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A Methodical Literature Study on Cognitive Radio Networks

Suman[1], Sumit Dalal[2], Rohini Sharma[3], Sumiran[4]

Student, Department of ECE, Sat Kabir Institute of Technology and Management, Bahadurgarh, Haryana, India[1]

Assistant Professor, Department of ECE, Sat Kabir Institute of Technology and Management, Bahadurgarh, Haryana, India[2]

Assistant Professor and Corresponding Author, GPGCW, Rohtak, Haryana, India [3]

Assistant Professor, Department of ECE, Sat Kabir Institute of Technology and Management, Bahadurgarh, Haryana, India[4]

ABSTRACT: The innovative technology known as cognitive radio network (CRN) was created to increase the effectiveness of spectrum usage. In the event that the licensed user is not using it, it grants secondary users the ability to broadcast on the licensed portions of the spectrum. Nonetheless, in the event that the primary user chooses to reclaim the spectrum, the cognitive radio must surrender it. A cognitive radio contributes to more efficient use of the radio spectrum by taking advantage of the underutilized region of the spectrum. Moreover, spectrum sensing is the most crucial ability a cognitive radio (CR) needs to have. With the aid of spectrum sensing, a CR must be able to accurately ascertain the target spectrum's condition. This is a very difficult problem for which numerous approaches have been studied over the years. The state of the art for several spectrum sensing methods for distinct CRNs is provided in this paper. This paper discusses both traditional and contemporary spectrum sensing approaches for several primary user signal types, including both narrowband and wideband signals. Many spectrum sensing methods that have been put forth over the years are covered in this publication. Narrowband and Wideband Sensing are the two primary categories into which the approaches can be broadly separated.

I. INTRODUCTION

The government licenses and allots the electromagnetic radio spectrum, a natural resource, to transmitters and listeners. A spectrum is an assortment of radio frequency wave wavelengths that can be used for wireless communication. These wavelengths are divided into brackets, or "Bands," which are then assigned to different uses, including radio broadcasting, TV, Wi-Fi, GSM/HSPA, 3G, 4G, TV, Wi-Fi, defense communication, mobile satellites, and aeronautical satellites. Although the electromagnetic spectrum is an infinite resource, its static allocation can lead to overcrowding in some bands more than others. Some of the other bands, such those used for TV or radio broadcasts, are largely empty, while the more commonly used telecom operator bands are frequently overcrowded. Due to this inefficient utilization of spectrum, a large portion of the less crowded bands remain unutilized, resulting in poor signal quality in the busy bands. The term "Spectrum Holes" refers to a band of frequencies that are designated to a primary user but are not being used by that user at a particular time or place due to underutilization of the electromagnetic spectrum [1].

A secondary user who cannot be served by his band may be granted entry into a spectrum hole at the appropriate time and location in order to increase the efficiency of spectrum use. The "Cognitive Radio," which makes use of a Software Defined Radio (SDR) to efficiently allocate spectrum by using the spectrum holes in one band to offset the congestion of another band, is capable of performing this kind of dynamic allocation.

II. LITREATURE REVIEW

Usually a governing body within a geographic area controls spectrum access. Users must pay a fee to a government agency, such the FCC in the US, in order to receive a license to access a particular frequency band. The user receives full, unrestricted access to that band in exchange. The wireless spectrum has always been viewed as a static quantity and separated into clearly defined pieces [2]. The exclusive right of access to these blocks belongs to licensed users,

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also referred to as main users (PU). Furthermore, the PU is not required to constantly use the spectrum it has been granted. Still, the limited resource has been congested and deficient because to the explosion of mobile communications and the ensuing exponential rise in the number of users of the spectrum. To ascertain the spectrum occupancy in the band between 3.45 GHz and 3.65 GHz, a recent study was carried out.

Spectrum Sensing

The accessibility of the spectrum and the presence of licensed users—also referred to as primary users—will be ascertained by spectrum sensing. Spectrum management will forecast the duration of time that unlicensed users, also known as secondary users or CR users, will be able to use the spectrum holes. With consideration for utilization costs, spectrum sharing aims to distribute the available bandwidth among secondary users in an equitable manner. The goal of spectrum mobility is to guarantee and uphold the smooth communication requirements as we go toward lighter spectrum. The most important component in building a cognitive radio network is the spectrum sensing function. The following methods are employed in spectrum sensing: interference detection, cooperative identification, and primary transmitter identification. Because there are so many unknowns involved in picking up signals to locate gaps in the band, such as channel uncertainty, noise uncertainty, sensing interference limit, etc., spectrum sensing is the most important duty. Therefore, these uncertainties must be taken into consideration when resolving the spectrum sensing issue in cognitive radio networks (CRN)[3].

