COMPARATIVE ANALYSIS OF NON-COOPERATIVE SPECTRUM SENSING TECHNIQUES IN COGNITIVE RADIO NETWORK

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Abstract: Cognitive radio (CR) is an integral system in telecommunications technology that gives unlicensed users access to licensed spectrums via dynamic spectrum access (DSA), to promote spectral efficiency. A significant operation in cognitive radio system is spectrum sensing. This paper evaluates and compares two of the major non-cooperative sensing techniques (energy and cyclostationary feature detector (CFD)) in order, to determine which gives better performance. Matlab Simulink was used as modeling and simulating tool for the evaluations. From the results, energy detector was simpler and faster but unlike CFD exhibited poor performance in corrupt channels.

Keywords: cognitive radio, spectrum sensing, non-cooperative, energy detection, cyclostationary feature

1. INTRODUCTION

Having a dependable and flexible wireless communication system has become more apparent in recent years. The integration of internet technologies into mobile communication systems to provide desirable services to users is now deemed a revolutionary step in wireless networks. The traditional approach of licensing and using electromagnetic spectrum resulted in spectral inefficiency [1]. The unequal use of the spectrum, as a result of market demand and the needs of various technologies has resulted in spectrum scarcity.

Cognitive radio mitigates the problem through improved licensing policies and suitable coordination resources, to essentially promote spectral efficiency via dynamic spectrum access (DSA) [2]. Cognitive Radio was coined by Joseph Mitola in 1999 while presenting a lasting solution to inefficiency in spectrum usage [3]. It allows unlicensed users to make opportunistic use of the licensed spectrum in the absence of the licensed users. Spectrum sensing is a core operation in cognitive radio as it analyses a licensed spectrum to determine the presence or absence of primary users [4].

In general, spectrum detection could be cooperative or non-cooperative [5]. In cooperative, the various cognitive radio systems of secondary users at a logical environment work together to assess the available spectrum around and determine spectrum holes (vacant spectrum). The holes on the account of efficiency and priority are then shared among these users. In non-cooperative method, a radio system works autonomously. The non-cooperative has various implementable techniques [6].

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Energy detection, Cyclostationary feature detection, and Matched filter detection are the major non-cooperative sensing techniques in cognitive radio [7].

Energy detection method is a non-coherent method which uses the energy content of a spectrum to determine the presence or absence of licensed users. The signal's energy is conserved in both the time and frequency domain [8]. Figure 1 shows the flow chart for conventional energy detection method.

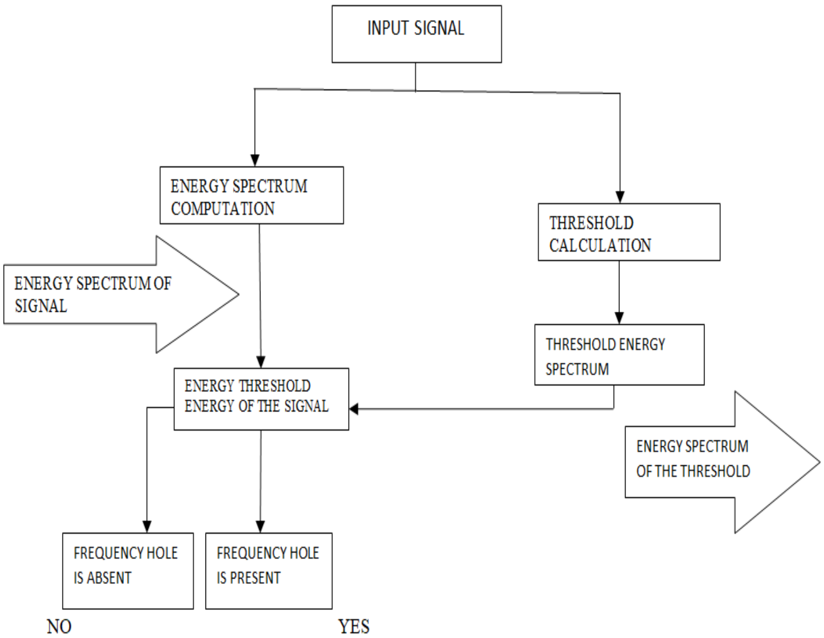

Fig. 1. Conventional energy detection method.

Matched filter unlike the energy detector is a coherent technique as it required prior information about the licensed users' signals. It is also a tool for maximizing the output signal to noise ratio (SNR) for a given inserted signals [9].

