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Spectrum Sensing Techniques for Cognitive Radio Networks: A Review

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ABSTRACT: Cognitive radio is one of the most promising technologies that resolves the problem of inefficient spectrum utilization by enabling secondary user to opportunistically utilize the unused licensed bands. The prime functionality of cognitive radio is spectrum sensing in which presence of the primary usersis accurately detected. In this paper various spectrum sensing methods are presented together with the discussion over their advantages and disadvantages.

KEYWORDS: Cognitive radio,spectrum sensing, primary user, secondary user.

I. INTRODUCTION

The electromagnetic radio spectrum is a valuable and limited natural resource which is regulated by Federal Communication Commission (FCC). The regulation is based on exclusive licensing of a particular band. Only a licensed user has the authority to use that band. In allocated spectrum, it has been found that some frequency bands are largely unoccupied most of the time, some are only partially occupied and remaining are heavily used, that means most of the allocated spectrum is underutilized. The inefficient usage of spectrum with growing demand of radio spectrum by several wireless devices has motivated the promotion of Cognitive Radio (CR) [1].FCC has defined cognitive radio as, “A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify the system operations, such as maximize throughput, mitigate interference, d facilitate interoperability and access secondary markets.” [2].

Cognitive radio allows secondary users, who have no spectrum licenses, to utilize the temporarily unused licensed bands without interfering with the license holders, also known as primary users. Hence cognitive radio should have the ability to accurately detect the spectral opportunities for the secondary users without any harmful interference to primary users; this ability is called spectrum sensing.

Further in this paper, traditional spectrum sensing techniques for narrowband spectrum sensing have been discussed. They are then followed by the existing wideband spectrum sensing techniques which have been discussed and categorized based on their sampling rates.

II. RELATED WORK

Spectrum sensing is the key functionality of cognitive radio networks. Many narrowband spectrum sensing algorithms, including energy detection matched filtering and cyclostationay feature detection algorithms, have been studied in literature [3, references therein]. Energy detection is the most common and well known spectrum sensing technique[4]. All these narrowband spectrum sensing techniques aim to detect spectral opportunities over narrow frequency range and make a single decision of the whole spectrum. Cognitive radio networks ultimately requires to exploit spectral opportunities over a wide frequency range from hundreds of megahertz to several gigahertz for achieving higher opportunistic throughput. This demand leads to wideband spectrum sensing techniques. Conventional wideband spectrum sensing techniques based on standard analog-to-digital converter (ADC) lead to high sampling rate or implementation complexity [5]; thus, revolutionary wideband spectrum sensing techniques such as sub-Nyquist wideband spectrum sensing or compressive sensing become increasingly important for next generation cellular network.

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III. NARROWBAND SPECTRUM SENSING

As the name implies itself, Narrowband Spectrum Sensing techniques identify spectral opportunities for secondary users over narrow frequency range. In other words, the bandwidth of interest is less than the channel coherence bandwidth. It works on bandwidth less the coherence bandwidth of the channel spectral opportunities are also less.Traditional narrowband spectrum sensing techniques include energy detection, matched filtering and cyclostationary feature detection shown in figure 1. The advantages and disadvantages of these techniques are summarized in Table 1.

A. *Energy detection:*

Energy detection is a non-coherent blind signal detection because it does not require the prior knowledge of the primary user. It is based on the fact that energy of the signal to be detected is always higher than the energy of the noise. It detects the presence of a signal by comparing the received energy with a known threshold. Threshold selection is a challenge in energy detection method because it depends on the noise variance. Both implementation and computational complexity are relatively low. The major drawback of this technique is that it impedes discrimination between sources of received energy namely primary signal and interference from other cognitive radios. It also has bad performance under low signal to noise ratio (SNR) regions.

B. *Matched filtering:*

Matched filtering is a coherent non-blind signal detection method. It is an optimum method of detection since it maximizes the SNR in the presence of additive noise. It requires the prior knowledge of the primary user and cognitive radios to be equipped with carrier synchronization and timing devices, which increase the implementation complexities. Matched filter estimates the presence of the primary user by correlating the signal with the time shifted version and comparing the predetermined threshold with the output of matched filter.