One common term for Cognitive Radio (CR) is the secondary user (CR) of the spectrum. According to this theory, the CR can only use the unused area of the spectrum once the primary user vacates it. The secondary user (CR) must scan the spectrum to find a spectrum hole since it is solely responsible for preventing interference. Once located, the CR needs to be able to broadcast to the vacant frequency range until the principal user initiates transmission again. The term "cognitive radio" refers to the requirement that the secondary user possess cognitive ability in order to do this. This suggests that CR needs to detect changes in the spectrum and modify its radio transmission settings accordingly[4] . Process flow of CRN is shown in Figure 1 as shown below.

A CR network's performance is often assessed at various Signal to Noise ratio (SNR) values. The ratio of the principal user signal intensity to the noise signal strength is known as signal-to-noise ratio, or SNR, in communication systems. Ordinarily, it is expressed in decibels (dB). In general, a CRN performs well when the SNR values are high. Generally, degradation is seen when the SNR drops. There comes a point at which the CR can no longer detect the PU signal when the SNR value drops further. This is referred to as the SNR wall, and the CRN's design and the spectrum sensing method being employed determine its value [5].

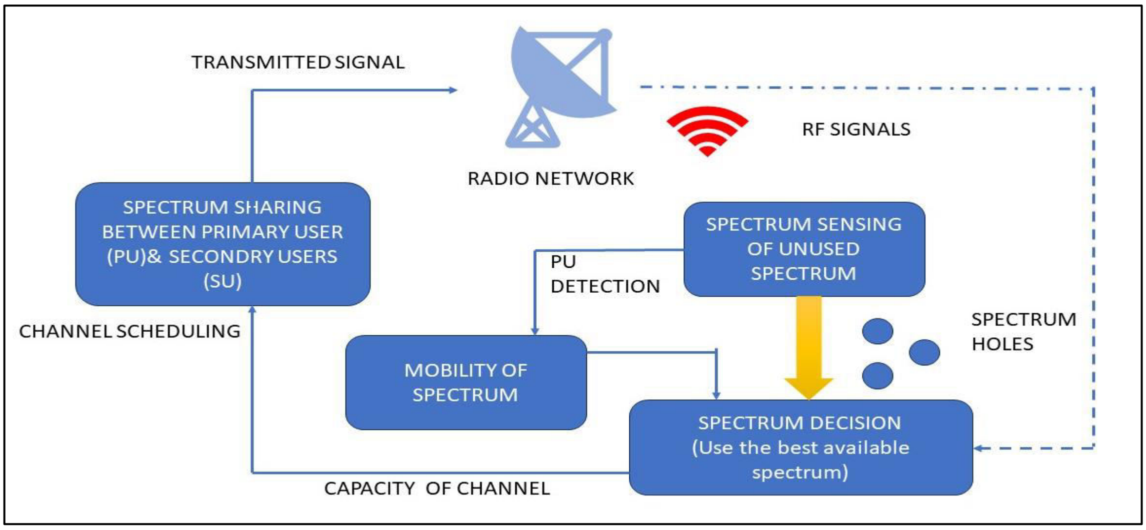

Figure 1: Process flow of CRN

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SPECTRUM SENSING TECHNIQUES

Broadly speaking, there are two types of spectrum sensing methods: narrowband and wideband. While wideband sensing senses multiple frequency bands simultaneously in search of an open frequency band to start transmission, narrowband spectrum sensing analyzes a single frequency band at a time. In statistical detection, statistical patterns in the PU signal are used to determine the existence of PU, whereas in energy identification, the CR detects the energy of the spectrum.

Larger bandwidth requirements derive from the high data transfer speeds required by modern communication methods and standards. Therefore, in order to locate an open band, CRs must sense a broad variety of frequencies in the spectrum [3]. Typically, the wideband is divided into multiple narrow bands, and sensing is carried out either in parallel or simultaneously. Figure 2 shows a detailed classification of spectrum sensing techniques.

NARROWBAND SPECTRUM SENSING

The earliest and most widely used methods of detecting the narrowband spectrum sense one frequency band at a time. Many strategies were developed, and all of the initial research on spectrum sensing in CRs was concentrated on narrowband spectrum sensing.