Cyclostationary feature detector makes use of the periodic properties of the spectrum for its analysis in detecting the presence or absence of primary users. These properties include frequency, period and other basic periodic properties of a spectrum. It analyses the spectrum by subjecting any of these properties to various logical processes and ultimately determine whether or not there is spectrum hole [10].

A significant operation in cognitive radio is its ability to assign the best available vacant primary spectrum to unlicensed users to provide desirable service, while avoiding interference with primary or licensed users [11]. Spectrum sensing is a key operation in cognitive radio. Each sensing technique implements algorithm that must decide one of the following two hypotheses:

$$H_1 : u(x) = a(x) + g(x) \tag{1}$$

$$H_0 : u(x) = g(x) \tag{2}$$

where a(x) is primary users' signal, u(x) is received signal by the secondary user, g(x) is the white noise present in the PUs spectrum.

- H_1 hypothesis indicates that both primary user's signal and noise are present in the spectrum and therefore cannot be used by secondary users, else it will create dangerous interference to the primary users.
- H_0 hypothesis tells that only noise is present as it is devoid of primary signals and hence it can be assigned to the secondary users.

Two major probable errors that could be encountered during spectrum sensing operation are the probability of false alarm and probability of missed detection [12].

Probability of false alarm as the name implies occurs when there are no primary signals present in the spectrum, but the analysis result shows there are, thereby preventing its opportunistic usage. The energy given off by the noise exceeds a certain threshold value thereby causing the detector to mistake it for the presence of primary user [12].

Probability of missed detection is a situation whereby primary user signal is present in the spectrum, but the analysis result shows only noise, thereby causing the spectrum to be assigned to secondary user and hence cause harm to the licensed user. The energy effused by the noise and primary user signal fail to reach a certain threshold value consequently causing the detector to mistake it for the absence of primary user [12].

Poor telecommunication and data/information access as a result of the congestion in the paths of the associated signals (unlicensed spectrums) may as of now still be relatively manageable and bearable, however, with the exponential increase in the number of telecommunication devices being added to the system, there is an imperative need and necessity to tap into the underused licensed spectrums in order to promote spectrum use efficiency generally.

As seen and established, cognitive radio is indeed much needed in telecommunication technology now and more especially in the impending future. Spectrum detection being a core operation in C.R. is however as much important as cognitive radio itself, as it essentially defines the successful application of C.R. in achieving its purpose. Therefore, it is important to pay quite enough attention to it, and seeing as there are several ways to achieve spectrum detection, it is therefore highly important to thoroughly assess and compare the techniques in order to determine and apply the one that will efficiently and optimally deliver the needed functionality.

This paper therefore compares two of the major non-cooperative spectrum detection methods under a number of metrics and evidently determines the better of the two. Several works have been carried out to evaluate the various sensing techniques (both cooperative and non-cooperative) in cognitive radio. Code integrated Matlab application have been used mostly by several authors to discern these techniques. Physical implementation and evaluations of the algorithms involved in some of these techniques have also been carried out.

A. Fanan et al. compared three main classes of spectrum sensing (energy detection, cyclostationary feature detection, and matched filter detection) through analysis in terms of time and spectrum resources consumed required prior knowledge and complexity [13].

Mansi Subhedar and Gajanan Biradjar worked on spectrum sensing techniques in cognitive radio networks. A survey of spectrum sensing techniques was presented the challenges and issues associated with implementation of the sensing techniques were discussed in detail to give comparative study of the various methodologies [14].

Tulika Mehta et al. worked on the comparison of spectrum sensing techniques in cognitive radio networks. The paper reviewed the various sensing techniques. It also presented the pros and cons of different spectrum sensing methods and performed comparisons in terms of accuracies, complexities, and implementation. Energy detection approach is the most preferable method when considering applicability because of its minimal computational and implementation requirements. As opposed to matched filter and other ways, the energy detection approach does not require the receivers to have any prior knowledge of the signals of the primary users [15].

Fatima Salahdine worked on spectrum sensing techniques for cognitive radio networks. She discussed the most recent developments in spectrum sensing methods for cognitive radio networks as well as comparisons between them. The article discussed the properties of the energy detector, wavelet, matched filter detector, and Euclidian distance spectrum sensing approaches. The report also provided various performance evaluation measures [16].

