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METHODS FOR DETECTING ENERGY AND SIGNALS IN COGNITIVE RADIO

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Abstract - *Cognitive radio (CR) technology has emerged as a promising solution to improve the efficient use of the radio frequency spectrum. The main idea behind cognitive radio is to enable unlicensed users to utilize the licensed frequency bands while avoiding interference with the primary users. To achieve this, cognitive radio systems need to be able to detect the presence of the primary users and adapt their transmission parameters accordingly. This paper presents a review of various methods for detecting energy and signals in cognitive radio systems.*

The paper first provides an overview of the cognitive radio concept and the importance of spectrum sensing in cognitive radio networks. Then, it describes the various signal detection techniques such as energy detection, matched filter detection, cyclostationary feature detection, and eigenvalue-based detection. Each of these techniques is discussed in detail with their advantages and limitations.

Furthermore, the paper presents state-of-the-art techniques for signal detection in the presence of noise and fading, such as cooperative spectrum sensing, compressive sensing, and machine learning-based approaches. The advantages and limitations of each of these methods are also discussed.

Key Words: Cognitive radio, energy detection, signals detection, threshold-based, cyclostationary-based, matched filter-based, spectrum sensing.

1. INTRODUCTION

Cognitive radio is a wireless communication technology that has the potential to revolutionize the way we use radio spectrum. Traditional wireless networks operate on a fixed set of frequencies, which can lead to inefficient use of the available spectrum. Cognitive radio systems, on the other hand, can detect available spectrums and adapt their transmission parameters to use the available spectrum efficiently.

The key feature of cognitive radio is its ability to sense the radio environment and adjust its behavior accordingly. This is achieved through various techniques collectively known as spectrum sensing. Spectrum sensing enables cognitive radio systems to detect the presence of licensed users and avoid interfering with their transmissions. It also enables cognitive radio systems to identify and use available spectrum that is not being used by licensed users.

Cognitive radio can be used in a variety of applications, including wireless broadband, public safety communications, and military communications. It has the potential to significantly increase the capacity and efficiency of wireless networks, as well as improve the reliability and security of wireless communications.

One of the key challenges in cognitive radio is ensuring that unlicensed users do not interfere with licensed users. To address this challenge, cognitive radio systems must be able to sense the radio environment accurately and reliably. They must also be able to adapt their behavior quickly and efficiently in response to changes in the radio environment.

Despite these challenges, cognitive radio has gained significant attention from researchers and industry experts alike. It is expected to play an important role in the development of next-generation wireless networks, which will be more efficient, reliable, and secure than current wireless networks.

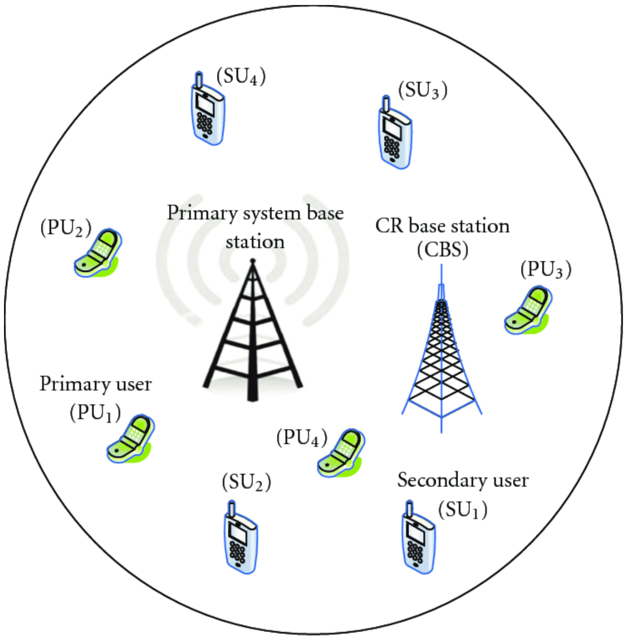

Figure-1: Cognitive Radio

1.1. Principle of Cognitive Radio

The principle of cognitive radio is to enable the efficient use of radio spectrum by allowing unlicensed users to access the spectrum when it is not being used by licensed users. This is achieved through the use of advanced radio technologies that enable cognitive radio systems to sense the radio environment and adapt their behavior accordingly.

