# Simulink based Cooperative (Hard Decision Fusion Method) and Non-Cooperative Spectrum Sensing in Cognitive Radio using Energy Detection Technique

Ikram Ilyas, Niger Fatema, Dr. Md. Abdur Rahman

**Abstract**— Resources such as the radio frequency spectrum is quite limited. Very often, this resource is not efficiently managed and the increased dependence on wireless devices in the modern era just adds to the problem. The concept of cognitive radio aims to overcome these problems by helping to achieve improved spectral management, utilization, and efficiency. One of the ways to improve the efficiency and utilization of an available frequency spectrum is to share it between the users. One of the most important step for spectrum sharing is spectrum sensing. Our research work has been concentrated upon the various spectrum sensing techniques, and in this paper, we have discussed about the Energy Detection Technique of Spectrum Sensing. We spoke about the basics of Cognitive Radio and implemented Simulink models for both Cooperative and Non-Cooperative spectrum sensing methods, and presented the achieved results. We have used the Hard Decision Fusion Method for Cooperative sensing. Also the merits and demerits of the Energy Detection technique has been mentioned. In this research paper all these things have been discussed.

**Index Terms**— Cognitive Radio, Cooperative, Energy Detection, Hard Decision Fusion, Non-Cooperative, Spectrum Sensing, Simulink, etc.

## 1 Introduction

MODERN wireless systems are capable of offering a wide variety of high data rate applications to various users at the same time. In order to realize this objective, they have to overcome the practical constraints imposed by the resources they need such as power and spectrum. But these resources are quite limited in nature. The rapid increase in the number of wireless systems and the scarcity of these resources, especially of the frequency spectrum, continues to be a problem.

Cognitive radio is a concept that aims to overcome these very problems by proposing an opportunistic spectrum usage [1] approach, in which the frequency bands that are not being used by their licensed users can be utilized by cognitive radios. Since cognitive radios do not need a license and they do not affect the operation of licensed systems, this approach leads to a highly economic and efficient usage of the frequency spectrum. The Federal Communication Commission (FCC) research report [2] show that, seventy percent of the allocated spectrum is under-utilized. So we need a technique to deal with the problem of spectrum under-utilization. Cognitive radio can sense external radio environment and use past information [3-4]. It can use the unused spectrum band dynamically without affecting the primary users.

The basic function of a cognitive radio is to sense the spectrum precisely by evading any chances of hindrance or interference to the primary or licensed users. By using spectrum sensing, cognitive radios can adapt themselves to the eternal wireless network. All the cognitive radio users can be divided into primary users (PU) and secondary users (SU). PU can be defined as the user who has the license to use a specific band of the spectrum. On the other hand, secondary users (SU) do have license to use the spectrum but can use the spectrum when the PU is absent. When the PU is present, the SU shifts its transmission to another frequency or changes their modulation parameters and never causes interference to primary users.

Various techniques have been used for identifying the presence of the PU signal transmission. The existing spectrum sensing techniques can be broadly divided into three categories: energy detection, matched filter detection, and cyclostationary detection [5-6]. Among them, energy detection technique has been mostly applied because it does not require any prior knowledge of the primary signals and has much lower complexity than the other two schemes.

## 2 Cognitive Radio

A Cognitive Radio is an adaptive multi-dimensionally aware intelligent wireless communication system that learns from its experience to reason, plan and decide future actions required to meet the consumers' needs.

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The two important characteristics of a cognitive radio are:

1. Cognitive capability- Cognitive capability refers to the ability of the cognitive radio technology to capture or sense the information from its radio environment.
2. Reconfigurability- Reconfigurability enables the cognitive radio to be programmed dynamically according to the radio environment [7].

Cognitive Radio mainly performs four functions:

1. Spectrum Sensing- Cognitive Radio continuously looks for the unused spectrum which is known as the spectrum hole. This property of cognitive radio is termed as spectrum sensing.
2. Spectrum Management- Once the spectrum holes are found, the cognitive radio selects the available hole or channel. This property of cognitive radio is termed as spectrum management.
3. Spectrum Sharing- Cognitive Radio allocates the unused spectrum (spectrum hole) to the secondary (cognitive) user, as long as primary user does not need it. This property of the cognitive radio is termed as spectrum sharing.
4. Spectrum Mobility- Cognitive Radio vacates the channel when a licensed (Primary) user is detected. This property of cognitive radio is termed as the spectrum mobility.

