Performance analysis of Energy detection, Matched filter detection & Cyclostationary feature detection Spectrum Sensing Techniques

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Abstract- The growing demand of wireless applications has put a lot of constraints on the usage of available radio spectrum which is limited and precious resource. However, a fixed spectrum assignment has lead to under utilization of spectrum as a great portion of licensed spectrum is not effectively utilized. Cognitive radio is a promising technology which provides a novel way to improve utilization efficiency of available electromagnetic spectrum. Spectrum sensing helps to detect the spectrum holes (underutilized bands of the spectrum) providing high spectral resolution capability. This is a review paper that compares the performance of three main spectrum sensing techniques.

Keywords- Cognitive Radio (CR), Energy Detection (ED), Matched Filter Detection (MFD), Cyclostationary feature Detection.

I. Introduction

The available radio spectrum is limited and it is getting crowded day by day as there is increase in the number of wireless devices and applications. In the studies it has been found that the allocated radio spectrum is underutilized because it has been statistically allocated not dynamically (allocated when needed). Also the approach of radio spectrum management is not flexible, since, each wireless operator is assigned a license to operate in a certain frequency band. In the present scenario, it has been found out that these allocated radio spectrums are free 15% to 85% most of the time i.e. they are inefficiently used depending upon the geographical area. Since most of the useful radio spectrum already allocated, it is difficult to find vacant frequency bands to either deploy new services or to enhance the existing ones. In order to overcome this situation, we need to come up with a means for improved utilization of the spectrum creating opportunities for dynamic spectrum access. [1]-[3].

The issue of spectrum underutilization in wireless communication can be solved in a better way using Cognitive Radio. Cognitive Radio is characterized by the fact that it can adapt according to the environment by changing its transmitting parameters, such as modulation, frequency, frame format, etc. The main challenges with cognitive radios are that it should not interfere with the licensed users and should vacate the band when required. For this it should sense the signals faster. This work focuses on the spectrum sensing techniques that are based on primary transmitter detection. In this category, three major spectrum sensing techniques "energy detection", "matched filter detection", and "cyclostationary feature detection" are addressed. This paper involves the comparative analysis of these spectrum sensing techniques for efficient working of cognitive radios.

II. Cognitive Radio

The concept behind the Cognitive users is that they have the ability to continuously sense the licensed spectrum to search the unused locations, once the hollow locations are identified; Cognitive radio users utilize those locations for transmission without interrupting the primary users. [4].The primary aim of a cognitive radio system is to get hold of a best available channel by using the cognitive capability and re-configurability. Cognitive capability is defined as the capacity of the radio system to gather information from the surroundings [5]. It requires very complex or sophisticated techniques in order to observe the sudden variations and changes in the radio environment without interfering with the existing users. Cognitive capability plays a major role to identify the unused or white spaces in the frequency spectrum at a particular time so as to select a suitable spectrum along with the suitable operating parameters. These unused channels are called spectrum holes or white spaces [5]. The cognitive radio enables the use of white spaces in the spectrum that become available temporarily. As soon as the primary user returns to its band, the cognitive user switches to a different spectrum hole or may stay in the same band but alters the power level and modulation method for avoiding interference to the existing licensed users in that band.

III. Spectrum Sensing

A major challenge in cognitive radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and quit the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary users. This technique is called spectrum sensing. Spectrum sensing and estimation is the first step to implement Cognitive Radio system [6].

Energy detection Spectrum Sensing

It is a non coherent detection method that detects the primary signal based on the sensed energy [1]. Due to its simplicity and no requirement of a priori knowledge of primary user signal, energy detection (ED) is the most popular sensing technique in cooperative sensing [7][8][9].

The block diagram for the energy detection technique is shown in the Figure 1. In this method, signal is passed through band pass filter of the bandwidth W and is integrated over time interval. The output from the integrator block is then compared to a predefined threshold. This comparison is used to discover the existence of absence of the primary user. The threshold value can set to be fixed or variable based on the channel conditions.