2. METHODOLOGY

For modelling and simulation of the algorithms for performance evaluation, a sine wave generator was used, as a typical representation of analog signals. For energy detection, the input analog signal is first passed through an additive white Gaussian noise channel to add noise to it and then into the band-pass filter to convert the analog signal to digital. Running this output through an FFT yields the proper coefficients. The signal's domain is also changed from time to frequency by the FFT. The Kaiser window acts to remove unwanted bands of frequency. Finally, the size of the received signal is quantified and squared by the Abs. Signals below the threshold are only noise as they are devoid of actual user energy. If and only if this threshold is crossed is a primary user said to be present. A relational operator was used to do this. Figure 2 shows the model for energy detector, and Figure 3 the Input sine wave generator configuration.

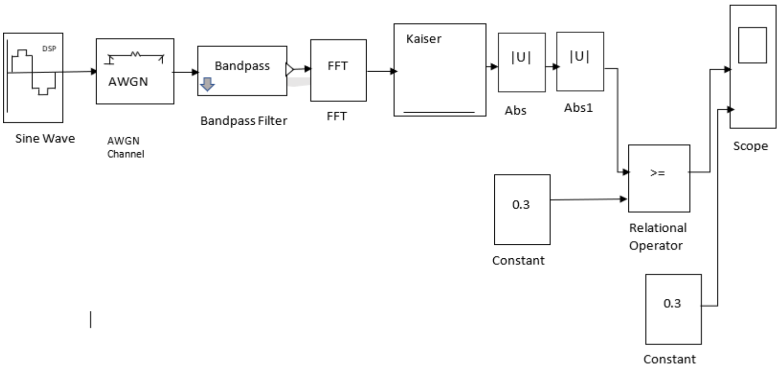

Fig. 2. Simulink model for energy detector.

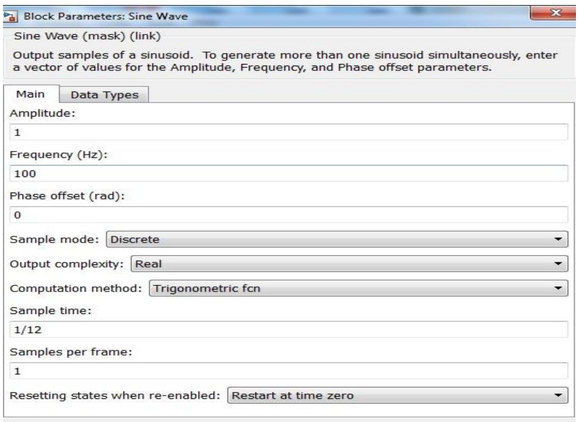

Fig. 3. Input sine wave generator configuration.

The Simulink model for Cyclostationary Feature Detection (CFD) is shown in Figure 4. The input analog signal is first passed through an additive white Gaussian noise channel to add noise to it and then into the band-pass filter to convert the analog signal to digital. There is a 12-bit analog to digital converter quantizer (V_{min} = 0V, V_{max} = 5V) in use.

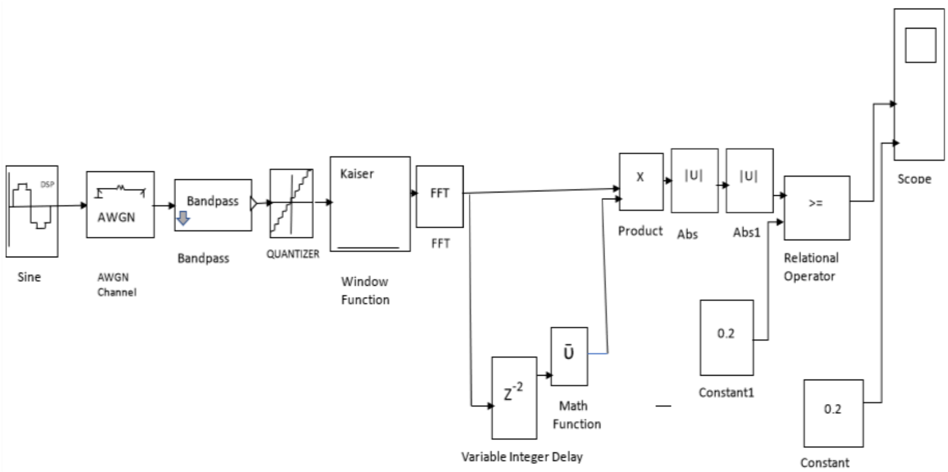

Fig. 4. Simulink model for cyclostationary feature detection.