Energy detection

The most widely used method of spectrum sensing is by far energy detection [6]. Its ease of implementation and lack of prior knowledge of the PU signal are the main factors contributing to its popularity. By comparing the energy detector output with a preset threshold, spectral holes are found. Energy detection may be used to detect all zero-mean constellation signals very effectively. An energy detector PU signal that is contaminated by Additive White Gaussian Noise (AWGN) noise is the most basic type of signal that may be found. The discrete-time received signal is specified at the receiver. Squaring and adding the discrete samples of the received signal yields the energy of any received signal that is a zero mean Ergodic signal. Energy can also be determined with an observation window size of W samples, in place of obtaining the entire signal. For spectrum sensing, the idea of windowing—selecting fewer samples than the entire signal length—is frequently employed.

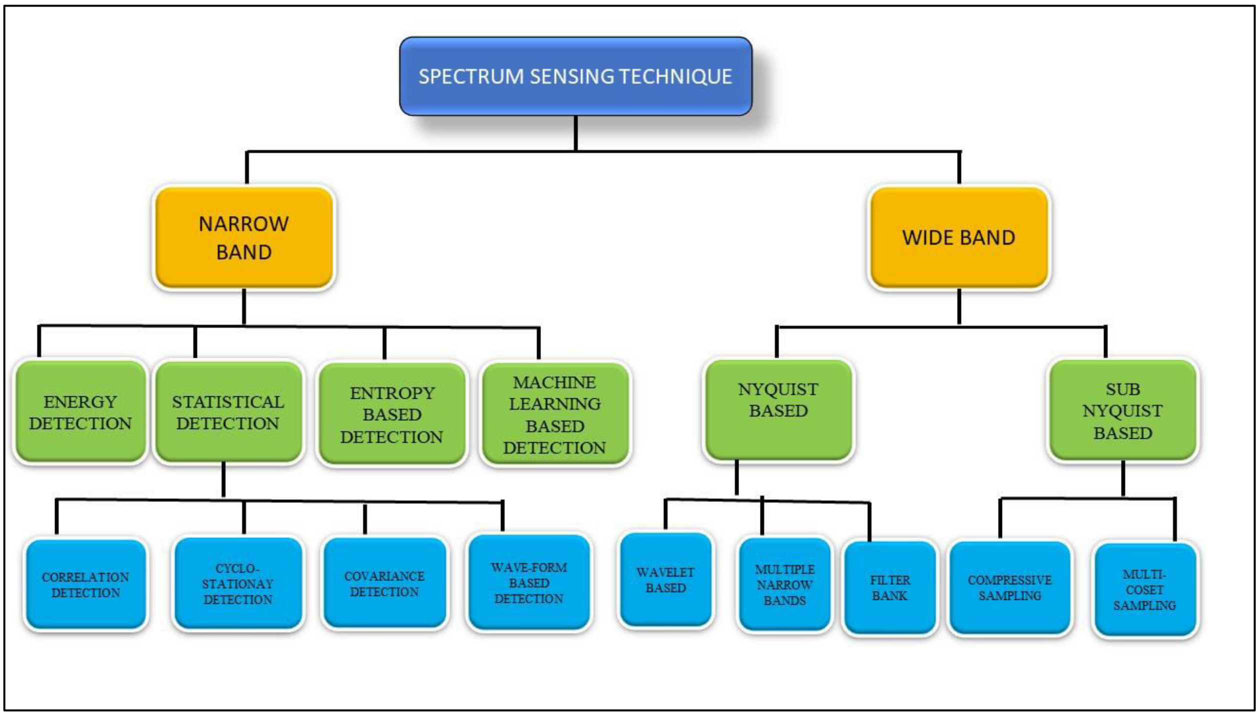

Figure 2: Classification of Spectrum Sensing Techniques

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STATISTICAL DETECTION

A large area of spectrum sensing known as "statistical detection" makes use of the PU signal's statistical characteristics to help in spectrum sensing. At the CR, parameters like correlation and covariance can be used to make better-informed spectrum sensing decisions. Distinctive sorts of statistical detection methods are discussed below:

Correlation detection

Since most signals have inherent correlation, which may be used to sense the spectrum, noise is by definition uncorrelated. Autocorrelation is a technique for spectrum sensing that involves comparing the received signal with a replica of itself. Even so, since noise samples are uncorrelated, autocorrelation will be practically nil when only noise is received. A choice is made on the kind of signal received based on this information. If the CRN is aware of the connection between the PU signals, then the Neyman-Pearson theorem becomes the best detector. By figuring out the received signal's cyclic autocorrelation function, or CAF, at the CR, gaps in the spectrum were found in [4]. Following the acquisition of the CAF, the Discrete Fourier Transform is applied to the CAF in order to compute the Cyclic Spectral Density (CSD). When the PU frequency equals the cycle frequency, the CSD reaches its maximum values.