## 3 Spectrum Sensing

Spectrum Sensing is a key aspect of Cognitive Radio. The 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 is sensed perpetually to allow channel mobility to another part of the spectrum; in case the primary user initiates to transmit [8]. 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 [9].

## 4 Types of Spectrum Sensing

### 4.1 Non-Cooperative Spectrum Sensing

In non-cooperative spectrum sensing, PUs signal are detected independently by CR user. Each user determines the presence and absence of PUs individually and acts accordingly. As shown in Fig. 1, 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. As shown in the Fig. 1, 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 [10].

### 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. Cooperative sensing decreases the probabilities of miss-detection and false alarm considerably. In addition, cooperation can solve hidden primary user problem and it can decrease the sensing time [11-13].

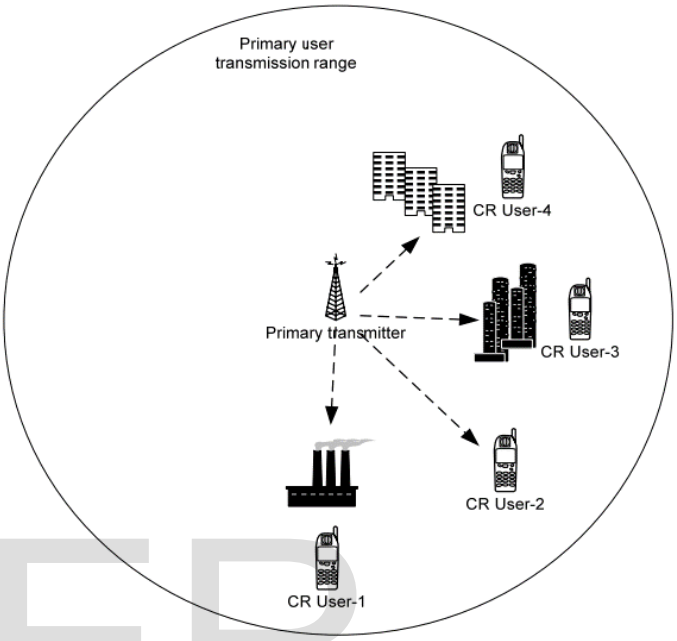



Fig. 1. Model of Non-Cooperative Technique

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).

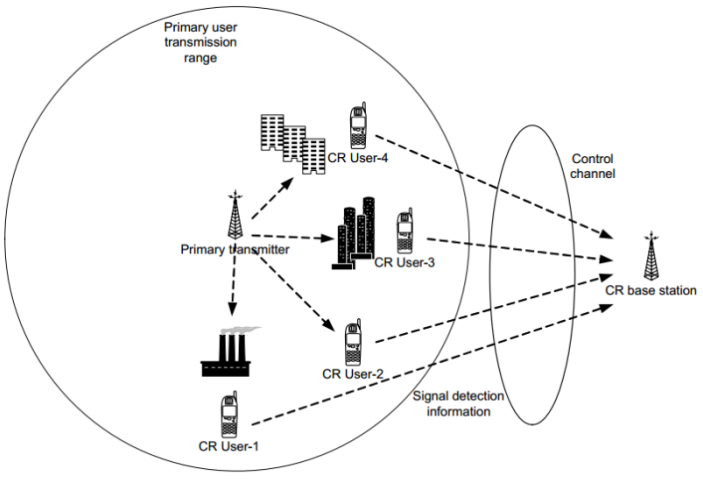



Fig. 2. Model of Cooperative Technique

Fig. 2 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 [14].

## 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 Energy Detection

If the previous information of the PU signal is anonymous, then this energy detection method is optimal for detecting any zero-mean constellation signals [15]. In this energy detection approach, in order to determine whether the channel is occupied or not, the received signal strength indicator (RSSI) or radio frequency (RF) energy in the channel is measured. The implementation of this method for spectrum sensing is shown in Fig. 3.

