COMPREHENSIVE ANALYSIS OF CYCLO-STATIONARY FEATURE DETECTION TECHNIQUE FOR EFFICIENT SPECTRUM USAGE:
FUTURE RESEARCH AND RECENT ADVANTAGES

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Abstract: Throughout the years various techniques were introduced to facilitate a better experience for communication channel users. Techniques like OFDM has enabled more efficiency, better performance, lower interface and many other advantages over previous techniques. But none of these techniques achieve maximum coverage of the spectrum. Cognitive radio is an intelligent approach to this situation. While there are various methods and theories that qualify to perform spectrum sensing in cognitive radio networks, cyclo-stationary sensing, energy detection and matched filter method stand out as the most used ones. In this paper we concentrate mainly on cyclo-stationary spectrum sensing under blind parameters and under OFDM modulation conditions. Simulation results of MATLAB code for the same are given as well.

Keywords: Cognitive Radio, Cyclo-stationary feature detection, Cooperative Sensing

I. Introduction

A) Brief description of cognitive radio networks
Communication technology has seen a rapid growth in the last decade with the emerging of 4G (that uses LTE systems and has enabled usage of voice calls and mobile data at the same time) and 5G (whose data speed is 10 times greater than that of 4G) which is being bought into use in various nations. With such advancements it is very important to consider the spectrum usage as well. While techniques such as OFDM/ OFDMA provide excellent voice quality and high speed, their spectrum usage is still limited to as less as 25% [2]. Thus, research for a technique that would cover maximum amount of the spectrum led to cognitive radio, introduced by Sir Joseph Mitola-III with Eleanor Maguire along-side in the year 1999.

The main function of cognitive radio revolves around spectrum sensing, detection; adjustment etc.cognitive radio differentiates all the users into two categories. The existing/ licensed user is called by the term primary user and the user that is requesting access to the spectrum is known as the secondary user [5]. Cognitive radio networks are designed in such a way that the same spectrum is shared by primary users and secondary users. Provided that the secondary users/ unlicensed users are certified under certain criteria and follow a protocol to ensure data security.
There are various approaches to spectrum sensing in cognitive radio networks. Comprehensive spectrum sensing and cooperative spectrum sensing are the most common ones. Comprehensive spectrum sensing maybe advantageous for wide band spectrums as it works by directly acquiring the compressed form of sparse signals which has most of the information contained in minimal parameters. This eases the recovery of original signal at receiver. But it is limited due to its randomness, uncertainty and slow structure [7].

On the other-hand in cooperative sensing every CR helps the others for sensing the spectrum effectively and in reduction of various sensitivity factors. This increases overall gain known as cooperative gain. For performance analysis of cooperative spectrum, we analyse the performance of the group rather than the individual CR.

The paper is coordinated in such a way that it explains the fundamentals of cooperative sensing whilst building up to the analysis of cyclo-stationary sensing technique. Section 2, gives an understanding of the classification of cooperative sensing, cooperative sensing models, elements of sensing and performance of detection. Section 3, thoroughly explains about various sensing techniques specifically cyclo-stationary feature detection. Section 4 gives a conclusion as to why cyclo-stationary is one of the best approaches to spectrum sensing and some information on possibility of future research regarding this topic.

II. Cooperative Sensing

A) Classification of cooperative sensing

Based on the connection between CRs and the method of functioning as a network, CRs can be classified into 3 types.

1. Centralized
2. Distributed
3. Relay Assisted

i) Centralized cooperative sensing network: Centralized CRN consists of a group of CRs connected to one central CR which regulates the information. Every CR in the network does the individual sensing and the results are reported back to the central CR which in turn analyses the data for primary user and sends the decision back to the CRs to act accordingly. The centralised CR is known as the fusion centre FC [12].

Three kinds of networks play an important role in the centralised technique. The connection established between the primary user and CR during the sensing is through the sensing channel. It is used when each CR is performing individual sensing operation and can be said as end to end connection between CR and PUs. The other type of channel is the connection established between CR and the fusion centre when the individual CR sends the data collected after sensing to the FCs for further intelligent decisions. this channel is known as reporting channel, an end to end connection between CR and FC.