The Kaiser is also used here to block undesirable bands of frequency and running this output through an FFT yields the proper coefficients. The FFT block also changes the signal from time to frequency domain. Windowing is followed by signal processing well before autocorrelation function. The absolute value of the signal is now compared with a fixed number to determine the presence or absence of primary user. The input sine wave generator characteristics for this approach are shown in Figure 5.

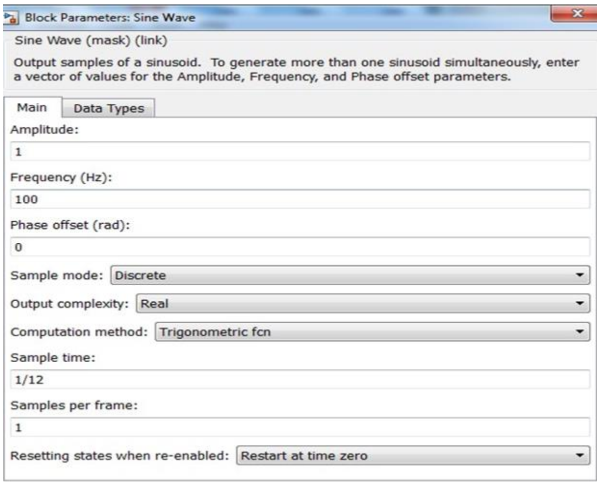

Fig. 5. Input sine wave generator properties for Cyclostationary feature detection.

3. RESULTS AND DISCUSSIONS

The simulation results (display of the scope) for the energy detection method are shown in Figure 6. The threshold is set to 0.3, and only users who cross it are active while all other users are inactive (vacant spectrums. The outcome reveals the presence and absence of the licensed users. In other words, the waveforms peaks show presence of primary users and the lows spectrum holes. From the results of the Cyclostationary detector given by Figure 7, the waveform peaks also show the presence whiles the lows absence of primary users. The licensed spectrums above the threshold are occupied by their users and the ones below the threshold are vacant and available for use opportunistically.

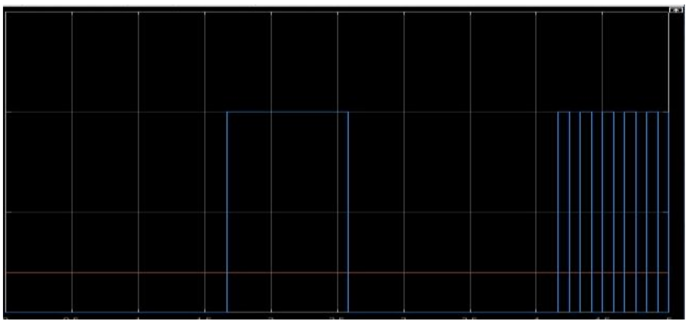

Fig. 6. Simulation results for energy detection.

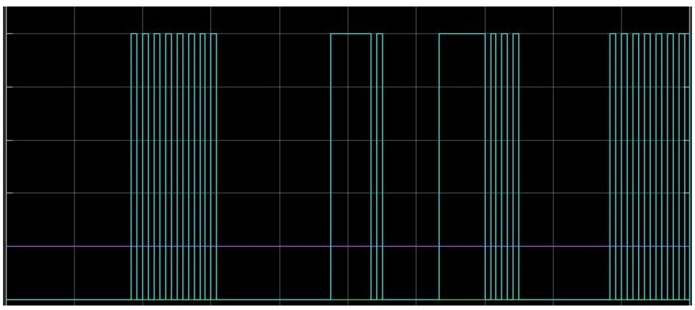

Fig. 7. Simulation results for cyclostationary detection.

3.1. Performance ratio
The three metrics for comparison between the two techniques are: speed, complexity and performance in a noisy or corrupt channel.

Figure 8 shows the performance of energy detector in the presence of Gaussian noise. The green color represents the spectrums/channels, purple color threshold and orange color the Gaussian noise. The number of waveforms (in blue color) around the regions with much Gaussian noise (waveforms in orange color) are few (only one), while those at regions with less Gaussian noise are much (6 waveforms), showing that the rate of detection is quite less around the regions with much noise and much in regions with relatively less noise. However, for cyclostationary feature detector as seen in Figure 9, the frequency of detection is variably much in virtually all the places. It detects several spectrums regardless of the noise level present. The green color being the detected spectrums while the orange represents the noise. It is therefore evident that energy detection has relatively poor performance when there is much noise involved.