The ED is said to be the Blind signal detector because it ignores the structure of the signal. It estimates the presence of the signal by comparing the energy received with a known threshold ν derived from the statistics of the noise. Analytically, signal detection can be reduced to a simple identification problem, formalized as a hypothesis test,

$$y(k) = n(k)........................H_0$$

$$y(k) = h * s(k) + n(k).........H_1 \qquad (1)$$

Where y(k) is the sample to be analyzed at each instant k and n (k) is the noise of variance σ^2. Let y(k) be a sequence of received samples k Є {1, 2….N} at the signal detector, then a decision rule can be stated as,

$$H_0 \text{....if } \varepsilon < v$$

$$H_1 \text{....if } \varepsilon > v \qquad (2)$$

Where $\varepsilon = |E\ y(k)|^2$

The estimated energy of the received signal and v is chosen to be the noise variance σ^2 [10].

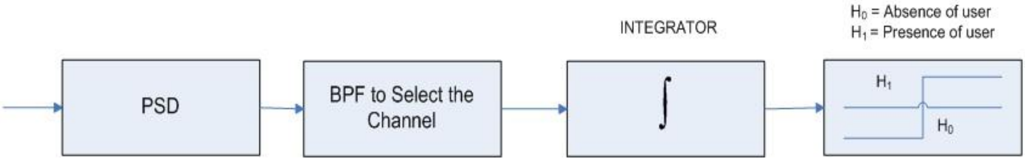

Fig. 1: Block diagram of Energy detection [1].

The “probability of primary user detection” and the “probability of false detection” for the energy detection method can be calculated by the given equations [10]:

$$P_d = P\,[Y > \lambda / H1] = Q_m\,(\sqrt{2\gamma}, \sqrt{\lambda}),$$

$$P_f = P\,[Y > \lambda / H0] = \Gamma\,(m, \lambda/2) / \Gamma\,(m) \qquad (3)$$

Where λ= SNR,

n= TW (Time bandwidth product)

Γ(.)= complete gamma function,

Γ(.,.)= incomplete gamma function,

Qm= Generalized Marcum function [11].

Matched Filter Spectrum Detection

A matched filter (MF) is a linear filter designed to maximize the output signal to noise ratio for a given input signal. When secondary user has a priori knowledge of primary user signal, matched filter detection is applied. Matched filter operation is equivalent to correlation in which the unknown signal is convolved with the filter whose impulse response is the mirror and time shifted version of a reference signal. The operation of matched filter detection is expressed as:

$$Y[n] = \sum_{k=-\infty}^{\infty} h[n-k]\,x[k] \qquad (3)$$

Where 'x' is the unknown signal (vector) and is convolved with the 'h', the impulse response of matched filter that is matched to the reference signal for maximizing the SNR. Detection by using matched filter is useful only in cases where the information from the primary users is known to the cognitive users [10].

Fig. 2: Block diagram of matched Filter detection [1].

Cyclostationary feature Spectrum Detection

It exploits the periodicity in the received primary signal to identify the presence of primary users (PU). The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences or cyclic prefixes of the primary signals. 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 [11].

Thus, cyclostationary feature detection is robust to noise uncertainties and performs better than energy detection in low SNR regions. Although it requires a priori knowledge of the signal characteristics, cyclostationary feature detection is capable of distinguishing the CR transmissions from various types of PU signals. This eliminates the synchronization requirement of energy detection in cooperative sensing. Moreover, CR users may not be required to keep silent during cooperative sensing and thus improving the overall CR throughput. This method has its own shortcomings owing to its high computational complexity and long sensing time. Due to these issues, this detection method is less common than energy detection in cooperative sensing [12].

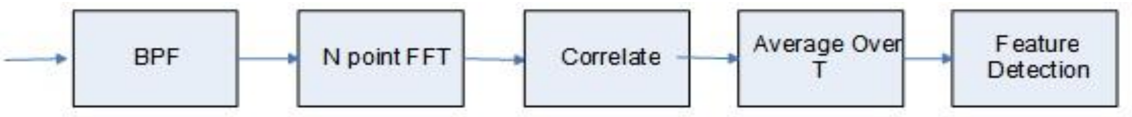

Fig. 3: Block diagram of Cyclostationary feature detection [1].