The key principle of cognitive radio is spectrum sensing, which enables cognitive radio systems to detect available spectrums and avoid interfering with licensed users. Spectrum sensing can be achieved through various techniques, including energy detection, cyclostationary feature detection, and matched filtering.

In addition to spectrum sensing, cognitive radio also relies on other advanced radio technologies, such as dynamic spectrum access and spectrum sharing. Dynamic spectrum access enables cognitive radio systems to dynamically allocate spectrum resources based on the current demand, while spectrum sharing enables multiple users to share the same spectrum resources without interfering with each other.

The principle of cognitive radio is to enable more efficient and effective use of the radio spectrum, which is a finite and valuable resource. By allowing unlicensed users to access the spectrum when it is not being used by licensed users, cognitive radio can significantly increase the capacity and efficiency of wireless networks, as well as improve the reliability and security of wireless communications.

The purpose of cognitive radio is to enable the efficient and effective use of radio spectrum by allowing unlicensed users to access the spectrum when it is not being used by licensed users. This is achieved through the use of advanced radio technologies that enable cognitive radio systems to sense the radio environment and adapt their behavior accordingly.

The primary purpose of cognitive radio is to address the spectrum scarcity problem, which arises due to the increasing demand for wireless communications and the limited availability of radio spectrum. By allowing unlicensed users to access available spectrums, cognitive radio can significantly increase the capacity and efficiency of wireless networks.

In addition to increasing the capacity and efficiency of wireless networks, cognitive radio also has several other purposes. It can improve the reliability and security of wireless communications by enabling dynamic spectrum access and spectrum sharing. It can also enable new wireless applications and services, such as wireless broadband, public safety communications, and military communications.

Overall, the purpose of cognitive radio is to enable more efficient, reliable, and secure wireless communications by making better use of the available radio spectrum. It is expected to play an important role in the development of next-generation wireless networks, which will be more advanced, flexible, and adaptable than current wireless networks.

2. DYNAMIC SPECTRUM ACCESS

Dynamic spectrum access (DSA) is a key technology used in cognitive radio systems to enable the efficient use of radio spectrum. DSA allows cognitive radio systems to dynamically allocate spectrum resources based on the current demand, enabling unlicensed users to access the spectrum when it is not being used by licensed users.

DSA is achieved through the use of advanced radio technologies, such as spectrum sensing, spectrum sharing, and interference management. Spectrum sensing enables cognitive radio systems to detect available spectrum and avoid interfering with licensed users, while spectrum sharing enables multiple users to share the same spectrum resources without interfering with each other. Interference management ensures that unlicensed users do not cause harmful interference to licensed users.

DSA has several benefits, including increased spectrum utilization, improved network capacity and efficiency, and reduced interference. It also enables new wireless applications and services, such as wireless broadband, public safety communications, and military communications.

However, DSA also has several challenges that must be addressed, including the need for accurate and reliable spectrum sensing, the need for efficient spectrum-sharing mechanisms, and the need for effective interference management techniques. These challenges can be addressed through ongoing research and development in cognitive radio technologies. Overall, DSA is a critical technology for enabling the efficient use of radio spectrum in cognitive radio systems. It has the potential to significantly increase the capacity and efficiency of wireless networks, as well as enable new wireless applications and services.

3. THE MAIN COMPONENTS OF COGNITIVE RADIO

The main components of cognitive radio include:

1. Radio Environment Sensor (RES): This component is responsible for sensing the radio environment and providing information about the available spectrum. It uses various spectrum sensing techniques to detect available spectra and avoid interfering with licensed users.

2. Spectrum Decision Module (SDM): The SDM is responsible for making decisions about which spectrum to use based on the information provided by the RES. It uses advanced algorithms to select the most appropriate spectrum based on factors such as signal quality, interference, and network capacity.

3. Spectrum Access Module (SAM): The SAM is responsible for accessing the selected spectrum and establishing a connection with other wireless devices. It uses advanced

radio technologies, such as dynamic spectrum access and spectrum sharing, to enable efficient use of the available spectrum.

4. Cognitive Engine (CE): The CE is the brain of the cognitive radio system, responsible for controlling and coordinating the other components. It uses advanced artificial intelligence and machine learning techniques to optimize the performance of the cognitive radio system and adapt to changing network conditions.

5. User Interface (UI): The UI provides a way for users to interact with the cognitive radio system and control its behavior. It can be a graphical user interface (GUI) or a command-line interface (CLI), depending on the specific application.

