Methods for Detecting Energy and Signals in Cognitive Radio: A Review

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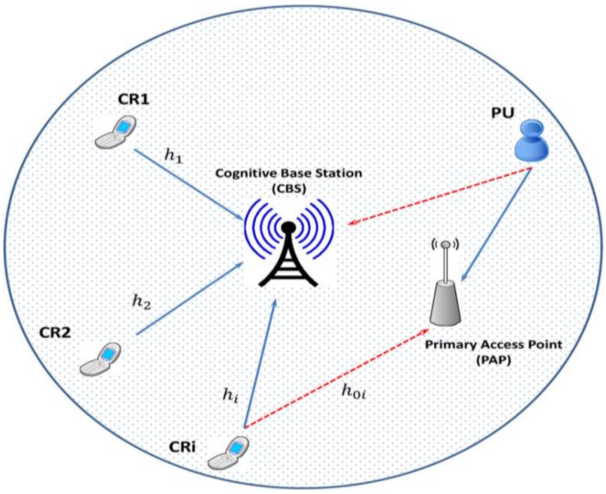
Abstract - *Cognitive radio is an emerging technology that allows for dynamic and adaptive use of the radio spectrum by wireless communication devices. The technology has gained significant attention in recent years due to its potential to address the increasing demand for wireless communication and the scarcity of available radio spectrum. In this review paper, we provide a comprehensive overview of cognitive radio technology, including its principles, architecture, and key components. We also discuss the major challenges and research directions in cognitive radio, such as spectrum sensing, channel selection, and security. Furthermore, we provide a survey of the recent advances and applications of cognitive radio in various domains, such as military communication, emergency response, and commercial communication. Finally, we conclude the review paper by summarizing the key findings and identifying the future research directions in cognitive radio. This review paper provides a valuable resource for researchers and practitioners interested in cognitive radio technology and its applications.*

Key Words: Cognitive radio, Wireless communication, Radio spectrum, Dynamic spectrum access, Spectrum sensing, Channel selection, Interference mitigation

1. INTRODUCTION

Cognitive radio is a type of wireless communication system that enables devices to use available radio frequencies dynamically and adaptively. It is also known as software-defined radio because it uses software to change the frequency, modulation, or other characteristics of the radio signal. The technology was developed to address the growing demand for wireless communication and the increasing scarcity of available radio spectrum.

The cognitive radio technology allows devices to sense the radio spectrum, analyze the available channels, and select the best frequency for transmission based on the quality of the signal, the bandwidth availability, and the interference level. This dynamic and adaptive use of the radio spectrum can improve the efficiency and performance of wireless communication systems, as it allows them to utilize underutilized frequency bands, avoid interference, and improve spectrum utilization.



Figuew-1: cognitive radio

1.1. Principle of Cognitive Radio

The principle of cognitive radio is to enable wireless devices to intelligently and dynamically adapt to their environment and make efficient use of available radio frequency spectrum. The technology operates on the principle of "dynamic spectrum access," which allows cognitive radio devices to detect and use available frequency bands in real-time.

The key principles of cognitive radio include:

Spectrum sensing: Cognitive radios are designed to detect and monitor the frequency spectrum, identifying available frequency bands that can be used for communication.

Spectrum management: Once an available frequency band is detected, cognitive radios can use algorithms to dynamically and automatically select the best frequency band for communication, optimizing system performance.

Interference management: Cognitive radios can detect interference from other wireless devices and adjust their operating parameters to avoid interference and improve network performance.

Spectrum sharing: Cognitive radios can share available frequency bands with other wireless devices, including licensed users, without causing interference, allowing for more efficient use of spectrum.

The principle of cognitive radio is to create a more flexible and efficient use of radio frequency spectrum, improving overall system performance and enabling new wireless applications and services.

1.2. Cognitive Radio Network

A cognitive radio network is a wireless network that utilizes cognitive radio technology to intelligently and dynamically manage the use of available radio frequency spectrum. It is a network of cognitive radios that communicate with each other and with other wireless devices to maximize the use of available frequencies and improve overall system performance.