Process flow diagrams

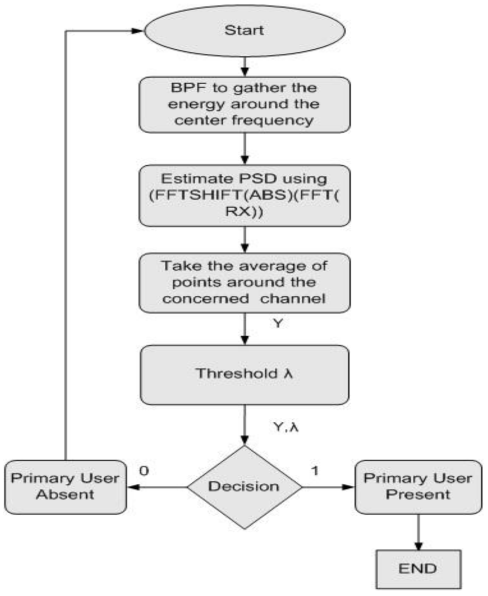

Fig. 4: Process flow diagram of Energy Detection.

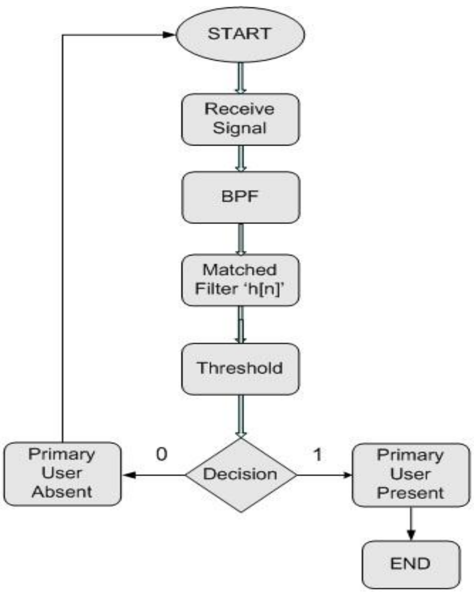

Fig. 5: Process flow diagram of Matched filter Detection.

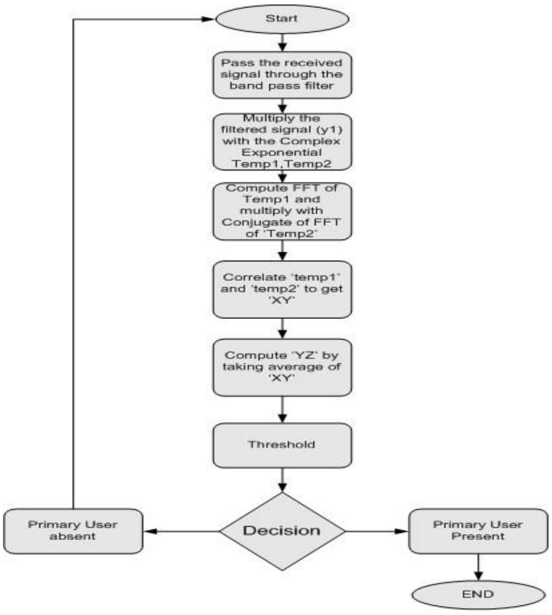

Fig. 6: Flow diagram of Cyclostationary feature Detection.

IV. Results And Analysis

An extensive set of simulations have been conducted using the system model as described in the previous section. The emphasis is to analyze the comparative performance of three spectrum sensing techniques. The performance metrics used for comparison include the "probability of primary user detection" and "probability of false detection". The number of channels and the number primary users considered in this analysis is twenty five and respectively. The SNR of the channels is considered to be precisely same and the channel model is AWGN with zero mean. The results are shown in Figure-7 and Figure-8.

Probability of Primary Detection

Figure-7 depicts the "probability of primary user detection" as a function of SNR for the three cases: (i) energy detection, (ii) matched filter detection and (iii) cyclo-stationary feature detection.

It is observed that for energy detection and matched filter detection, much higher SNR is required to obtain a performance comparable to cyclostationary feature detection. For energy detection, about 16 dBs higher SNR is needed to achieve 100% probability of detection whereas for matched filter detection, about 24 dB s higher SNR is required. For cyclostationary feature detection, 100% probability of detection is attained at -8 dBs. Cyclostationary feature detection performs well for very low SNR, however the major disadvantage is that it requires large observation time for occupancy detection. Matched filter detection performs well as compared to energy detection but restriction lies in prior knowledge of user signaling. Further, cyclostationary feature detection algorithm is complex as compared to other detection techniques.