4. METHODS OF SPECTRUM SENSING

Several methods of spectrum sensing can be used in cognitive radio systems. Some of the most commonly used methods include:

1. Energy Detection: This method involves measuring the energy level of the received signal and comparing it to a pre-defined threshold. If the energy level is above the threshold, it is assumed that the spectrum is being used by a licensed user, and the cognitive radio system avoids using that spectrum.

2. Cyclostationary Feature Detection: This method involves detecting the cyclostationary features of the received signal, which are periodic patterns in the signal caused by the modulation scheme used by the transmitter. The cognitive radio system can use these features to detect the presence of a licensed user and avoid interfering with their transmissions.

3. Matched Filtering: This method involves filtering the received signal using a filter that is matched to the known characteristics of the transmitted signal. If the filtered signal exceeds a pre-defined threshold, it is assumed that the spectrum is being used by a licensed user, and the cognitive radio system avoids using that spectrum.

4. Wavelet-based Detection: This method involves decomposing the received signal into different frequency sub-bands using wavelet transforms. The cognitive radio system can then analyze each sub-band to determine if it is being used by a licensed user.

5. Compressive Sensing: This method involves randomly sampling the received signal and using advanced algorithms to reconstruct the signal and detect the presence of licensed users.

5. WAVELET PACKET TRANSFORM

Wavelet Packet Transform (WPT) is a signal-processing technique that is used in cognitive radio systems for spectrum sensing. WPT is a variant of the wavelet transform that decomposes a signal into sub-bands at multiple levels of resolution.

WPT uses a tree structure to decompose a signal into sub-bands at different levels of resolution. At each level, the signal is decomposed into two sub-bands, one containing high-frequency components and the other containing low-frequency components. This process is repeated recursively until the desired level of decomposition is reached.

The advantage of WPT over other spectrum sensing techniques is that it provides a more detailed analysis of the signal by decomposing it into multiple sub-bands at different levels of resolution. This allows for more accurate detection of licensed users and better utilization of the available spectrum.

However, WPT also has some limitations, such as increased computational complexity and the need for accurate knowledge of the signal characteristics. These limitations can be addressed through the use of advanced algorithms and hardware, as well as ongoing research and development in cognitive radio technologies.

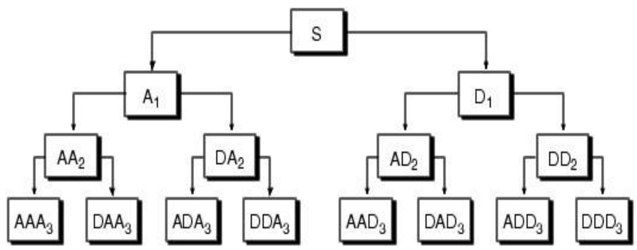

Figure-2: Structured analysis of a wavelet packet.

6. CYCLOSTATIONARY SPECTRUM SENSING

Cyclostationary Spectrum Sensing (CSS) is a signal-processing technique used in cognitive radio systems for spectrum sensing. CSS is based on the observation that signals transmitted over wireless channels exhibit cyclostationary properties, which are periodic variations in the statistical properties of the signal.

CSS involves detecting the cyclostationary features of the received signal and using them to determine the presence or absence of licensed users. The cyclostationary features can be extracted using various techniques, such as cyclic autocorrelation and cyclic power spectral density.

The advantage of CSS over other spectrum sensing techniques is that it can provide more accurate and reliable detection of licensed users, even in noisy and fading channels. It can also provide information about the modulation scheme and other characteristics of the licensed user, which can be useful for interference management and other applications.

However, CSS also has some limitations, such as increased computational complexity and the need for accurate knowledge of signal characteristics. These limitations can be addressed through the use of advanced algorithms and hardware, as well as ongoing research and development in cognitive radio technologies.

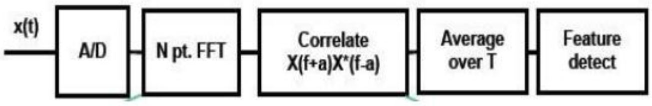

Figure-3: Detector of Cyclic Stationary Features

6.1. FM SIGNAL DETECTED IN SDR

To detect FM signals using SDR, you will need to follow these basic steps:

1. Connect your SDR device to your computer using a USB cable.
2. Install and open an SDR software program, such as SDR Sharp or GNU Radio.
3. Configure the software to tune to the desired FM frequency. In the case of FM radio, the frequency is usually in the range of 87.5 MHz to 108 MHz.
4. Once you have configured the software to tune to the FM frequency, you should be able to see the FM signal on the software's spectrum analyzer display.

