Simulink based Cooperative (Hard Decision Fusion) and Non-Cooperative Spectrum Sensing in Cognitive Radio Using Cyclostationary Detection

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Abstract:*Radio frequency spectrum is a quite limited resource. With the increased dependence on modern wireless devices, the management and proper utilization of the spectrum has become a major challenge. The concept of cognitive radio aims to overcome these problems by helping to achieve improved spectral management, utilization, and efficiency. To sense the unoccupied spectrum gap is one of the essential tasks of cognitive radio. There are many spectrum sensing algorithms available for cognitive radio. This paper describes cyclostationary based detection method of cooperative and non-cooperative spectrum sensing for cognitive radio. The fusion method used for the cooperative sensing is the hard fusion detection method. Cyclostationary based detection method is used to sense the unoccupied spectrum gap through cyclic autocorrelation function in Simulink.. We also spoke about the basics of Cognitive Radio and implemented Simulink models for both Cooperative and Non-Cooperative spectrum sensing methods. Also the merits and demerits of the Cyclostationary Detection technique has been mentioned. In this research paper all these things have been discussed.*

Keywords: Spectrum Sensing, Cognitive Radio, Non-Cooperative, Cooperative, Hard Decision Fusion, Cyclostationary Detection, Simulink, etc.

1. Introduction

For the past few years, radios have been evolving and getting smarter. The communication systems that are in use today are able to adapt and alter in varying hostile conditions, depending on diverse variables to maintain connectivity. For example, 3G devices change their output power to make sure that power imbalances between different users do not take place. A cognitive radio is one such adaptive device and is considered to be very smart with decision making capabilities [1]. It is known to be an artificial brain capable of making decisions to sense, share and mobilize the channels in the spectrum. This also aids in analyzing the spectrum [2].

Dynamic Spectrum Access is often used alongside Cognitive Radio. Dynamic Spectrum Access involves sharing of the spectrum between the primary and secondary users [3]. The primary or licensed user is given priority as they hold the license. The secondary user is given permission to make use of the spectrum whenever the primary user is not active. The moment the primary user accesses the spectrum, the secondary user has to shift to an unused portion of the spectrum.

Cognitive Radio can find applications in various fields ranging from the military to the public safety domain. There is a mixture of centralized and decentralized networks, heterogeneous systems that need to interoperate with each other. Many of these systems need to be deployed in extremely hostile conditions. Networks might need to use varying amounts of bandwidth either temporarily or for longer durations. Cognitive Radio makes initial deployment easier by facilitating self-configuration of networks wherever possible with suitable architectures [4]. In places where rapid deployment is a necessity, any reduced manual configuration is a welcome move.

Spectrum Sensing is a key aspect of Cognitive Radio. Our objective is to utilize the empty channels in the spectrum to reduce the traffic in congested areas. Proper sensing forms the backbone of this software defined radio. Also, communication should not be marred by fading. Spectrum sensing in cognitive radio is applicable to radio frequencies only. Observing the unused spectrum of a licensed user is crucial to a cognitive radio. So, the primary user (PU) is sensed perpetually to allow channel mobility to another part of the spectrum; in case the primary user initiates to transmit [5]. This calls for an efficient hardware with negligible error percent. The threshold for detection forms the crux. This should be in consideration of the interference in the worst-case scenario. In sensing the primary user correctly, future spectrum analysis and decision making processes are assisted. It can be said as managing the spectrum dynamically [6].

Spectrum sensing methods are energy detection based, matched filter detection based and cyclostationary feature based [7]. Cyclostationary feature detection is concerned with the cyclically varying property or the periodicity in signal pattern. This periodicity is exhibited by primary user signal and hence can be taken advantage of, for our estimation analysis. The cyclostationary behavior preordained can be used to establish the probability of the presence of the signal [8]. This work tries to achieve sensing of this loose spectrum based on cyclostationary method.

2. Cognitive Radio

Cognitive radio technology is the key technology that enables a Next Generation (xG) network to use spectrum in a dynamic manner. The term, cognitive radio, can formally be defined as follows [9]:

A ''Cognitive Radio'' is a radio that can change its transmitter parameters based on interaction with the environment in which it operates.