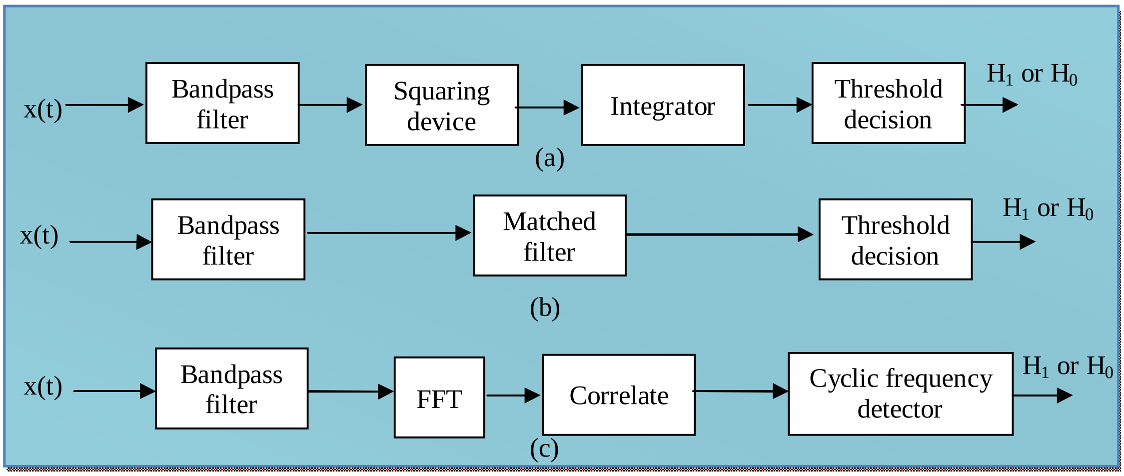

Fig 1: Block diagrams for narrowband spectrum sensing techniques: a) energy detection; b) matched filtering; c) cyclostationary feature detection

C. *Cyclostationary feature detection:*

Cyclostationary feature detection is based on the principle that most of the signals show periodic characteristics, present in modulations, carriers, cyclic prefix and other periodic features. Since noise does not exhibit periodicity, the signal can be successfully detected. It requires partial prior knowledge of the primary user. It can also discriminates

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between different types of primary users by using their cyclostationary features. However computational cost is relatively high.

Spectrum sensing techniques	Advantages	Disadvantages
Energy detection	Easy to implement. Low computational cost. Does not require prior information of the primary user.	Poor performance for low SNR. Cannot differentiate users.
Matched filtering	Optimal performance. Low computational cost.	Requires prior information of the primary user.
Cyclostationary feature detection	Valid in low SNR region Robust against interference	Requires prior information of the primary user. High computational cost.

Table 1: Summary of advantages and disadvantages of narrowband spectrum sensing algorithms.

IV. WIDEBAND SPECTRUM SENSING

Wideband spectrum sensing (WSS) techniques determine spectral opportunities for secondary users over wide frequency range.Frequency bandwidth of interest is larger than the coherence bandwidth of the channel. For example, for determining spectral opportunities in the whole ultra-high frequency (UHF) TV band, between 300 MHz to 3GHz, wideband spectrum sensing should be employed. Narrowband spectrum sensing cannot be directly applied to WSS because they made single decision for the whole spectrum, impeding identification of individual spectrum opportunities. Wideband spectrum sensing can be broadly categorized into two types: Nyquist wideband sensing and sub-Nyquist wideband sensing. The advantages, disadvantages and challenges of both techniques are summarized in Table 2.

