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A Review on Cooperative Spectrum Sensing using Cyclostationary Feature Detection for Cognitive Radio Networks

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ABSTRACT

With some recent developments in the field of wireless communication rapidly, users are getting a number of applications which require the precious bandwidth to work on. As the bandwidth is limited, the available spectrum is being congested day by day. Cognitive Radio System (CRS) plays an important role in such scenario. It adapts the parameters and protocols dynamically to provide unused spaces in the total usable spectra. There are a number of ways to detect the unused spectrum/holes/white spaces like Energy Detection, Matched Filter Detection, Cyclostationary Feature Detection (CFD), Wavelet Transform, Covariance based Method. Spectrum sensing can be significantly improved by allowing different users to share their local sensing observations and to cooperatively decide on the licensed spectrum occupancy. The main advantage of this technique is that it is robust to random noise and interference from other modulated signals, no synchronization is required and it gives optimal detection performance in very low SNR region. On the other hand, it has some limitations such as high computational complexity and increased sensing time.

***Keywords*--** Cognitive radio, cooperative spectrum sensing, cyclostationary feature detection

I. INTRODUCTION

Since spectrum is a finite resource, the efficient use of available spectrum is a important requirement for designing of wireless system. The transceiver in cognitive radio (CR) communication has the power to observe that communication channels are in use and that don't seem to be, and instantly get in empty channels whereas avoiding occupied ones. For the further discussion, it is useful to distinguish between the two different definitions of cognitive radio:

- All the transmission parameters, i.e., multiple-access method, modulation format, coding, as well as center frequency, transmission times, bandwidth, and so on are adopted by a fully cognitive radio. Although a fully cognitive radio is interesting from a scientific point of view, it currently seems too complicated for practical purposes.
- A "spectrum-sensing cognitive radio," only adapts the transmission frequency, bandwidth, and time according to the environment. Such cognitive radio is also called Dynamic Spectrum Access (DSA).

There are three kinds of models for DSA:

- Dynamic exclusive model.
- Open sharing model
- Hierarchical access model

The key principle of hierarchical cognitive radio is that the secondary users do not disturb the primary users. Such non disturbance can be achieved by three fundamental approaches: interweaving, overlay, and underlay. In the interweaving approach, the radio first identifies those parts of the spectrum that are not being used at a certain time, and transmits in those; thus, such a radio is a spectrum-sensing radio. In an overlay approach, the cognitive radio detects the actually transmitted signal of the primary user, and adjusts its own signal in such a way that it does not disturb the primary receiver (RX) even though it transmits in the same band. In the underlay approach, the secondary user actually does not adapt to the current environment, but always keeps its transmit Power Spectral Density (PSD) so low that its interference to primary users is insignificant. [13]

II. PRINCIPLES OF INTERWEAVING

Clearly, the strategy involves three steps:

- **Spectrum sensing**: the cognitive radio has to identify which parts of the time–frequency plane are not used by primary users. The sensing has to be done in the presence of noise, so that the sensing cannot be completely reliable. Furthermore, it is important to determine the signal level of the detected radiation. [13]

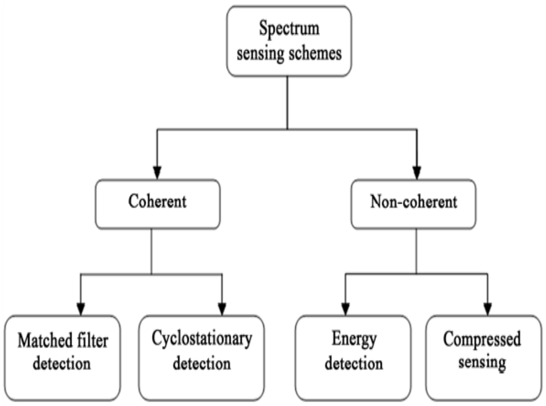

Figure 1: Types of Spectrum Sensing

- **Spectrum management**: here, the secondary system decides when, and in which part of the spectrum, to transmit. This decision is difficult for several reasons:

(1) The secondary system has only causal knowledge of the spectrum occupation, i.e., it knows only which parts of the spectrum were free in the past and the present, but it has to make assumptions (that are not necessarily correct) about how the primary system will work in the future, i.e., at the time when the secondary system will actually transmit.