From this definition, two main characteristics of the cognitive radio can be defined [10, 11]:

1. Cognitive capability: Cognitive capability refers to the ability of the radio technology to capture or sense the information from its radio environment. This capability cannot simply be realized by monitoring the power in some frequency band of interest but more sophisticated techniques are required in order to capture the temporal and spatial variations in the radio environment and avoid interference to other users. Through this capability, the portions of the spectrum that are unused at a specific time or location can be identified. Consequently, the best spectrum and appropriate operating parameters can be selected.
2. Reconfigurability: The cognitive capability provides spectrum awareness whereas reconfigurability enables the radio to be dynamically programmed according to the radio environment. More specifically, the cognitive radio can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design [12].

The cognitive radio concept was first introduced in [13, 14], where the main focus was on the radio knowledge representation language (RKRL) and how the cognitive radio can enhance the flexibility of personal wireless services. The cognitive radio is regarded as a small part of the physical world to use and provide information from the environment.

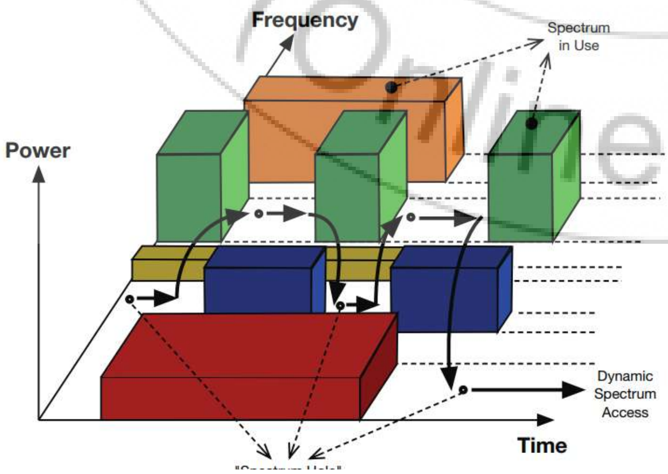

Figure 1: The Spectrum-Hole Concept

The ultimate objective of the cognitive radio is to obtain the best available spectrum through cognitive capability and reconfigurability as described before. Since most of the spectrum is already assigned, the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users as illustrated in Figure 1. The cognitive radio enables the usage of temporally unused spectrum, which is referred to as spectrum hole or white space [10]. If this band is further used by a licensed user, the cognitive radio moves to another spectrum hole or stays in the same band, altering its transmission power level or modulation scheme to avoid interference as shown in Figure 1.

3. Spectrum Sensing

One of the main important features of CR is to sense the spectrum. Spectrum sensing is essential task of CR to detect the existence of primary user. These techniques depend on transmitter parameter, i.e. at which frequency the transmitter is operating [15]. A hypothetical model for transmitter detection techniques [16] are:

$$\begin{aligned} y(t) &= n(t), \text{when PU is absent} \\ y(t) &= Ax(t) + n(t), \text{when PU is present} \end{aligned} \tag{1}$$

In eq. (1),*x(t)* is the signal transmitted by primary user, *n(t)* is additive white Gaussian noise (AWGN), A is the amplitude of channel and *y(t)* is the signal received by the secondary user (SU) [16]. Spectrum sensing algorithm is classified in different methods which are Matched filter, Energy detector, Cyclostationary feature detection, and other sensing techniques [15].

4. Types of Spectrum Sensing

4.1 Non-Cooperative Spectrum Sensing

The PUs signal are detected independently by each CR user in non-cooperative spectrum sensing. The presence and absence of PUs are individually determined and acted upon accordingly by each CR user. As shown in Figure 2, CR users detect primary signal and decide on their own whether the signal is present or absent. However, this technique cannot detect the primary signal properly due to fading and shadowing. In the Figure 2, CR User-2 can detect primary transmitter signal more accurately than the other users because CR User-2 detects the signal in the line of sight (LOS) condition [5].