Cyclostationary detection

A signal is referred to as cyclostationary if any of its statistics, including the first or second moment, are periodic [4]. A signal is referred to as cyclostationary if any of its statistics, including the first or second moment, are periodic. By figuring out the received signal's cyclic autocorrelation function, or CAF, at the CR, gaps in the spectrum were found in [4]. Following the acquisition of the CAF, the Discrete Fourier Transform is applied to the CAF in order to compute the Cyclic Spectral Density (CSD). When the PU frequency equals the cycle frequency, the CSD reaches its maximum values. No peaks will be seen if the received signal contains no PU signal. The detection likelihood can be maximized by utilizing the characteristic that only PU signal will have peaks in the CSD and comparing the CSD value with a threshold.

Covariance based detection

Utilizing the covariance matrix of the obtained PU signals and singular value decomposition (SVD), the covariance-based detection technique for spectrum sensing detects the existence of PU signals [3]. The covariance matrix's eigen values are found using the SVD, and the ratio of the maximum to minimum eigen values is used to compare the result to a predetermined threshold in order to identify the existence of the signal. The obtained PU signal's covariance matrix is calculated, and the maximum and minimum eigenvalues are then obtained by applying SVD to the covariance matrix. These values are then utilized to carry out the specified hypothesis test. Because covariance-based detection depends on noisy power estimate, it performs better than energy-based identification.

ENTROPY-BASED DETECTION

The quantity of information contained in a signal is measured by its entropy. Entropy is another measure of information obtained through signal understanding, since it eliminates all uncertainty regarding a signal. The PU signal's existence or absence in a signal that the CR has received can be ascertained using this characteristic. The conventional approach for calculating a signal's entropy is based on a histogram. The number of bins in the histogram corresponds to the number of energy levels in the PU signal [7]. Using this method, the CR calculates the entropy of the received signal and compares it with a threshold to determine spectrum occupancy. When the PU signal is there, entropy should be low; when random noise is the only thing received, entropy should be high.

Matched filter

Since the matching filter maximizes the SNR, it is the best detection technique for narrowband systems' spectrum sensing in AWGN noise. Correlating a copy of the sent signal with the received signal at the CR allows for the implementation of this filter. Regretfully, the matching filter necessitates total comprehension of the transmitted signal properties, which are usually unidentified to the CR [8].

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MACHINE LEARNING BASED SPECTRUM SENSING

A machine learning algorithm's main goal is to find a mathematical formula that, when given inputs, may be used to solve real-world issues. The system's output to many inputs (referred to as training data) is calculated to create the mathematical formula. When the algorithm receives any new input, it uses this information to make decisions about the predicted outcome. Distinguishable and unique characteristics of the data—serve as the input for the machine learning algorithm. There could be multiple features present in each dataset element, and each feature would be utilized to pinpoint a unique characteristic or attribute of the data. Based on the kind of data that is available, machine learning may be generally divided into Supervised Learning, Unsupervised Learning and Reinforcement Learning. The CR's goal is to use spectrum sensing to determine whether the PU signal is there or not. It is clear from this that the spectrum sensing issue is a machine learning classification issue. Any classification technique can then be used to efficiently feel the spectrum with the right dataset. Based on features taken from the received signal at the CR, the authors in [9] employed a linear and polynomial classifier to determine whether the PU signal was there. BPSK modulation of the PU signal is done while utilizing a Rayleigh channel model. Energy and correlation were the features taken from the received signal at the CR. The fusion center receives the resulting characteristics and uses the data it receives as distinct features from all of the network's CRs. To build a framework for the system, the classifier was initially trained on training data that included energy and correlation variables. Next, utilizing testing data, the system's efficiency was ascertained.

WIDEBAND SPECTRUM SENSING

Sensing in a certain frequency band is necessary because traditional CRs are anticipated to limit themselves to specified bands of the spectrum. CRs must, however, also be able to scan a wide range of frequencies in order to locate an accessible frequency band for transmission, as a consequence of the advent of contemporary communications technologies and the rise in spectrum occupancy and high data rates that follow. Thus, the idea of wideband spectrum sensing is born [10].