To decode the FM signal and hear the audio, you will need to use a demodulation algorithm in the software. In SDRSharp, for example, you can choose the "WFM (Stereo)" demodulation option to demodulate the FM signal and output the audio to your computer's sound card.

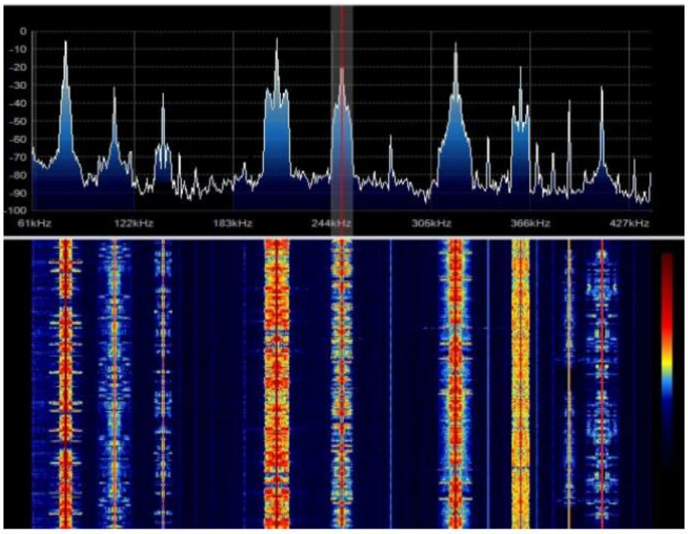

Figure-4: Detected FM signal in SDR

To detect the energy in a random signal using Simulink, you can follow these steps:

1. Open Simulink and create a new model.
2. Add a Random Signal Generator block to the model and configure it to generate a random signal with the desired properties, such as amplitude and frequency.
3. Add an Energy Detector block to the model and connect it to the output of the Random Signal Generator block.
4. Configure the Energy Detector block to detect the energy in the signal using a specified integration time and threshold.
5. Run the simulation and observe the output of the Energy Detector block to determine if the energy in the signal is above or below the specified threshold.
6. The Energy Detector block in Simulink is designed to detect the energy in a signal by integrating the signal over a specified time interval and comparing it to a pre-defined threshold. If the energy in the signal is above the threshold, it is assumed that the spectrum is being used by a licensed user, and the cognitive radio system avoids using that spectrum.