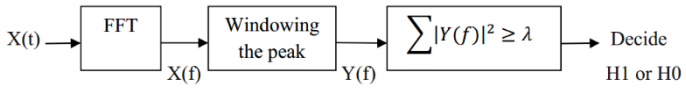



Fig. 3. Energy Detection Method

Firstly, in order to select the bandwidth of interest; the input signal is filtered by a band-pass filter. After getting the square of the output signal, it is integrated over the observation interval. At the end, the output from the integrator is compared to a predetermined threshold value to conclude the presence or absence of the PU signal. The received signal *X(t)* is sampled in a time window are first passed through an FFT device, in order to get the power spectrum *X(f)*. Then the peak of this power spectrum is located, and after windowing the peak of the spectrum, we obtain *Y(f)*. Then the signal energy in the frequency domain is collected and the following binary decision is made:

$$H1, \quad if \sum |Y(f)|\hat{}2 \geq \lambda$$
$$H0, \quad otherwise$$

Though the merit of this method is that it can be implemented without prior knowledge of PU, it still has some drawbacks also. The first hitch is that it shows poor performance under low SNR conditions, because at low SNR, noise variance is not accurately known [15]. Another issue is the inability to differentiate between the primary user and the other secondary users which are sharing the same channel [16]. The threshold selection is also knotty since it is highly vulnerable to the changing background noise and interference level.

## 7 Simulations and Results

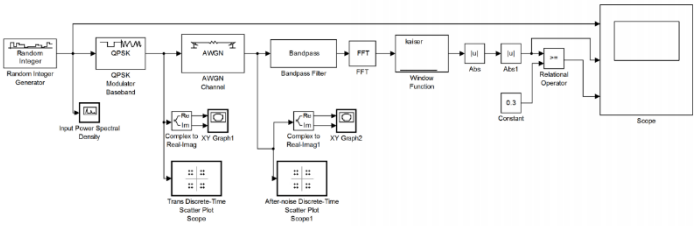
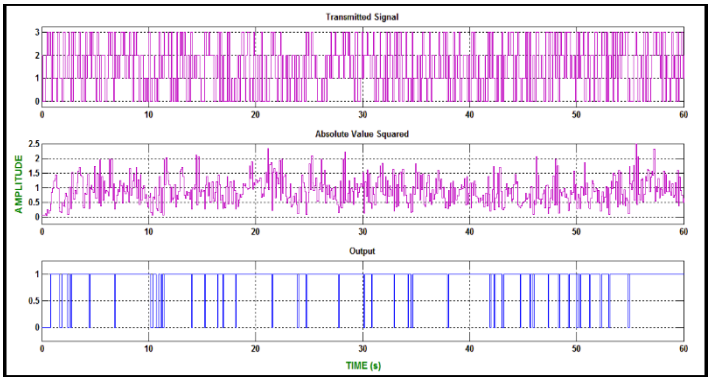


Fig. 4. Simulink model for non-cooperative spectrum sensing using energy detection

Fig. 5. Simulation results (scope) from the non-cooperative spectrum sensing model. The final output is shown in blue.