A. *Nyquist wideband sensing:*

As the name itself implies, Nyquist wideband sensingapproachesarebasedon the Nyquistratesampling of the signalin the frequency band of interest. These techniques directly obtain the wideband signal using a standard ADC and then use digital signal processing techniques to detect spectral opportunities. However Nyquist wideband sensing approaches lead to high sampling rate and implementation complexity. For example frequency range of interest is 0 ~20 GHz; according to Shannon's theorem it should be uniformly sampled by a standard ADC at or above the Nyquist rate i.e., 40 GHz, which will not be feasible to next generation cellular networks.

Block diagram of traditional Nyquist wideband sensing is shown in figure 2. The wideband signal x(t) was first sampled by a standard ADC at or above the Nyquist rate, after which a serial-to-parallel conversion circuit (S/P) was used to divide sampled data into parallel data streams. Fast Fourier transform (FFT) was used to convert the wideband signals to the frequency domain. The wideband spectrum X (f) was then divided into a series of narrowband spectra X_1(f)…..X_M (f). Finally, spectral opportunities were detected using binary hypotheses tests, where H0 denotes the

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absence of primary users and H1 denotes the presence of primary users. The optimal detection threshold was jointly chosen by using optimization techniques.

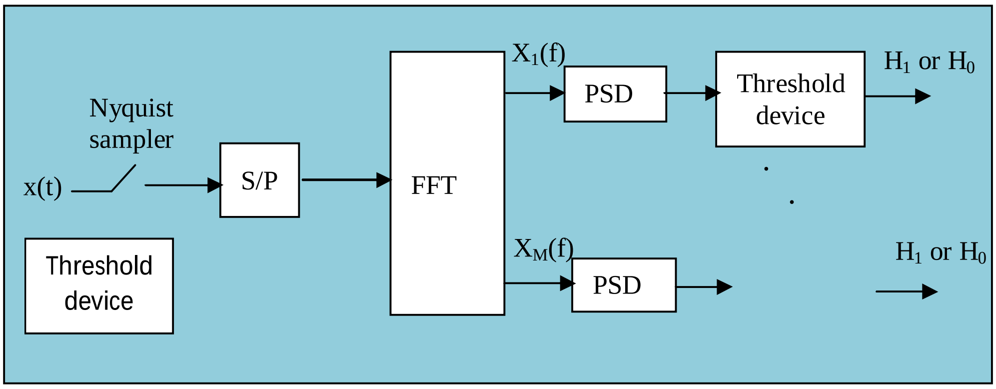

Fig 2: block diagram of Nyquist wideband spectrum sensing techniques

B. *Sub-Nyquist wideband sensing:*

Sub-Nyquist sensing, also known as compressive sensing or compressive sampling (CS), refers to the techniques of recovering a signal from the samples obtained usingarate significantly lower than theNyquistrate.CS relies on two principles: sparsity of the signals of interest, and incoherence of the sensing modality. Sparsity can be defined as "if information rate of a continuous time signal is much smaller than suggested by its bandwidth, then signal is said to be a sparse signal." As the wideband spectrum is inherently sparse due to the low percentage of spectrum occupancy, CS becomes a promising techniques to realize wideband spectrum sensing by using sub-Nyquist sampling rates and reduce burden on the ADCs.

	Nyquist wideband sensing	**Sub-Nyquist wideband sensing**
Advantages	Simple structure	Low sampling rate Signal acquisition cost
Disadvantages	High sampling rate Energy cost	Sensitive to design imperfections
Challenges	Reduce sampling rate Save energy	Improve robustness to design imperfections

Table 2: Summary of advantages, disadvantages and challenges of wideband spectrum sensing algorithms.

V. Conclusion

In this paper, spectrum sensing techniques for cognitive radio are categorized based on their sensing frequency range and advantages/disadvantages of each technique are discussed. Wideband spectrum sensing finds more spectral opportunities for secondary user and achieves higher opportunistic throughput than the narrowband spectrum sensing in

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cognitive radio networks.Conventional wideband spectrum sensing techniques based on standard ADCs lead to high sampling rate or implementation complexity; thus, sub-Nyquist wideband spectrum sensing or compressive sensing techniques become increasingly important.

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BIOGRAPHY

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