Other than these, every CR is connected to one specific channel called the control channel that is important for reporting data. Usually for a cognitive radio ad hoc network, if there is an absence of fusion centre, any user from the CRN can take up the job of Fusion Centre.

ii) Distributed cooperative sensing network: This is just like the centralized CRN but the absence of Fusion centre. In this case the distributed CRs gather information and make an intelligent decision together. The work is done iteratively. Every CR does individual sensing and shares its data with fellow users in the transmission range with a special pre-programmed algorithm. Then this information is analysed based on the requirement and for the presence of primary users. If the channel is adaptable, then the CRs...
proceed with allotment. Else the CRs repeat the process again until effective decision is made by the CRs [19].

**iii) Relay assisted cooperative sensing network:** Relay assisted cognitive radio network is the effective approach compared to the above two. It is highly applicable when the CRN consists of CRs with both weak sensing channel and weak reporting channel. Imagine a CRN consisting of 5 CRs namely CR1, CR2, CR3, CR4, CR5. Assume that CR1 and CR2 have weak sensing channel while CR3 and CR5 suffer from weak reporting channel. In this case, CR1 and CR2 can act as relays and help transmit the sensing report to other CRs or Fusion Centre in case of centralized CRN. CR4 which has both strong sensing channel and reporting channel can also act as relay for CR3 and CR5 whilst reporting its data at the same time.

Further-more in distributed systems every CR that is intermediate is a relay for the CR from which it receives data.

**B) Elements of cooperative sensing**

Elements of cooperative sensing give us a better step by step idea of how the entire process of sensing, testing and concluding to a decision takes place. It’s a combination of various fields that might branch out too other specifications as well. The key elements of cooperative sensing are as follows:

1. **Cooperation models:** Parallel fusion network models, Game theoretical models.
2. **Sensing techniques:** These techniques include sensing/ reading the radio frequency environment, performing signal processing on the observed results to notice the presence of a primary user or a white space.
3. **Hypothesis testing:** This is the test that confirms the presence or absence of a primary user in the said spectrum and is performed in either primary block or advanced block or at both the stages.
4. **Control channel and reporting:** This is concerned with the transmission of the obtained report from the primary block to the advanced block/ fusion center by adjusting the bandwidth requirements and preventing fading as much as possible.
5. **Data fusion:** Process in which the reports from various CR users are combined by signal. **User selection:** Refer to effectively selecting the best CR user (and his data) and setting proper range to maximize gain and reduce cooperation overhead.
6. **Knowledge base:** This stores the information of the sensing (such as the most effective CR, presence of PU in a spectrum) for the further intelligent operations by the CRN. This can be previous knowledge such as knowledge gained from training of the CRN or can be the one gained from performing sensing operations multiple times.

The models of a cognitive radio network such parallel fusion model, game theory model etc., describe the functioning and cooperation between the CRs in the network.

**III. Sensing Techniques**

Spectrum sensing in a cognitive radio network is one of the most crucial part. It is required that the sensing is done with maximum accuracy to increase the cooperative gain. Another important aspect when it comes to spectrum sensing is the time taken. It always beneficial that the sensing is done in lowest time possible which will give the network extra time to further analyse the sensing results and report back with precision [20].

Based on characteristics of being coherent/non-coherent and narrow-band/wide-band, sensing techniques are categorized as follows: Energy detection technique, matched filter method and
cyclo-stationary feature detection stand as the most adapted techniques. This paper mainly focuses on cyclo-stationary feature detection however; a brief description of matched filter and energy detection is given later in the paper.

A) Cyclo-stationary feature detection:

Cyclo-stationary sensing is a wide sense stationary coherent process having a narrow band bandwidth. A process is said to be cyclo-stationary if the statistical properties of the signal vary cyclically with time [15]. These signals exhibit first order and second order statistics and wide sense cyclo-stationary signals fall under the category of second order statistics. Mathematically, wide sense cyclo-stationary signal can be written as

\[
\mu[x(t)] = \mu[x(t + T)] \text{ for all values of } t
\]

\[
R_{xx}(t, \tau) = \mu[x(t + T; \tau)] \text{ for all values of } t
\]

That is, the mean and auto-correlation will be same between two points of a random process and since noise is random and does not possess these properties, it is easy to differentiate between noise and signal.

