the Mean function of x (t) will be -

$$Mx(t) = E[x(t)] \quad (12)$$

$$Mx(t) = E[s(t) + n(t)] \quad (13)$$

$$Mx(t) = E[s(t) + n(t)] \quad (14)$$

Where,

x (t) = Received signal.

s (t) = Transmitted Input signal.

E = Expectation operator.

M_X (t) = Mean function of x (t) and also a Periodic function with period T_0.

Hardware realization of a cyclostationary feature detection, spectrum sensing technique is quite complex.

2.4 Matched Filter Detection

It is widely used spectrum detection technique which is able to achieve the good performance when a secondary sensing node can perform a coherent detection of the primary signal (PU) which is helpful to maximize the SNR. Accordingly, the secondary sensing node has to have prior information or knowledge about the primary signal such as the preamble, signaling for synchronization, pilot patterns for channel estimation and even modulation orders of the transmitted signal [10]. Detection by matched filter is useful only in cases where the information from the PUs is known to the CRs. Block Diagram of the technique is shown in the Figure 2.3.

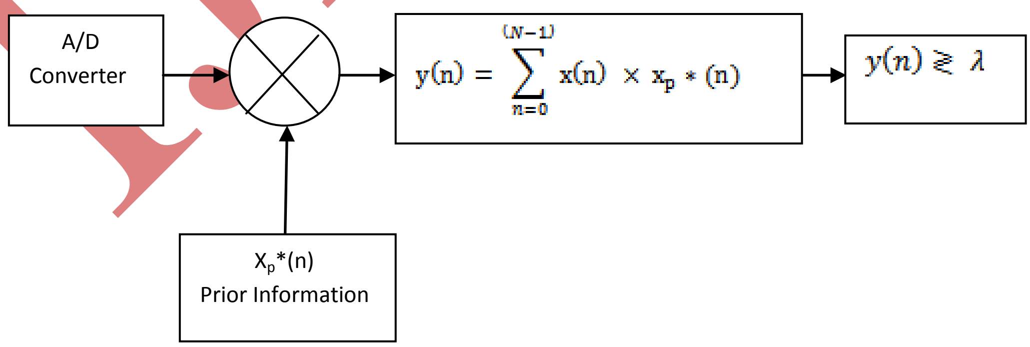

Fig 2.3: Matched Filter Detection

Here, input signal received by analog to digital (A/D) converter and output of A/D converter x (n) is multiplied with prior information signal xp*(n). The multiplied signal is fed to summation block and finally, the matched filter output y (n) is compared to threshold to determine the presence or absence of PU signal [11]. The mathematical expression of matched filter detection is expressed as:

$$y(n) = \sum_{n=0}^{(N-1)} x(n) \times x_p * (n) \tag{15}$$

Where, x (n) = Input transmitted signal.

x_p*(n) = Conjugate of Known Pilot data.

y (n) = Received signal.

n=1, 2, 3, 4…………...N

The matched filter sensing technique is too expensive for sensing multiple primary spectra. The more hardware implementation is requires for synchronization and knowledge of input signal is required to construct the reference signal that leads to the implementation complexity and large power consumption [12].

III. RESULT

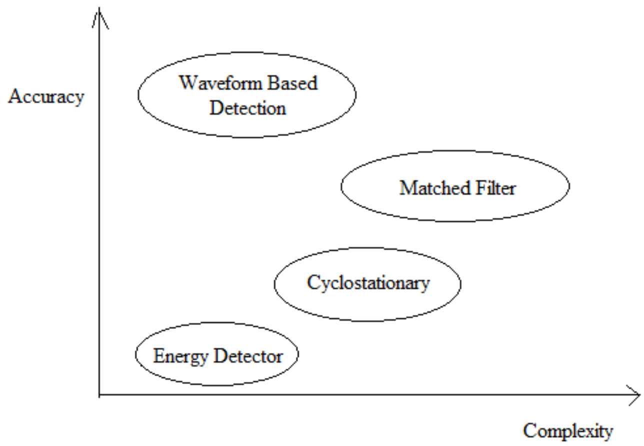

Fig 3.1: Sensing methods in terms of their sensing Accuracies and Complexities.

A basic comparison of spectrum sensing techniques is shown in Figure 3.1. Waveform-based sensing (WBS) technique is more strong or beneficial than energy detector (ED) and cyclostationarity feature detection (CFD) because of the coherent processing that comes from using deterministic signal component. The performance of energy detector based sensing is restricted when two common assumptions do not hold. The noise may not be stationary and its variance may not be known. However, in the presence of co-channel or adjacent channel interferers and noise becomes non-stationary due to that energy detector based schemes fail while cyclostationarity-based algorithms are unaffected. However, information from various cognitive radios can be collective to get more precise spectrum awareness.

IV. CONCLUSION

Spectrum is a very important resource in wireless communication systems and it has been a crucial point for research and development efforts over the last several decades. Cognitive radio is technique used to utilize the available spectrum more efficiently. One of the important basics of cognitive radio is sensing the available spectrum band. In this paper, the spectrum opportunity and spectrum sensing concepts are re-computed by considering different dimensions of the spectrum space. Evaluation of spectrum usage in multiple dimensions including sensing time, frequency used, used space, spectrum angle and code gives identification opportunities in these dimensions and developing algorithms for fast sensing techniques.

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