Also from the results, energy detection irrespective of the signal to noise ratio made the first detection. It took the energy detector approximately "1.6 secs" to detect, which is lesser than the approximate "1.85 secs" expended in the case of Cyclostationary. This is therefore evidence that the energy detector is quite faster than the Cyclostationary feature detector.

Lastly, in terms of hardware requirements (complexity) as seen in the Figures 2 and 4, energy detector employs a total of 11 components. Cyclostationary feature detector employs 15 components, having 4 more components than the energy detector. The energy detector requires relatively a smaller number of hardware components. Cyclostationary feature detector therefore exhibits higher complexity.

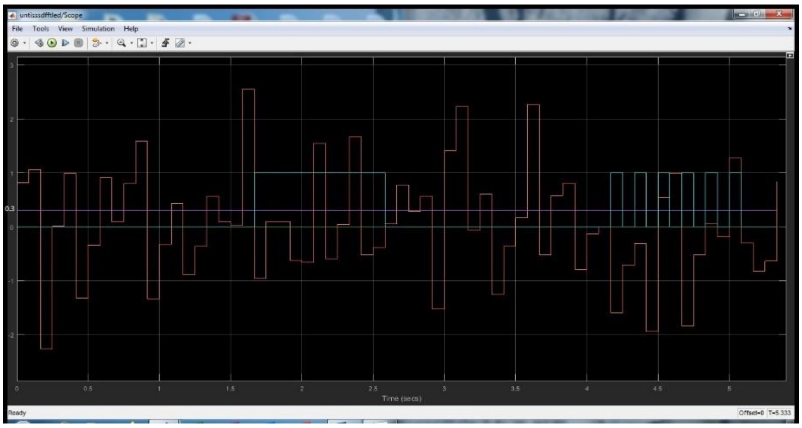

Fig. 8. Result for energy detector with white gaussian noise.

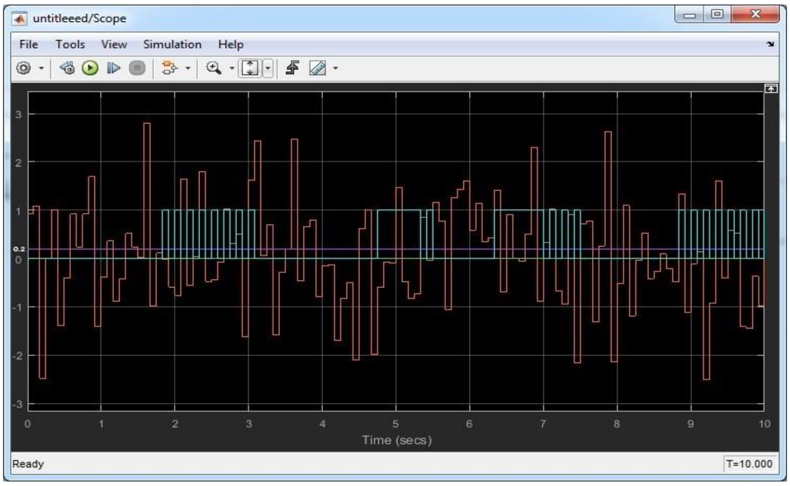

Fig. 9. Result for Cyclostationary feature detector with white Gaussian noise.

4. CONCLUSIONS AND RECOMMENDATION

In order, to improve spectrum usage and hence lessen spectrum scarcity, cognitive radio was developed. One of the key components of cognitive radio networks is spectrum sensing, which is extensively covered in this paper, parts of which are cyclostationary and energy detectors. The energy detector has the advantages of speed and simplicity. Because it doesn't need to know the signal to detect it, this sort of spectrum sensing is sometimes called semi-blind spectrum sensing. Although simple to use, the energy detector's performance suffers in noisy or corrupt channels. As for Cyclostationary feature detector, both its implementation and computing complexity are quite ambiguous. Even though it has a significant degree of sophistication, it however performs admirably in noisy or corrupt channels.

Knowing the ability and specialty of each of these two methods, it could easily be imagined that the combination of the two to achieve spectrum detection would be highly phenomenal. The energy detection method with its speed and cyclostationary its flexibility would together present a result that is quite satisfactory and pleasing in every possible application.

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