In a cognitive radio network, each cognitive radio has the ability to sense its environment, including the frequency spectrum and the activity of other wireless devices in the area. Based on this information, the cognitive radio can make intelligent decisions about which frequency bands to use and how to avoid interference with other wireless devices.

Cognitive radio networks can operate in different modes, including opportunistic mode, where the system can dynamically access unused frequency bands, and spectrum sharing mode, where the system can share frequency bands with licensed users. The technology can be used in various applications, including wireless networking, cellular communications, and public safety systems.

Cognitive radio networks offer several advantages over traditional wireless networks, including improved spectrum utilization, better resistance to interference, and increased network capacity. The technology has the potential to revolutionize the way we use wireless spectrum, enabling more efficient and effective use of radio frequencies and supporting the development of new wireless applications and services.

2. COGNITIVE RADIO STATION

A cognitive radio station is a wireless communication device that is equipped with cognitive radio technology, allowing it to intelligently and dynamically adapt to its environment and make efficient use of available radio frequency spectrum. A cognitive radio station typically consists of a transceiver, a processor, and an antenna, and is capable of detecting and using available frequency bands in real-time.

3. LITERATURE REVIEW

A literature review is a critical evaluation of the existing body of research on a specific topic. It involves analyzing, summarizing, and synthesizing relevant scholarly articles, books, and other sources to identify current knowledge gaps, identify key themes, and provide a broader context for the research. The summary of all research paper are given below:

Sharma: The beginning of this article provides a comprehensive introduction to the topic of energy detection. The issue with the conventional method of energy detection is that it is unable to discern between the principal signal and the background noise. In this particular piece of research, an unique method of energy detection known as squared energy detection is suggested. Calculating the performance of the proposed squared energy detection system requires employing performance measures such as the probability of detection and the probability of a false alarm. The test statistic is compared in the spectrum sensing technique that was presented with the mean value of the difference between the squares of two samples. The test statistic is now compared with the new threshold, which is related to the intensity of the signal that has been received. This causes the odds of successfully detecting a signal to rise when using this approach.

Abdulsattar, Hussein: Energy Signal Detection is a figure of merit that has been established as a basis for quantitative evaluation of the design of a radiometer, including its calibration architecture and algorithm. It was determined that the challenge of spectrum detection techniques should incorporate energy detection in both the time domain and the frequency domain. Energy detection has been accepted as an alternate approach for spectrum sensing in CRs owing to the fact that its circuit in the actual implementation is simple, and it does not need any information about the signal that has to be detected in order to do so.

Fernando: Because of its ease of use and general applicability (regardless of the signal format that needs to be detected), as well as its low computational and implementation costs, energy detection has become a popular spectrum sensing technique for cognitive radio. This popularity can be attributed to its low costs. Yet, the most significant disadvantage it has is the well-known limits in its detecting performance. It has been demonstrated that a variety of alternative spectrum sensing methods are superior to energy detection; however, this comes at the expense of significantly increased computational cost and a restricted field of application because such methods are typically developed for the purpose of improving the detection of specific signal formats. An enhanced technique for detecting energy has been proposed as a result of this body of work. This technique has the potential to outperform the traditional technique for detecting energy while maintaining the same level of complexity and computational cost as well as its general field of applicability. The capabilities of the suggested technique have been shown via an analytical evaluation of the algorithm's performance as well as corroboration with experimental data.

Hemant: After that, the result of the error rate calculation for primary energy and the output of the error rate calculation for the noise signal are added together and shown, which is what is presented while the user is running the programme. Via the examination of this output, the existence of the principal user may be determined. If the result is 1, this indicates that the principal user is logged in. In such case, the principal user is not present. Analyzing the energy spectrum of the main user is still another method for determining whether or not the primary user is present. According to this method, the primary user is present if the energy peaks are higher than the threshold value; otherwise, the primary user is not there. While looking at the energy band diagram, one can notice that all of the peaks are higher than the threshold value; this suggests that there is a main user present. Even in the absence of a main user, the energy detector is able to determine whether or not a primary user is present in environments with low signal-to-noise ratios. The most significant limitation of energy detection is that it is unable to differentiate between background noise and the signal's own energy. If the energy detector is operating in situations with a low SNR, it will detect that the main user is present anywhere throughout the spectrum if the noise is white. After determining the energy of the principal user signal, the signal is compared to an experimental threshold value; for this example, we have decided that the threshold value will be equal to 55 e-5. In Simulink, the comparison is carried out through the Error rate calculation block. The input data from the energy out port is compared with the input data from the constant threshold port in this block. It does so by dividing the total number of uneven pairings of data elements by the total number of input data elements coming from a single source in order to arrive at a running statistic that it refers to as the error rate. If the inputs are bits, then the block computes the bit error rate; otherwise, it computes the symbol error rate. We have to utilise this block to either compute the symbol or bit error rate. In the event that the inputs consist of symbols, it will calculate the symbol error rate.