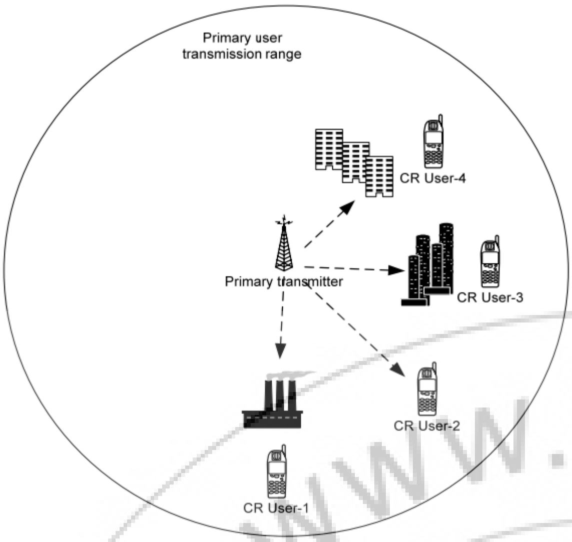

Figure 2: Non-Cooperative Spectrum Sensing

4.2 Cooperative Spectrum Sensing

Cooperation is proposed as a solution to problems that arise in spectrum sensing due to noise uncertainty, fading, and shadowing. The probabilities of miss-detection and false alarm considerably decreases in cooperative sensing. Also, the hidden primary user problem can be solved and the sensing time can be decreased using cooperation sensing [18, 19].

In this technique, the cognitive radio users are populated in the range of primary transmitter to perform its individual signal detection using some detection methods and determine the reliability of its own detection results. We adopt the hard decision fusion method for this evaluation, in which the users send a binary local decision to the data fusion center (FC).

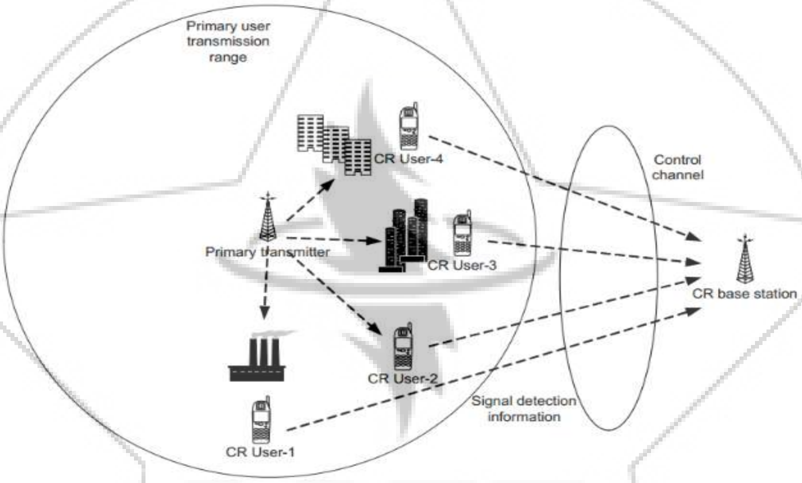

Figure 3: Cooperative Spectrum Sensing

Figure 3 shows the system model of cooperative signal detection where only one cognitive radio user could be able to detect the primary signal. The other cognitive radio users are not able to distinguish existence of the primary signal by fading and shadowing effect. The users are populated in the range of primary transmitter. Under this condition, it is expected that it can improve the signal detection probability. Collaboration amongst cognitive radio users is theoretically more accurate and convenient.

In order to improve the probability of signal detection, the data fusion center collects local signal detection information of each cognitive radio users and performs final decision in accordance with the decision rules.

There are two types of fusion rules in the case of cooperative spectrum sensing. Hard decision and Soft decision. In this paper, we have presented the hard decision fusion for the cooperative sensing method. In this scheme, each user decides on the presence or absence of the primary user and sends a one bit decision to the data fusion center. The main advantage of this method is the fact that it needs limited bandwidth [20].

5. Spectrum Sensing Techniques

There are various spectrum sensing techniques which are employed for spectrum sensing such as:

5.1 Matched Filter Detection

The matched filter (also referred to as coherent detector), can be considered as a best sensing technique if CR has knowledge of PU. It is very accurate because it maximizes the received signal-to-noise ratio (SNR). Matched filter correlates the signal with its time shifted version. Comparison between the final output of matched filter and predetermined threshold will determine the PU presence. Hence, if this information is not accurate, then the matched filter operates weakly.