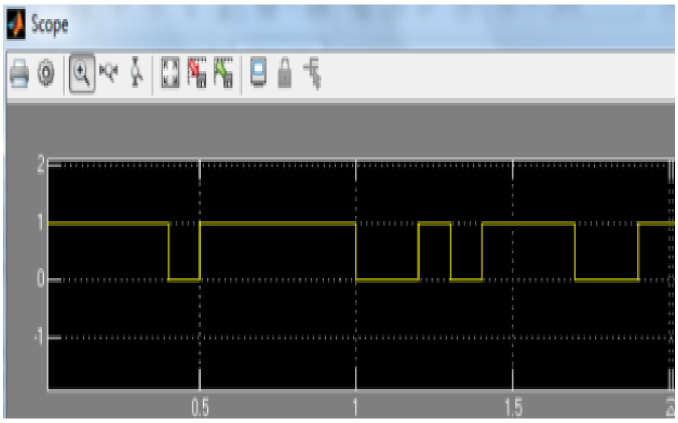

Figure-5: the detection of energy in a random signal using Simulink

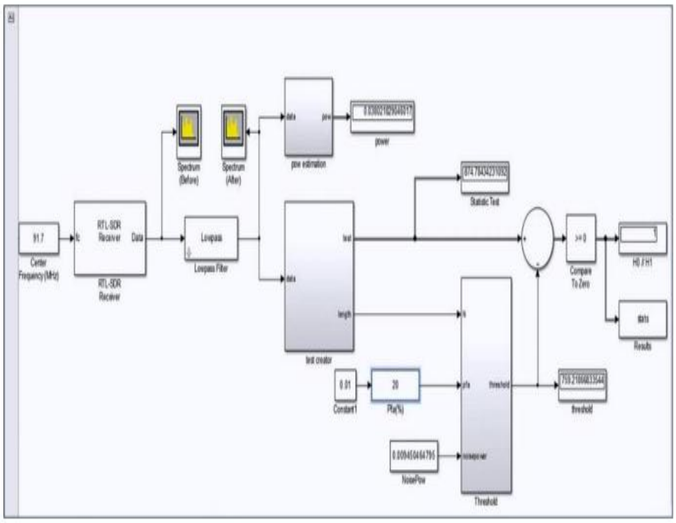

Figure-6: Detection of Energy Using RTL-SDR inside Simulink

The electromagnetic spectrum just before a low-pass filter is applied: The spectrum of a signal before passing through a low-pass filter will depend on the characteristics of the signal and the frequency response of the filter. In general, a lowpass filter is designed to pass signals with frequencies below a certain cutoff frequency and attenuate signals with frequencies above the cutoff frequency.

If the signal contains frequency components below the cutoff frequency of the filter, these components will be passed through the filter and appear in the output signal with little or no attenuation. However, if the signal contains frequency components above the cutoff frequency, these components will be attenuated or removed by the filter, resulting in a reduction in the amplitude of these components in the output signal.

The spectrum of the signal before passing through the lowpass filter will typically contain a range of frequency components, some of which will be attenuated or removed by the filter. The exact shape and distribution of the spectrum will depend on the specific characteristics of the signal and the filter.

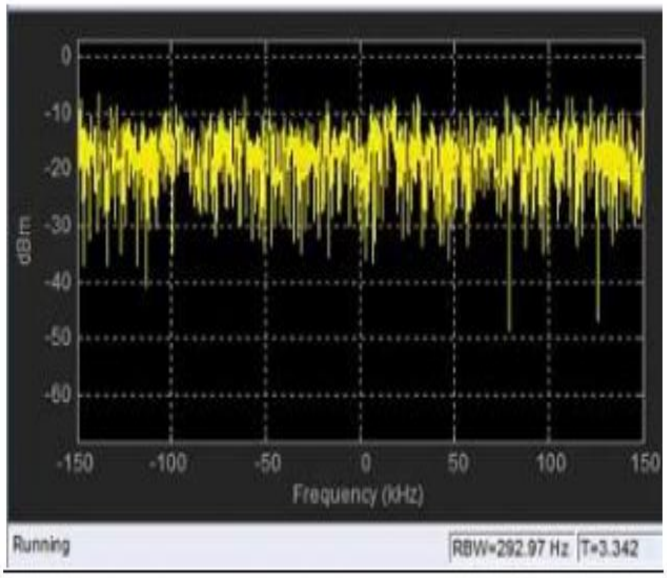

Figure-7: Detection of Signal before Low-Pass Filtering

7. SPECTRUM AFTER THE LOWPASS FILTER

The spectrum of a signal after passing through a lowpass filter will depend on the characteristics of the signal and the frequency response of the filter. In general, a lowpass filter is designed to pass signals with frequencies below a certain cutoff frequency and attenuate signals with frequencies above the cutoff frequency.

After passing through the lowpass filter, the frequency components of the signal that are below the cutoff frequency will remain largely unchanged in amplitude, while the frequency components that are above the cutoff frequency will be attenuated or removed from the signal. Therefore, the spectrum of the signal after passing through the lowpass filter will typically have a reduced amplitude for frequency components above the cutoff frequency.

The shape and distribution of the spectrum after passing through the lowpass filter will depend on the specific characteristics of the signal and the filter. In general, the filter will cause a gradual reduction in the amplitude of the frequency components as the frequency increases, with the reduction becoming more pronounced as the frequency approaches the cutoff frequency.