Probability of False Detection

Figure-8 illustrates the "probability of false detection" for three transmitter detection based spectrum sensing techniques versus SNR.

It is observed that "probability of false detection" of cyclostationary feature detection is much smaller as compared to other two techniques. In fact, it is zero for the range of SNR considered in this study i.e., -30 dB to +30 dBs. It is further seen that the "probability of false detection" for energy detection technique is inversely proportional to the SNR. At low SNR we have higher probability of false detection and at high SNR we have lower probability of false detection, because energy detection cannot isolate between signal and noise. The probability of false detection for energy detection and matched filter detection approaches zero at about +14 dBs and +8 dBs respectively.

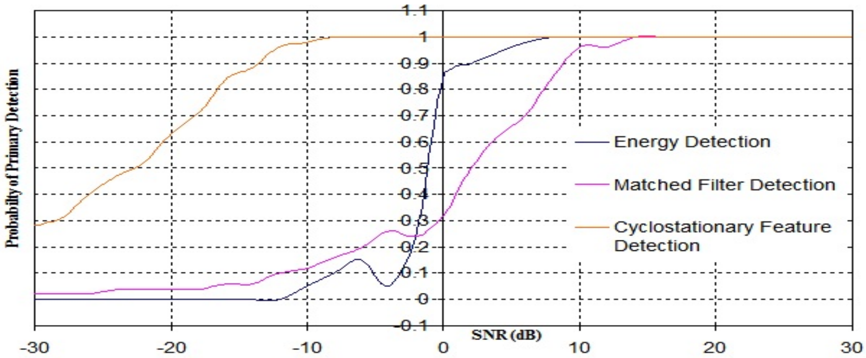

Fig. 7: Probability of Primary Detection.

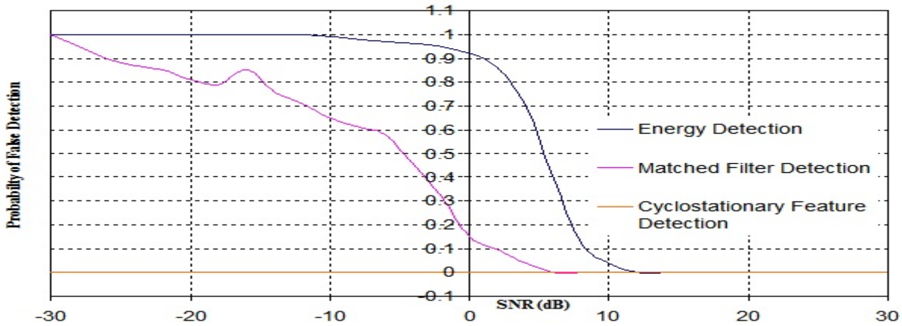

Figure 8: Probability of False Detection.

I. Conclusion

To efficiently utilize the wireless spectrum cognitive radios were introduced which opportunistically utilize the holes present in the spectrum. The most essential aspect of a cognitive radio system is spectrum sensing and various sensing techniques which it uses to sense the spectrum. In this paper the main focus was on Energy Detection, Matched Filter Detection and Cyclostationary feature Detection spectrum sensing techniques. The advantage of Energy detection is that, it does not require any prior knowledge about primary users. It does not perform well at low SNR values, it requires a minimum SNR for its working. The result in the paper shows that Energy detection starts working at -7 dB s of SNR. Matched filter detection is better than energy detection as it starts working at low SNR of -30 dB s. Cyclostationary feature detection is better than both the previous detection techniques since it produces better results at lowest SNR, i.e. for values below -30 dB s. the results shows that the performance of energy detection gets better with increasing SNR as the "probability of primary detection" increases from zero at -14 dB s to 100% at +8 dB s and correspondingly the "probability of false detection" improves from 100% to zero. Similar type of performance is achieved using matched filter detection as "probability of primary detection" and the "probability of false detection" shows improvement in SNR as it varies from -30 dB s to +8 dB s. the cyclostationary feature detection outclasses the other two sensing techniques as 100% "probability of primary detection" and zero "probability of false detection" is achieved at -8 dB s, but the processing time of cyclostationary feature detection is greater than the energy detection and matched filter detection techniques.

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