5.2 Cyclostationary Feature Detection

Implementation of a Cyclostationary feature detector is a spectrum sensing technique which can differentiate the modulated signal from the additive noise. A signal is said to be Cyclostationary if its mean and autocorrelation are a periodic function. Cyclostationary feature detection can distinguish PU signal from noise, and used at very low

Signal to Noise Ratio (SNR) by using the information present in the PU signal that are not present in the noise.

5.3 Energy Detection

Energy detection is the most popular way of spectrum sensing because of its low computational and implementation complexities. The receivers do not need any knowledge about the primary users. An energy detector (ED) simply treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal.

6. Cyclostationary Detection

Man-made signals are normally not stationary but some of them are cyclostationary, showing periodicity in their statistics. This periodicity can be utilized for the detection of a random signal which has a particular modulation type in a background of noise. Such detection is called cyclostationary detection. The signal of the PU can be detected at very low SNR values if it exhibits strong cyclostationary properties. If the autocorrelation of a signal is a periodic function of time *'t'* with some period then such a signal is called cyclostationary and this cyclostationary detection is performed as follows:

$$Rx(\tau) = E[x(t+\tau)x*(t-\tau)\,e\text{^}(-j2\pi\alpha t)] \qquad (2)$$

In eq. (2), *'α'* is cyclic frequency and *E [.]* is the statistical expectation operation. The spectral correlation function (SCF) denoted by *S(f, α)*, also called the cyclic spectrum is obtained by computing the discrete Fourier transformation of the cyclic autocorrelation function (CAF).

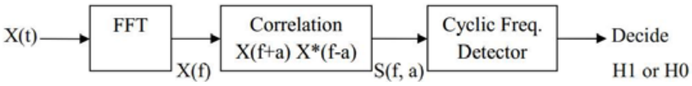

Figure 4: Cyclostationary Detection Method

Detection is completed finally by searching for the unique cyclic frequency corresponding to the peak in the SCF plane. This approach is vigorous to interference and random noise from other modulated signals, because different modulated signals have different unique cyclic frequencies while noise has only a peak of SCF at zero cyclic frequency. The implementation of this method for spectrum sensing is shown in Figure 4.

7. Simulations and Results

Figure 5 gives the Simulink based model for non-cooperative systems using cyclostationary detection. First, the input signal is given to the AWGN channel.

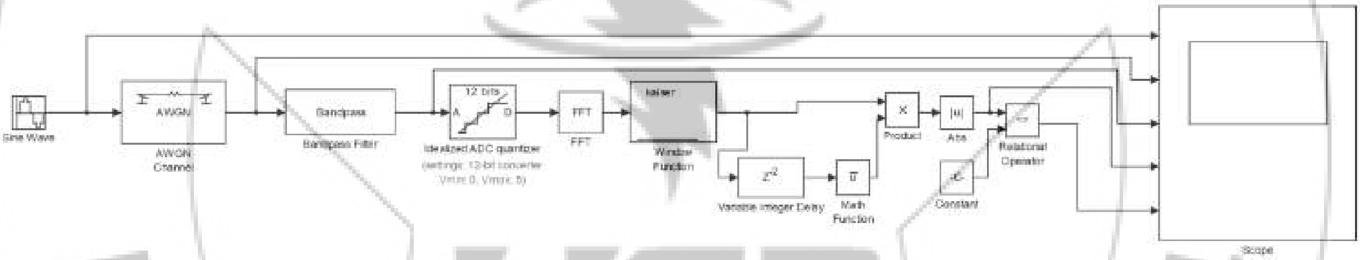

Figure 5: Simulink model for non-cooperative sensing using Cyclostationary detection

The Additive white Gaussian noise (AWGN) is a basic noise model or also used as a channel model that occur in nature with constant spectral distribution. Additive because it is added to any noise. White because it has uniform power across the frequency band. Gaussian because it has a normal distribution in the time domain. The AWGN channel is a good model for many satellite and deep space communication links [17].