Kale el.al: Using time domain analysis, we are able to achieve detection for the number of users in accordance with the threshold formula. According to the results of the pfa study, pfa=0.1 is the optimal value. According to the findings of the SNR study, detection works best when noise levels are low. In the temporal domain, there is no indication of the user's frequency. Hence, the frequency domain will play a role in our future study. The work being presented is connected to 16QAM modulation. The investigation and use of digital modulation OFDM in cognitive radio will be the focus of our study in the near future. Spectrum sensing will be our focus in the work we conduct in the future, and we will use the frequency domain technique.

Sindhubargavi: In the event that the threshold energy is higher than the energy of the signal, the spectrum hole will be created. Many conclusions may be drawn from this investigation, including the following: the threshold energy is determined by the available noise value, the false alarm likelihood, and the frequency. The PCA detection method is used in order to carry out the computation of signal power in addition to noise power. The typical PCA method yields a ratio of SNR that does not correspond to the value of the real SNR. The power of the signal as measured by the PCA approach is not the same as the power that is actually conveyed. The standard principal component analysis (PCA) technique's findings have been subjected to the use of the first order correction term, which equals the ratio of signal power to noise power to the real signal's signal-to-noise ratio (SNR).

Nayak, Sharma: The concept of cooperative spectrum sensing for the purposes of data fusion and decision fusion has been thoroughly researched. In order to adjust the outcome, a respectable method known as ANFIS is suggested, and as was to be anticipated, it enhances the result. The implementation of the model makes use of a generalised k-out-of-n rule. The inclusion of several relays or the cooperative network has a number of beneficial effects; nevertheless, the channel detection time will lengthen as a result of this multi-relay involvement. Thus, the inclusion of CSI (channel status information) is strongly recommended for the purpose of determining whether channel is operating efficiently. If more than one route has the same CSI, the system will pick a path at random to take if they all have the same score. The system will choose the road that has the best CSI over the last three iterations automatically.

Rawat, Korde: It was shown that every detection method has a minimum SNR threshold value, below which the method is unable to function in a reliable manner. So, when there is noise present in the signal, employing cyclostationary detection will be helpful, but using energy detection will result in failure as soon as the noise in the signal surpasses the threshold. When the amount of noise in the signal is more than the threshold, the performance of the cyclostationary detection approach was shown to be superior than that of the energy detection technique.

Upadhyay: MATLAB SIMULINK Model is used in order to do the simulation of the energy detection approach using OFDM for spectrum sensing. These spectrum gaps in the spectrum of the principal user may be noticed with the assistance of this model, and secondary users are offered opportunities in a manner that is appropriate. Calculating performance and BER may also be accomplished with the assistance of the BER and Eb/N0 curve.

Youness: Using a dynamic threshold selection that was determined by evaluating the amount of noise that was present in the received signal, we proposed an approach that was based on improved energy detection to raise the chance of detection while decreasing the risk of a false alarm. A method that is based on the sample covariance matrix eigenvalues of the received signal is used to conduct the measurement that determines the degree of noise. The GNU Radio software and USRP devices were used in order to put the suggested strategy into action. According to the findings, the dynamic selection of the sensing threshold that was presented in this study is able to enhance the chance of detection while simultaneously reducing the likelihood of a false alarm being triggered.