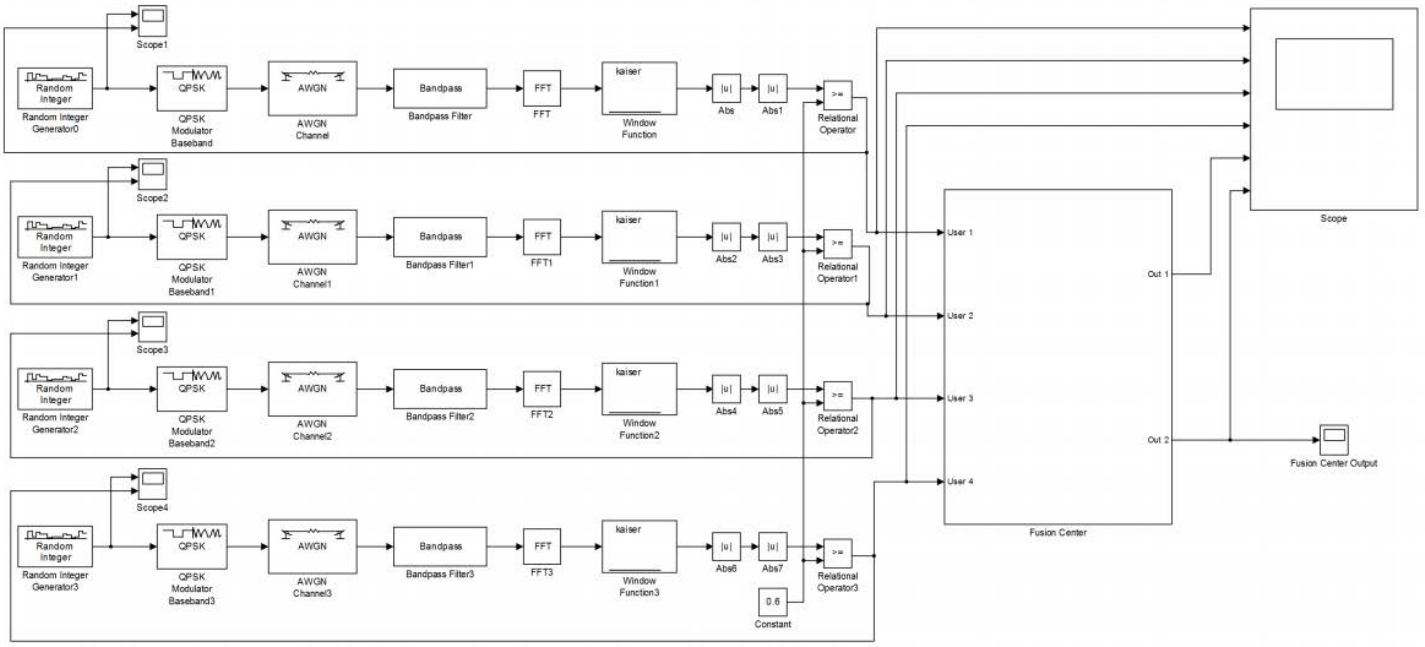



Fig. 6. Simulink model for Hard Fusion Cooperative Spectrum sensing, showing 4 users and the Fusion Center (FC)