After that, the signal is passed through a band-pass filter. Here, band-pass filter is used to pass particular band of frequency and reject the frequencies outside that range. The main function of a filter in a transmitter is to limit the bandwidth of the output signal to the band allocated for the transmission. Then it is converted into a digital signal by quantization. Quantization is the process of mapping a large set of input values to smaller set, such as rounding values to some unit of precision. After that, the signal is passed through the FFT block which convert the time domain signal into a frequency domain signal.

Windowing technique is used for reducing undesirable oscillation in the band. After windowing, function signal is processed for autocorrelation function. In this autocorrelation function, the signal correlates with itself. The product block is used so that the signal can be multiplied with its conjugate function. Then, the absolute value of the signal is compared with a predetermined threshold value for detecting the primary user. The threshold is set to $7.5x10^5$ and if the user crosses the threshold value, only then the user is present, otherwise the user will be idle (spectral holes) and at that instant the secondary user can utilize that space.

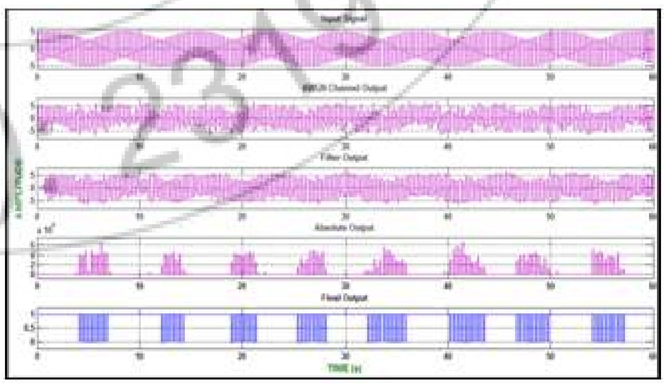

Figure 6: Simulation results (scope) from the non-cooperative spectrum sensing model

Figure 6 gives the simulation results (display of the scope), which shows the original transmitted signal, the output of the

AWGN channel, the output of the band-pass filter, the magnitude of the modulated signal, and finally the output after the signal has been compared with the pre-determined threshold value.