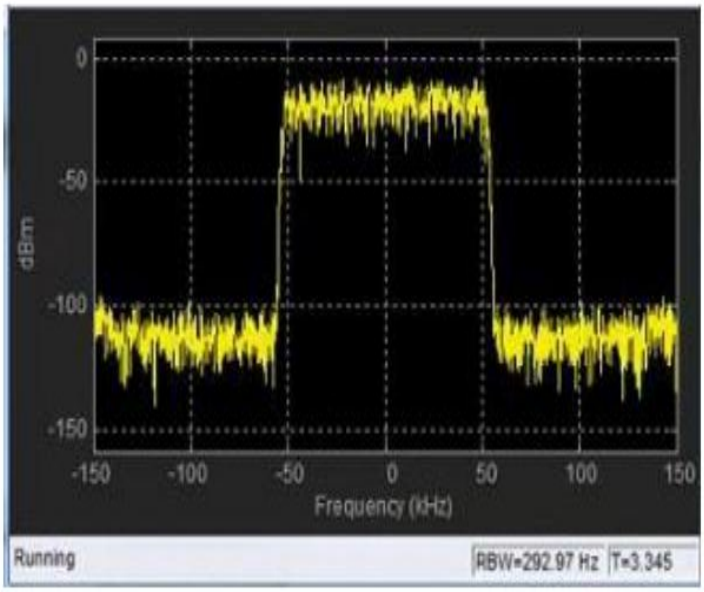

Figure-8: Spectrum After passing through the lowpass filter

8. RTL-SDR SOURCE'S RAPID FOURIER TRANSFORMATION OF THE INCOMING SIGNAL.

The frequency sink block will display a plot of the frequency spectrum of the received signal, showing the amplitude of each frequency component. The x-axis of the plot represents the frequency range of the signal in Hertz (Hz), and the y-axis represents the amplitude of each frequency component.

It is important to note that the FFT block in GNU Radio allows you to specify various parameters, such as the windowing function and the size of the FFT. These parameters can affect the accuracy and resolution of the FFT, and should be chosen based on the characteristics of the signal being analyzed.

Overall, performing FFT of the received signal by RTL-SDR Source in GNU Radio can be a powerful tool for analyzing and understanding the frequency content of a signal. It can help to identify specific frequency components or patterns in the signal and can be used to optimize and improve the performance of wireless communication systems.

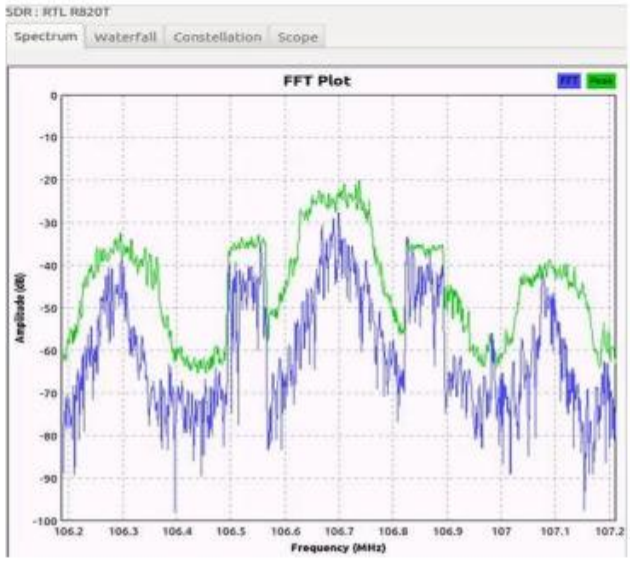

Figure-9: FFT PLOT

9. CONCLUSION

The Use of a Vast Assortment of Radio Techniques Allows for the Accomplishment of Spectrum Detection Spectrum identification using subjective radio methods performed far better than the traditional method of vitality detection when the noise was opaque, which is the actual scenario. This was the case even though the conventional approach had been used. Because of this, it is a method that is extremely good for identifying range in Cognitive Radio even when the noise is quite opaque. This is the case because of the way that the noise is distributed. The reason for this is the manner that the system operates. This is a consequence of the effect that this has had on the situation. Even in situations in which the noise does not entirely block one's line of sight, this remains the case. RTL-SDR in Simulink, SDR#, and GNU Radio were some of the tools that were used to determine the nature of the signal as well as the quantity of energy that it had. Other tools that were utilized were RTL-SDR. We were able to establish whether or not a certain frequency band is being used at the current moment as a result of Cognitive Radio's generosity in sharing this information with us. We were able to arrive at this conclusion as a direct result of the study that we carried out. The concept that is known as "cognitive radio" offers the opportunity to make effective use of portions of the electromagnetic spectrum that are now being underutilized and provides the moniker "cognitive radio." Nonetheless, cyclostationary spectrum sensing delivers a much higher level of computational difficulty in addition to a higher degree of complexity when compared to energy detection spectrum sensing. The reason for this is that cyclostationary spectrum sensing uses a more sophisticated algorithm, and as a result, it is more difficult to understand.

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