(2) The sensing information on which the decisions of the secondary system is based are not perfect.

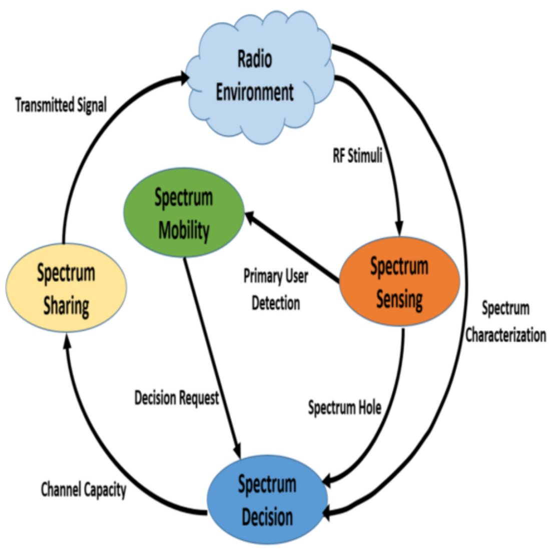

Figure 2: Principles of interweaving

- **Spectrum sharing**: A decision on how to divide up the free spectrum that the secondary system uses. It must be noted that spectrum sharing and spectrum management are strongly related – spectrum might be usable for a particular secondary transmitter (TX), but not for another. [13]

III. CYCLOSTATIONARY FEATURE DETECTION

Cyclostationary feature detection is also termed as non-blind sensing technique since it requires certain information of PU signal. In order to segregate PU signal and CR signal, this technique analyzes signals periodicity. Based on the periodicity, this detection method can easily isolate the noise from the PU signal. Primary User (PU) signals are combined with sine wave carrier signals, repeating spreading code sequences, or cyclic prefixes, all of which have a built-in periodicity, their autocorrelation and mean show periodicity which is characterized as being cyclostationary. Noise is a wide sense stationary signal having no correlation. With the help of spectral correlation function, it is possible to distinguish noise signal energy from modulated PU signal energy and thus sense if PU is present. [12] Basic flow diagram of CFD is shown below:

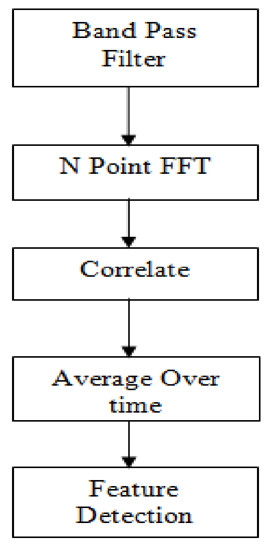

Figure 3: Block Diagram of CFD

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:

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

Cyclic spectral density (CSD) is obtained as:

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

The signals which the primary users transmits are generally coupled along 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. Correlated signal's fourier transform provides peak at frequencies which are specific to a signal and looking 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. [14]

IV. LITERATURE REVIEW

A. Cyclostationary-Based Cooperative Compressed Wideband Spectrum Sensing in Cognitive Radio Networks (IEEE 2017)

A cooperative cyclostationary compressed spectrum sensing algorithm is proposed to enable accurate, reliable and fast sensing of wideband spectrum. In the proposed algorithm each secondary-user (SU) sends the compressed data vector to the fusion center (FC) which has a copy of the sensing matrices for all cooperated SUs. Then, at the FC, the fast Fourier transform accumulation method (FAM) based on cooperative multitask compressive sensing (MCS) algorithm is employed to recover the spectral correlation function (SCF) from the compressed measurements. The proposed algorithm has two main components. The first component exploits the cooperation between SUs to produce an estimate of the investigated signal spectrum using multi-task compressive sensing. In the second component, the cyclic feature detection is performed based on the recovered SCF function. Simulation results obtained provides us the wellness and the effectiveness of the proposed method against both noise uncertainty and sampling rate reduction. [1]