System model: The block diagram of cyclo-stationary feature detection in a cognitive radio network is as shown below

![Fig.1. Block illustration of cyclo-stationary feature detection in cognitive radio network.](image)

The first-order statistics of cyclo-stationary signals give us temporal characteristic whereas; the second order statistics are based on graphical representation of spectral redundancy. When it comes to cognitive radio networks, second order statistics are the ones mostly preferred. In, synchronous averaging method is used to extract signal parameters [13]. Time synchronous method is a very effective way to reduce background noise. The waveform is first averaged in time buffer and then the fast Fourier transform is calculated and the signal is sampled by giving a trigger pulse as input. The input trigger pulse should be in synchronization with the periodicity of the signal and hence, it reduces the random noise. Therefore, after time synchronization, the second order cyclo-stationary signal’s auto-correlation function is given as

\[
R_{xx}(t, T) \approx \frac{1}{2N+1} \sum_{n=-N}^{N} x(t + \frac{T}{2} + nT_0) x^*(t - \frac{T}{2} + nT_0)
\]

Where \( t \) is the time period, \( T_0 \) is the period of cycle, \( N \) is number of samples.

The Fourier transform of the above equation yields

\[
R_{xx}(t, \tau) = \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} R_{xx}(t, \tau) e^{j2\pi n \tau/T_0} dt
\]

and the fourier coefficients can be obtained as

\[
R_{xx}^\alpha(t, \tau) \approx (x(t + \frac{T}{2}) x^*(t - \frac{T}{2}) e^{-j2\pi\alpha t})
\]

Where \( \alpha \) denotes second order cycle frequency and the primary user signal is

\[
S_x^\alpha(f) = \int_{-\infty}^{\infty} R_x^\alpha(\tau) e^{-j2\pi\tau f} d\tau
\]
Cyclo-stationary feature detection is a special form of sensing in which even at zero cyclic frequency, the auto-correlation function is not zero. At $\alpha = 0$, cyclic auto-correlation becomes usual auto-correlation.

In initial stages, the modulated signals are coupled with signals that exhibit cyclo-stationary behaviour, which induces periodicity in the signal. A noise in signal can be detected by spectral correlation function of primary user signal to read features like mean, auto-correlation etc [22], and this spectrum is a cyclic 2D spectrum [15]. From cyclo-stationary feature detection, we can guess the choice of modulation scheme, type of roll of factor used by the pulse shaping filter and other physical waveform characteristics of the filter [18]. This information will be gathered more accurately on cyclo-stationary feature detection, rather than in energy detection and matched filter approach. In, the probabilities of detection and false alarm over an Additive White Gaussian Noise (AWGN) channel are given as

$$P_D = 1 - (1 - Q\left(\frac{\sqrt{2\gamma}}{\sigma}, \frac{\lambda}{\delta}\right))^K,$$

$$P_{fa} = 1 - (1 - e^{-\frac{\lambda^2}{2\delta^2}})^K$$

Where $P_D$ and $P_{fa}$ are probabilities of detection and false alarm respectively, $Q$ is generalized Marcum function, $\sigma^2$ is the variance, $K$ is the number of branches in the network, $\gamma$ is the signal to noise ratio and $\lambda$ is threshold. $\delta$ is given as

$$\delta^2 = \frac{\sigma^2}{2N^1}; \text{ Where } N \text{ is the number of samples}$$

The above approaches are used while considering blind parameters. One of the most successful approaches was using cyclo-stationary feature of signals modulated by orthogonal frequency division multiplexing [24],[23].

**B) Cyclo-Stationary feature of OFDM signals:**

Recently, researches have been showing that the cyclo-stationary OFDM signals can be modified to get the required features; depicts how upon pilot induction, subcarrier mapping and Cyclic Delay Diversity the specified features are achieved, without the requirement of extending the spectral bandwidth as the decision information is embedded within the signals and can be delivered during the transmission itself.

In this approach, the CRs in the network are given a signature for identification and a mapping relation is constructed between these signatures and decision information [21]. It is a highly used technique and is also deployed in LTE and advanced LTE systems. The key functioning is obtained by first modulating the symbols by using OFDM technique, and then are shifted cyclically according to cyclic delay based on the number of antennas and in the final step, the cyclic prefix is added.