Nyquist sampling

Conventional techniques for narrowband systems might be applied to wideband spectrum sensing, but doing so would necessitate normal analog to digital transformations at Nyquist Rate from CRs. This might ultimately lead to an unaffordable high sampling rate or extreme functional complexity due to the large variety of frequencies. Numerous Nyquist-rate-based spectrum sensing methods have been presented in spite of these disadvantages.

Wavelet based

Wavelet transform can be implemented to the received signal at the CR if it spans various frequency bands with undetermined frequencies and power. By finding the local maxima in the wavelet transform modulus, the wavelet transform functions as an edge detector and assists with recognizing the edges of the filled frequency bands [11]. CR can begin transmitting at a frequency band once it has been identified as available and its location established. The channel might be split into several bands and monitored concurrently to reduce latency.

Multiple narrowband

A different strategy is to divide the broad frequency range into multiple smaller bands. Then, spectral sensing is carried out on each narrow band utilizing the narrow band methods covered in the preceding section[3]. Nevertheless, this strategy is unsatisfactory since it requires a high sensing time that is incompatible with the needs of contemporary communications.

Filter bank

Using filter banks is a substitute to the numerous narrowband techniques. The wideband signal is routed through many prototype filters using this technique. These filters modify the received signal to a baseband frequency, and each one has a unique core frequency. Consequently, the appropriate wideband section is down-converted and essentially sent via a low-pass filter for each filter. The condition of the PU signal in that frequency range can be ascertained by passing the filter's output via an energy detector or any other narrowband detecting method. This allows for much lower baseband

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sample rates to be used for the analysis of the wideband signal. But because the filter bank runs in parallel, execution becomes more complicated.

SUB-NYQUIST SAMPLING

A sub-Nyquist spectrum sensing methodology can be utilized, however it takes very high sample time to divide the wideband into smaller narrowbands and very high sampling rates while scanning the full wideband for the existence of PU signals. By using this method, the CR can determine whether there are any spectral transmission possibilities for the CR by detecting any PU signals that are occupying the wideband spectrum at sampling rates lower than the Nyquist sampling rates. This enables the CR to scan a broad range of frequencies at a reduced sampling rate without causing a noticeable rise in sensing time.

Compressive sensing

With the use of compressive sampling, a signal can be effectively retrieved with comparatively less samples than those needed with traditional sampling, which adheres to the Nyquist criterion [12]. Since there is little use of the spectrum, PU signal transmissions are usually dispersed throughout the broad range of frequencies. This makes it possible to recover the received signals using compressive sensing at sample rates that are lower than the necessary Nyquist rates. The goal of compressive sampling is to retrieve the signal from a small collection of linear measurements by taking advantage of the sparsity of signals. A signal having few non-zero elements is called a sparse signal.

Multi-coset sampling

Another Sub-Nyquist sampling technique is multi-coset sampling, which selects a subset of samples from a standardized grid by employing a sampling rate that is higher than the Nyquist rate. The primary benefit of multi-coset sampling is that the sample rate is j times smaller than the Nyquist rate. But it can be difficult to derive a distinct solution for the wideband spectrum occupancy from a small number of data.

III. CONCLUSIONS

Broadly speaking, there are two types of spectrum sensing strategies: narrowband and wideband. Of the two, narrowband spectrum sensing has received greater attention in the scientific community. Because it is so easy to use, energy detection is by far the most popular kind of spectrum sensing technique. It is used in many configurations under Rayleigh and AWGN. The primary difficulty in energy detection, as demonstrated by fading conditions and several studies, is choosing the best threshold. Conversely, better results are obtained when the presence of the PU signal is detected using its established statistical characteristics. These characteristics consist of cyclostationary and correlation. The performance is significantly enhanced by these features, particularly in fading environments. Entropy is another characteristic that can be utilized to identify the existence of a PU signal. Since noise is unknown, its entropy is substantially higher than that of the PU signal; this property is utilized to identify when the spectrum is occupied. When using this strategy, the performance decreases in fading situations but increases in an AWGN channel for varying SNR levels. Energy is typically employed as the characteristic that separates the PU signal from noise. Certain research projects use characteristics other than energy and demonstrate notable performance gains. Studies on the AWGN and fading channel conditions have shown that SVM and Naive-Bayes perform better than other algorithms most of the time.

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