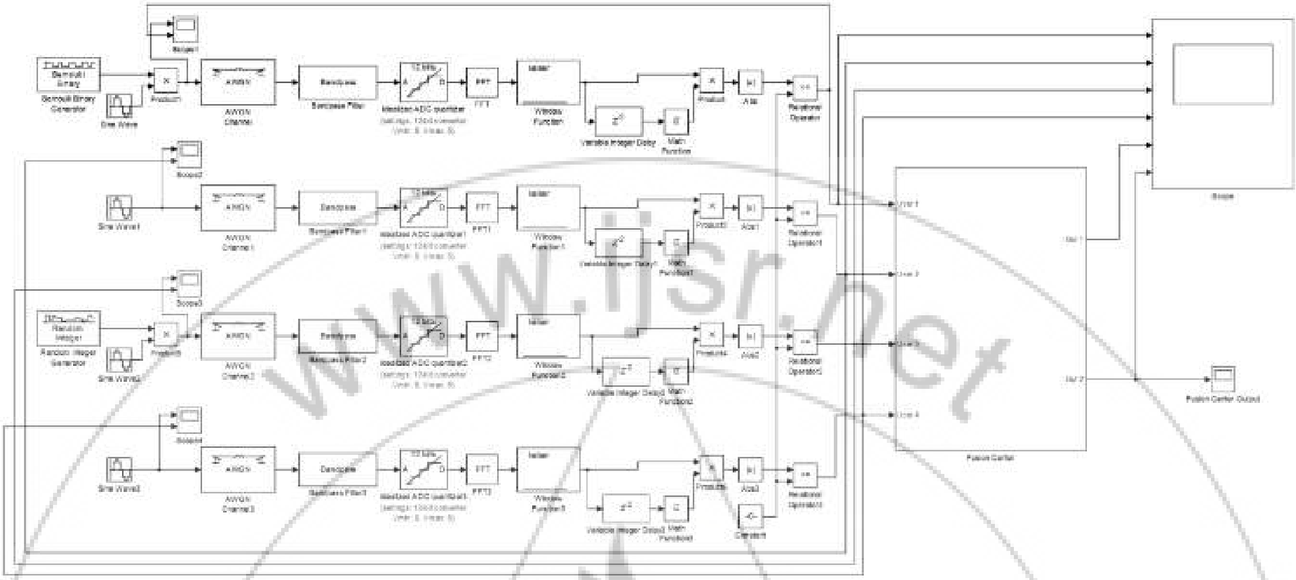

Figure 7: Simulink model for Hard Fusion Cooperative Spectrum sensing, showing 4 users and the Fusion Center

Figure 7 shows threshold comparison of 4 users using cyclostationary detection (CD) method. There are 4 users with different signal values which are compared with the threshold value. The threshold value is set at $7.5\times10^5$and it is generated using a 'constant' block. The 'Relational Operator' block compares the input signal value with threshold signal value and the difference of both values is shown on the Scope for each of the 4 users in Figure 8. The combination of signals received by the FC before any decision and the output result of Hard Decision (AND) fusion Cyclostationary Detection method for cooperative sensing is also shown in Figure 8.

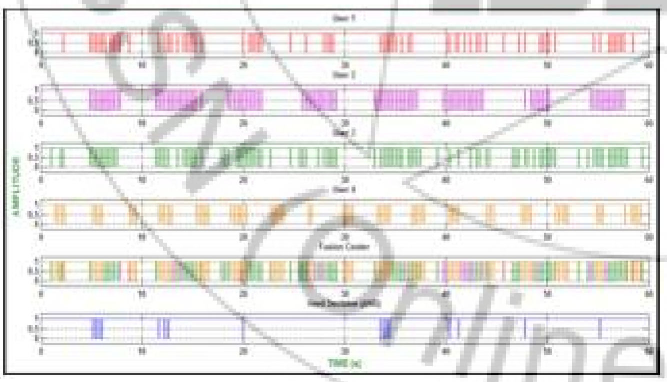

Figure 8: Simulation results (scope) for the cooperative model. The output from each of the 4 users are shown. The combination of the signals at the Fusion Center (FC) before any decision is applied is also shown, and in the end is the output after the AND fusion decision is applied.

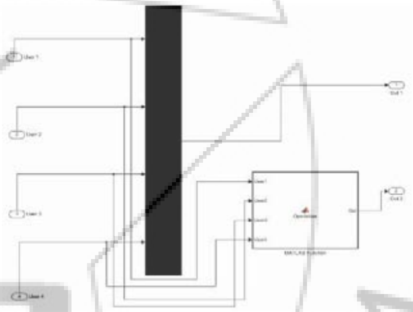

Figure 9: Inside the 'Fusion Center' block subsystem. The AND or OR operation for Hard Fusion Decision is performed by changing the algorithm in the 'MATLAB Function' block.

The 'Fusion Center' subsystem block of Figure 7 has been shown in detail in Figure 9. We have used a 'MATLAB Function' block in which the necessary algorithms can be written using MATLAB codes to perform the AND or OR operation of the Hard Decision Fusion Method.

8. Future Scope

Digital Television (DTV) worksby adopting the methodology of the cognitive radio and utilizes the TV spectrum white spectrum.It is the transmission of audio and video by digitally processed and multiplexed signal in contrast to the totally analog and channel separated signals used by analog television. It is an innovative service that represents the first significant evolution in television technology since color television was invented in the 1950s.

Our future work will mainly concentrate on exploring the prospects, and overcoming the challenges of introducing cognitive radio technology, and in turn, the DTV in the developing countries.

9. Conclusion

In this paper we have implemented Simulink based spectrum sensing using Cyclostationary Detection technique. The cyclostationary detection is first shown for a single user (Non-Cooperative) and then the process is carried out for 4 users transmitting different types of signals (Cooperative). The final output for both types is shown in blue. The presence or absence of the primary user is decided based on the threshold. The merits of the Cyclostationary Detection technique is that it is robust in low SNR and robust to interference, whereas the demerits of this technique is that it requires partial information of the primary user and that it has a high computational cost.

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