![Fig.2. Block illustration of cyclo-stationary feature detection in OFDM signals](image-url)
\[ S_x(f) = \frac{1}{\sqrt{N_A N}} \sum_{l=0}^{\infty} g(f - lM) \sum_{k=0}^{N-1} c_{l,k} W_N^{k \Delta f T} W_N^{k(l+1)M-f}, \]

Where \( W_N = e^{j2\pi/N} \) and \( M \) is dependent on length of cyclic prefix.

And the function \( g(n) \) can be given as,

\[ G_{[0,M-1]}^N = \begin{cases} 1, & n = 0,1,2, ... M-1 \\ 0, & \text{elsewhere} \end{cases} \]

Where data symbols are said to be independent statistically. The system is considered to be MISO i.e., multi-input single-output, as there will be a single receiver antenna at the receiver end which is the fusion centre [17]. The further details of data analysis and hypothesis testing of this are mentioned in [Error! Reference source not found.].

C) Energy detection and Matched filter sensing techniques:

Energy detection technique: Energy detection sensing method calculates the energy of the received \( N \) sample. Now the square magnitude of FFT average of those \( N \) samples should be compared with the threshold to detect the primary users. If the energy calculated using FFT of \( N \) samples is higher than the threshold then it concludes that primary user is present if not the primary user is absent. This sensing technique is very simple and easy as it does not require any prior knowledge about the primary signal. But there is a high chance of false alarm in this technique, as the noise signals with the energy of primary signal might lead to a false information that the primary user is present in the channel while in reality the spectrum is available for use [18],[19]. The performance of this technique is highly dependent on noise which is random thus using a static threshold may degrade the performance of energy detection. Hence, in order to perform a successful sensing it is required to have a prior knowledge of the noise type, which may not be possible in all conditions.

Matched filter detection technique: Matched filter is one of the superlative methods of detection of primary users when the transmitted signal is known before. This technique does not require much time and the detection process is done in less amount of time when compared with other techniques. This is main advantage of matched filter detection. It is a coherent method because it is required to know the information of primary user before starting the process. So, this method is very veracious and it increases the received SNR. The main disadvantage of this method it requires a lot of power and prior knowledge of PU transmission signal modulation order, the modulation type, the pulse shape and the packet format. Alternatively, if this information is not precise, then the matched filter will not work properly and also it requires extra hardware on nodes for synchronization with PU’s.

IV. Simulation Outputs and Observations

Fig 3 depicts the possibility of sensing error under various conditions. Sensing results is considered to be errored if the results display a false alarm or miss the presence of a primary user in the spectrum.
Fig 3: sensing error possibility in Rayleigh fading and AWGN channel under different SNR.

From the figure 3, it could be said that the system works better in AWGN channel than in Rayleigh fading channel. It is also observed that at high SNR i.e., at 10dB, sensing error is always as low as 0.1. But in low SNR conditions, the possibility of error is highest. But in comparison with other techniques, this process has shown to have better performance, if the channel is adjusted accordingly.

From fig 4, it is observed that noise certainty affects the performance of the network. But it is still possible to perform sensing with noise uncertainty unlike matched filter or energy sensing where it is necessary to know about possible noise in the channel. In comparison with fig 3, we can say how the knowledge about the noise in the channel and how particular noise, affects the performance of the channel.

Fig 4: effect of noise uncertainty on the signal for various SNR conditions.
Fig 5: probability of detection and false alarm under two different SNR conditions.

The above figure shows the performance of the channel i.e., successful detection of primary user or false alarm. For SNR of 5dB, the probability of detection is increasing linearly with the probability of false alarm and the probability of detection has highest value of 1 whereas the probability of false alarm falls behind, meaning high chances of successful sensing. Fig 5, shows how at even low SNR levels, the probability of detection is high.

V. Conclusion

As cyclo-stationary feature detection is vigorous to noise uncertainties it performs better than energy detection in low SNR regions. Cyclo-stationary process is capable of determining the CR transmissions from various type PU signals. This eliminates the process of synchronization which is used in energy detection of cooperative sensing. Besides the CR user may not be able to be implicit during the cooperative sensing and this improves the overall CRN performance. Though this process takes long time, it still reduces noise complexity. There are on-going researches on sensing by combing two or more techniques such as Cyclo-stationary feature detection and energy detection. But the channel through-put in these cases is almost the same as cyclo- stationary feature detection. But there are chances of getting a better spectrum sensing technology if the studies continue. There is a possibility of finding the perfect technique which might be adaptable as well.

References