B. Cyclostationary Feature based Detection using Window Method in SIMO Cognitive Radio System (IEEE 2016)

With some recent developments in the field of wireless communication at rapid pace, users are getting a number of applications which require the precious bandwidth to work on. As the bandwidth is limited, the available spectrum is being congested day by day. Cognitive Radio System (CRS) plays an important role in such scenario. It dynamically adapts its parameters and protocols to provide unused spaces in the total usable spectra. There are a number of ways to detect the unused spectrum/holes/white spaces like Energy Detection, Matched Filter Detection, Cyclostationary Feature Detection (CFD), Wavelet Transform, Filter Bank, Eigenvalue based Detection, Covariance based Method, Multiple antenna method and Multitaper Method. In this paper, a spectrum sensing technique is proposed which is based on the cyclostationary spectrum sensing in multiple antenna cognitive radio by Maximal Ratio Combining (MRC) method. Spectral Correlation Density (SCD) is computed by FFT Accumulation Method (FAM) to perform Cyclic Analysis. Simulation results show that CFD for lower SNRs as the proposed scheme can detect the primary user with a probability of 90 percent approximately at 20dB. [2]

C. Group-based Multi-bit Cooperative Spectrum Sensing for Cognitive Radio Networks (IEEE 2016)

In cooperative spectrum sensing, a multi-bit combination rule shows better sensing performance than one-bit hard combination rules at the sacrifice of the reporting overhead. In order to overcome the trade-off between the sensing performance and the reporting overhead, they proposed a group-based multi-bit cooperative spectrum sensing scheme with a limited reporting overhead. The proposed scheme uses contention based reporting for restraining the reporting overhead along with achieving multiuser diversity with an increased number of secondary users (SUs). Also, Secondary Users report one-bit sensing results to a fusion center instead of sending multi-bit quantization information and the rest of the information is embedded in the time slot. The simulation results declares that, as the number of SUs increases, the proposed scheme improves the sensing performance as well as the average throughput of SUs whereas the conventional one-bit or multi-bit combination schemes show a trade-off between the sensing performance and the throughput of SUs. [3]

D. Cyclostationary Detection Based Spectrum Sensing for Cognitive Radio Networks. (2015)

Cyclostationary detection Based spectrum sensing is used for cognitive radio networks. The already available first-order and second-order cyclostationary detection algorithms is precised, which can be thereafter used as a brief tutorial on detection theory of the cyclostationary signals. After this, a cooperative spectrum sensing method for a cognitive radio networks with multiple terminals and one fusion center is proposed. It is shown that the proposed method have reliable performance even in low signal-to-noise ratio (SNR) region. Also, the increasein number of secondary users (SUs) leads to improved detection performance, especially at low SNR. [4]

E. Simple Diversity Combining Techniques for Cyclostationarity Detection Based Spectrum Sensing in Cognitive Radio Networks(IEEE 2014)

Simple diversity combining techniques for cyclostationarity detection based spectrum sensing in cognitive radio networks is discussed. The provided techniques depends on maximum cyclic autocorrelation function (MCAS) techniques. The MCAS judges whether received signals include an orthogonal frequency division multiplexing (OFDM) signals or not, by comparing the peak and non-peak values of a cyclic autocorrelation function (CAF). The presented diversity techniques attempt to increase signal-to-noise ratio (SNR) of CAF which is composed of the peak and non-peak values of CAF. In the presented techniques, the CAF SNRs which obtained at some received antennas are combined whereas general diversity combining techniques combines some received signals. The presented results are compared with some conventional results, and computational and theoretical analysis results show that the presented techniques can improve the spectrum sensing performance. [5]

F. A Weighted Diversity Combining Technique for Cyclostationarity Detection Based Spectrum Sensing in Cognitive Radio Networks. (IEEE 2015)

A weighted diversity combining technique for the cyclostationarity detection based spectrum sensing of orthogonal frequency division multiplexing signals in cognitive radio is presented. In cognitive radio systems, secondary users must detect a desired signal in an extremely low SNR environment. In these environments, multiple antenna techniques like maximum ratio combining are not effective as energy of target signal is also not strong and it is difficult to obtain the signal synchronization of some of the received signals. For traditional cyclostationarity detection based spectrum sensing, they have used a cyclic autocorrelation function (CAF). In this paper, a CAF Signal to Noise Ratio is defined using the signal and noise components of the CAF, and we attempt to improve sensing performance to use a different weight for each component of the CAF. The presented results are compared with some conventional results and show that the presented technique can improve the spectrum sensing performance. [6]