Snehal: As a consequence of the simulation and the findings, it was discovered that the AWGN channel provides the greatest performance for energy detection in comparison to the other channels. Nevertheless, if the noise power is higher than the signal-to-noise ratio (SNR), the Energy Detection method will not function correctly. The ease with which Energy detection can be implemented is the system's primary strength. According to the simulation results, it is also apparent that the Matched filter has superior performance in comparison to the Energy detection in each of the three channels. However, the primary disadvantage of the Matched filter is that it requires prior knowledge, such as the modulation type and order, the pulse shape, and the packet format. In addition, the sensing of the spectrum requires a distinct matching filter detector to be used for each frequency. The conclusion that can be drawn from this investigation is that the Matching filter works better than the energy detector in each of the three channels (AWGN, Rayleigh fading, and flat fading).

Mahdi et.al: Spectrum sensing in cognitive radio applications was addressed with the presentation of an adaptive energy detection technique that was based on EMD. This technique makes use of the capacity of EMD to deconstruct a signal into IMFs, the energy of which may be exploited for channel discovery. The approach relies on the capabilities of EMD. The energy of the initial IMF is scaled in order to do an evaluation of the noise-only model, which is then employed in order to produce a detection threshold at some confidence interval (). In terms of Pd and Pfa, the scaling model that was suggested demonstrates much higher performance than the fixed scale model did. In addition, the EMD-based energy detector (built on the use of the suggested scale model) outperforms both ED (with a noise uncertainity) and MME over a range of SNR values, demonstrating superior performance in each case.

Goyal, Mathur: In this study, the basic notion of cognitive radio and its functions were introduced in a concise fashion. Also, spectrum sensing, which is the most sophisticated component of CRN, was analysed in depth. Since inefficiency in the use of spectrum and energy both become critical problems, energy-efficient CRNs are being offered as a potential solution to solve energy conservation concerns in the context of contemporary wireless communications. This topic analyses and answers the issues that impact the energy usage in non cooperative and cooperative spectrum sensing. It is offered in this review. Research contributions made up to this point clearly imply that the CRN's energy efficiency may be improved by optimising the number of secondary users and selecting a suitable sensing period. Further improvements in energy efficiency are also possible via the use of relevant methods for reporting. The roles of spectrum allocation and sharing, administration, and handoff were also discussed in this article in relation to CR's impact on energy efficiency.

Deshmukh, Shruti: In this study, we discussed the energy detection of spectrum sensing for cognitive radio networks using BPSK and QPSK modulated signals in the presence of sampling period, sampling frequency, and noise ratio. These factors were taken into consideration alongside the signal's sampling period and frequency. Signals modulated with BPSK and QPSK were used to accomplish this. We keep an eye out for signals that are free, and when we find them, we relay those detections to the secondary user through switching that is handled by the FPGA. In addition to that, we examined the ROC curves of Pd in comparison to Pfa. While doing Monte Carlo simulations in MATLAB R2014a, the chance of detection as well as the possibility of a false alarm are both affected by the signal-to-noise ratio in varying degrees. This might be construed to show that the detection probability decreases as the false alarm probability decreases in proportion to an increase in the signal-to-noise ratio (SNR), and vice versa. This would be a demonstration of the inverse relationship between the two variables. In order to do this, the hardware in the form of an FPGA platform is being used to carry out the functions of the energy detector as well as the switching of the absence signal.

Sanjog, Yelalwar: In this study, a comparison is made between the ED approach and the ANN algorithm for SS. As compared to the ED approach, the ANN demonstrates superior performance. The amount of time needed to make a choice is 1 second for the ED technique and 14 milliseconds for the ANN algorithm, respectively. The ANN produces accurate results even with a low SNR. By employing the ANN algorithm, the zero error rate can be achieved at an SNR of -5dB, however when using the ED approach, the smallest error rate that can be achieved is 0.1. In the case of the ED technique, the performance of the system is dependent on the associated threshold value. In the case of the ANN algorithm, the performance is dependent on the number of hidden layers. Whether using the ED technique or the ANN algorithm, the Pd = 1 target may be achieved with an SNR of -1 dB or -6 dB, respectively. When the SNR is equal to -5dB, the ANN method achieves an accuracy of 100%, whereas the ED method achieves an accuracy of 70%. The ED technique is simpler than the ANN approach since it does not need training data, previous understanding of the signal, or a multilayer network. This makes the ED method less complicated.