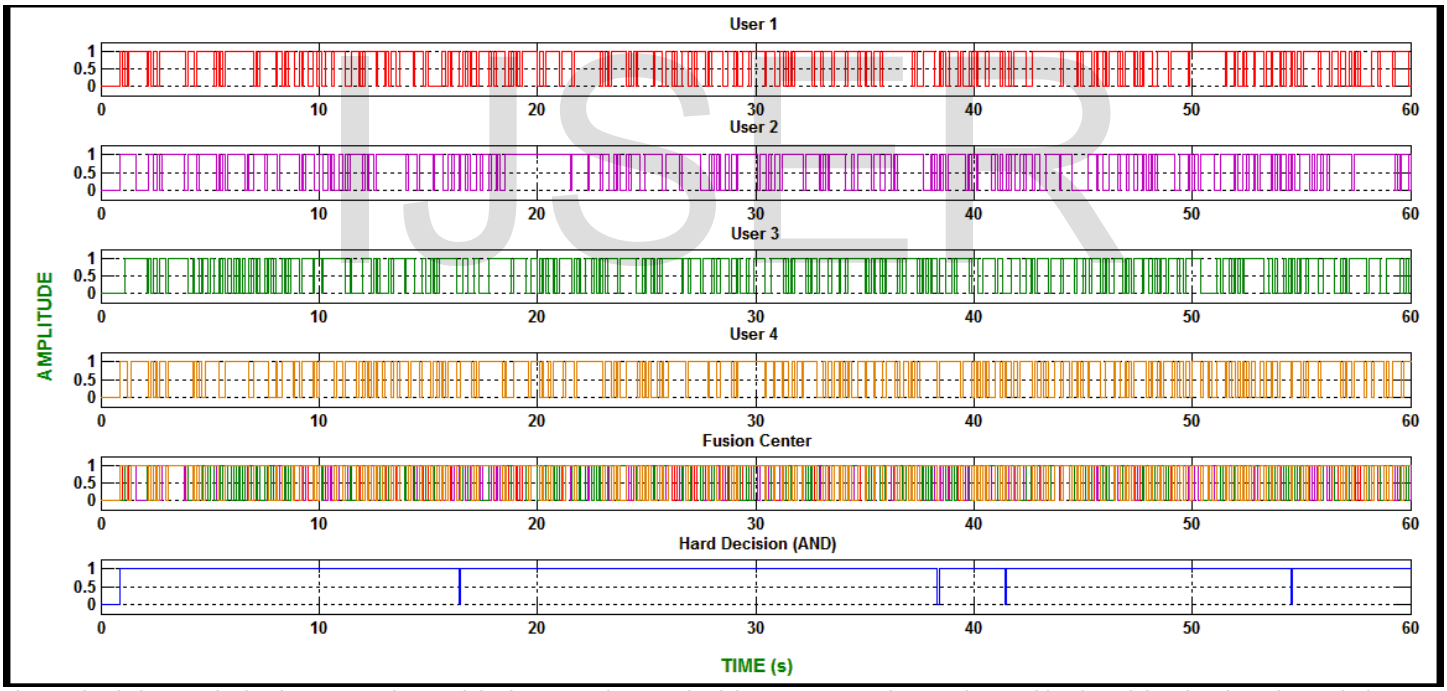



Fig. 7: Simulation results for the cooperative model. The output from each of the 4 users are shown. The combination of the signals at the FC before any decision is taken is also shown and in the end (in blue) is the output after the AND fusion decision occurs.

Fig. 4 gives the Simulink based model for energy detection using for non-cooperative systems. Here, a random integer generator is used as the input signal and then is QPSK-modulated before passing through the AWGN channel. This output is then passed through a band-pass filter and an FFT to get the corresponding coefficients. The signal is converted from time domain to the frequency domain by the FFT block. The magnitude of the received signal is then taken and it is squared.

A minimum amount of signal is considered to be noise. The received signal is assumed to be present if and only if the threshold is crossed. This is done with the help of a relational operator.

Fig. 5 shows the simulation results (display of the scope), which shows the original transmitted signal from the random integer generator, the squared magnitude of the modulated signal, and finally the output after the signal has been compared with the pre-determined threshold value. The threshold

is set to 0.3 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.

Fig. 6 shows threshold comparison of 4 users using energy detection (ED) method. There are 4 users with different signal values which are compared with threshold value. Threshold value is set at 0.6 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 Fig. 7.

The combination of signals received by the FC before any decision and the output result of Hard Decision (AND) fusion Energy Detection method for cooperative sensing is also shown in Fig. 7.

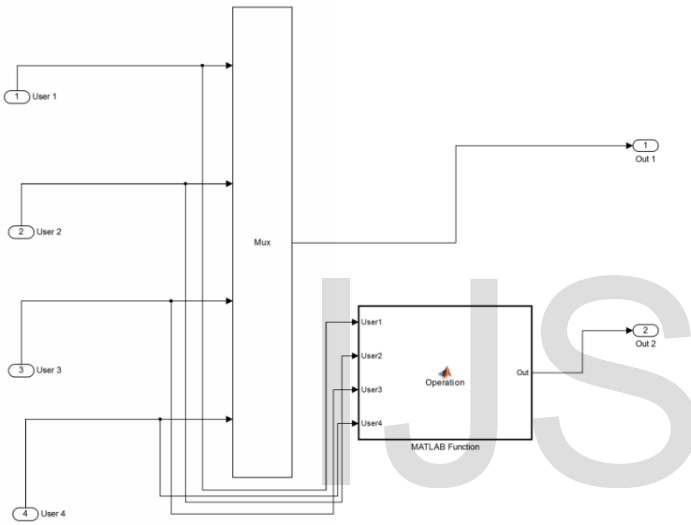



Fig. 8. Inside the 'Fusion Center' block subsystem. The AND or OR operation for Hard Fusion Decision is performed by changing the algorithm in the 'MATLAB Function' block.

The 'Fusion Center' subsystem block of Fig. 6 has been shown in detail in Fig. 8. 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 Conclusion

In this paper we have implemented Simulink based spectrum sensing using Energy Detection technique. The energy detection is first shown for a single user (Non-Cooperative) and then is carried out for 4 users (Cooperative). The output of both types is shown in blue. The presence or absence of the primary user is decided based on the threshold. The merits of the Energy Detection technique is that it has a low computational cost and does not require any prior information about the PU. The demerits are that it cannot work in low SNR and cannot distinguish between users sharing the same channel.

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