G. Performance Analysis of Cyclostationary and Energy Detection Spectrum Sensing Techniques. (IEEE 2015)

The latest policies of spectrum allocation results in inefficient use of spectrum. In today's scenario dynamic spectrum access is the need and cognitive radio is a novel technology which improves spectrum utilization. In this paper cognitive radio along with spectrum sensing techniques is taken into account. Energy detection based spectrum sensing techniques and cyclostationary detection based spectrum sensing techniques are discussed in detail along with their block diagrams and flow charts. The paper also illustrates the performance analysis of energy detector over various fading environments viz. AWGN, Rayleigh, Rican and MIMO. Implementation of energy and cyclostionary detectors is performed using Matlab and their results are shown using graphical analysis with the help of ROC (receiver operating characteristics) curves. [7]

H. Experimental Analyses of Spectrum Sensing Using Cyclic Autocorrelation Function Diversity Combining Techniques in Cognitive Radio. (IEEE 2014)

Experimental analyses of spectrum sensing of an orthogonal frequency division multiplexing signal using cyclic autocorrelation function (CAF) diversity combining techniques in cognitive radio is discussed. Traditionally, the CAF diversity combining based spectrum sensing technique has been presented. The techniques is based on an equal gain combining and has a low computational cost in comparison with other cyclostationarity detection based spectrum sensing using space diversity. The paper provides the experimental results to validate the effectiveness of the CAF diversity combining technique. For experimental analyses, a testbed for the evaluation of multiple receive antennas based spectrum sensing is developed. The developed testbed is mainly composed of a Universal Software Radio Peripheral (USRP) / GNU Radio which is one of the software defined radio receiver, and the spectrum sensing technique is experimentally demonstrated at an anechoic chamber using 470710MHz frequency band allocated to ISDB-T (terrestrial digital broadcasting) in Japan. From these results, the effectiveness of the CAF diversity combining techniques is validated. [8]

I. *Performance of Cooperative Spectrum Sensing with Soft Data Fusion Schemes in Fading Channels. (IEEE 2013)*

Cognitive radio (CR) systems should have the ability to detect the presence of licensed primary user (PU) reliably. Cooperation among multiple CRs helps to enhance the reliability of detection of the PU in case of unreliable decision by a single CR due to channel uncertainties. In this paper, cooperative spectrum sensing (CSS) based on energy detection in cognitive radio networks (CRN) which uses soft combination of the observed energy values from different CRs is considered. More precisely, we study the performance of CSS with several soft data fusion schemes namely, (a) Square law selection (SLS) (b) Square law combining (SLC) (c) Maximal ratio combining (MRC) that can be applied at fusion center (FC). The performance of CSS has been assessed under several cases of sensing (S) channels such as AWGN, log-normal shadowing, Rayleigh and Rician fading channels. Comparative performance of CSS for various soft data fusion schemes under different fading channels has been studied for various values of average S-channel SNRs, time bandwidth products, different number of CRs. The effect of shadowing and fading parameters on missed detection performance of CSS is shown. Further, the performance comparison between soft data fusion schemes and hard decision fusion schemes is also highlighted. [9]

V. CONCLUSION

To efficiently utilize the wireless spectrum cognitive radios were introduced which utilize the holes present in the spectrum. The most important aspect of a cognitive radio system is spectrum sensing and various sensing techniques which it uses to sense the spectrum. Spectrum is an extremely important resource in wireless communication systems, and it has been a central point for research over the last decades. CR is one of the best solutions to utilize the available spectrum more efficiently through opportunistic spectrum usage. CSS is an efficient technique to improve detection performance by exploring spatial diversity at the outflow of cooperation overhead. 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. The performance of energy detection gets better with increasing SNR because of the increase in "probability of primary detection" from zero at -14 dB to 100% at +8 dB and correspondingly the "probability of false detection" improves from 100% to zero. The second-order cyclic features present in modulated signals is used to detect the signals.

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