Kenan: In order to improve the spectrum sensing accuracy of cognitive radio networks, the authors of this paper offer a novel threshold expression model that is based on an online learning algorithm. The probability of detection, false detection, and false alarm have all been subjected to in-depth statistical analysis, and the optimal decision threshold expression has been re-defined in order to reduce the likelihood of making a mistake in the decision-making process. Numerical results derived from simulations on AWGN and several fading channels (Rayleigh, Nakagami-m, Rician, and Weibull) are shown in order to demonstrate the performance of the proposed approach and compare it with the technique of dynamic decision threshold determination. The detection performance of the energy detection- and matching filter-based spectrum sensing has been significantly enhanced according to the newly suggested sensing technique, even in environments with a low signal-to-noise ratio (SNR). In further research, one of our goals is to implement and evaluate the performance of the suggested algorithm using a variety of spectrum sensing techniques. In addition, we will concentrate on the optimisation of certain expressions that are used in the algorithm in order to lessen the amount of mathematical complexity and speed up the detection process.

Alexandru et.al: Within the scope of this study, a novel ED method for spectrum sensing in CR systems is proposed. The approach that has been suggested utilises an adaptive sensing threshold that is designed to reduce the DEP and has minimum overhead, since the value of the ideal threshold is discovered by a one-step iterative process. Both of these features contribute to the algorithm's overall efficiency. The performance of the proposed method is shown by the presentation of numerical results acquired from simulations. These data are also used to compare the proposed approach to the adaptive CED algorithm. According to the findings, the proposed algorithm performs better than the CED algorithm when it comes to spectrum sensing. This leads to lower values for the DEP for all of the values of the spectral utilisation ratio that are of practical interest for CR systems that give SU access to licenced spectrum. The suggested method will be implemented and validated using SDR systems from the USRP family, according to our plans. In this context, we will also place an emphasis on the optimisation of the expressions that are used in the method to estimate the decision threshold in order to minimise the amount of computational complexity as well as the amount of time spent sensing.

Rammani, Mazhar: The primary lessons that can be learned from the simulations are summarised as follows: Dual-threshold energy recognition does not function well when the background noise is unexpected. In spite of the unpredictability of the noise, the adaptive spectrum sensing approach works to optimise the detection threshold of the energy detector. When the signal-to-noise ratio (SNR) drops below the noise unpredictability threshold, a commutable dual threshold spectrum recognition approach works better than the other two algorithms. This occurs when the detection probability decreases.

Rahul st.al: This article provides some background information on cognitive radio technology, including its several categories and various spectrum sensing approaches. The study presented in this article makes a contribution to the energy detection technique and approach, which is ultimately carried out via MATLAB code. MATLAB and MATLAB simulation were used throughout all of the tasks presented in this research. In order to investigate how well energy detection works, the results of the simulation are obtained for varying numbers of samples.

Jun et.al: A novel approach to sensing spectrums has just been developed. +The suggested technique is derived from ED, but unlike ED, it does not need an estimation of the noise variance in order to calculate the threshold. This is because, in contrast to ED, the computation of the threshold in this method does not require prior knowledge of the noise variance. +us, it has the potential to considerably lessen the effect that the noise variance has on uncertainty. Gaussian and Rayleigh fading, two traditional channel models, are taken into consideration here. +e The results of the simulations have shown that the proposed method performs significantly better than the ED method when there are two or more antennas for a Gaussian channel and three or more antennas for a Rayleigh fading channel. In addition, the proposed method outperforms the ED method when there is no noise variance estimation.

4. CONCLUSION

Energy detection, on the other hand, involves detecting the presence of primary users by measuring the energy in the frequency band of interest. The received signal is passed through a bandpass filter, and the energy of the filtered signal is calculated. If the energy exceeds a predetermined threshold, the presence of the primary user is detected. Energy detection is simple to implement and requires no knowledge of the primary user signal characteristics but is less reliable than matched filter detection.

In summary, signal and energy detection methods are used in cognitive radio to detect the presence of primary users in the frequency bands of interest. Matched filter detection is more reliable but requires knowledge of the primary user signal characteristics, while energy detection is simple to implement but less reliable.

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