Cognitive Radio Principles and Spectrum Sensing

J. Divya lakshmi , Rangaiah. L

Abstract: ***Cognitive Radio is an all intelligent radio network that is advancement over the conventional radio. The difference between the traditional radio and cognitive radio is that all the unused frequency spectrum is utilized to the best of available resources in the cognitive setup unlike the traditional radio. The major advantage of the cognitive radio is that it can detect channels that are available from the spectrum and modify the parameters used for transmission so that the several unused frequencies can be used concurrently. The research conducted on the cognitive radio is in its primitive stages. However, the need of the hour is the detailed surveys and descriptions of the cognitive radio sensing mechanisms. The operating behavior of the radio will also be improved using the cognitive radio. This paper details the sensing and interference mechanisms of the cognitive radio and explains how and why the cognitive setup is far excellent compared to the conventional radios. There are numerous technologies used in the cognitive radio setup such as the Adaptive radio and Software Defined Radio (SDR). The applications of the findings of this paper can be extended to cognitive radio design and implementation.***

Keywords – Cognitive Radio, Radio Spectrum, Radio Transmission, Spectrum Sensing.

I. INTRODUCTION

Radio has been around since more than a century. The concept of radio is such that all the users who are utilizing the frequency band may interfere. The increasing number of the users will severely limit the frequency bands. The wireless systems have grown exponentially in the last decades, which are aggravating the problem. The details of the frequencies allocated prove that the shortage of newer frequencies is a big challenge for the growing demand. The newer wireless systems designed has no frequencies. It is a problem for every growing new system because the platform is seizing in a few years. It is also important to remember that reallocation of the existing systems is also not an option. This major challenge is the first and the most important reason that incepted the concept of cognitive radio. The use of the available signal processing technologies to allocate frequencies to the new users is the concept used in cognitive radio. The requirements for the new technology were no degradation of the quality, allocation of frequencies to a large number of new users, not to disturb the existing users, and higher data rate.One effective way is to utilize the same frequency bands more efficiently with technical expertise. There are several changes that need to be done for the newer frequencies to be accommodated in the same spectrum. The changes expected from the authorities in this regard have been proven to be ineffective.

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The different types of bands are radio, TV, satellite, air traffic control, etc. There are different functions in the life cycle of a cognitive radio in an environment. Sensing, Analysis, Reasoning, and Adaptation are the major phases which are considered for the smooth operations of the cognitive radio, as shown in figure 1.

II. COGNITIVE CYCLE

The sensing phase is responsible for detecting the spectrum for white spaces. The availability of the

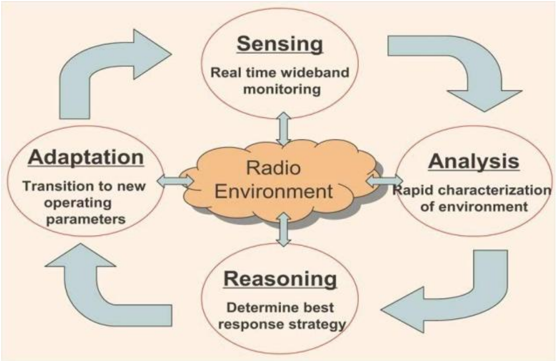

Fig.1. Cognitive radio cycle [2]

Space frequency band that is free from the primary users. This space is available for the other transmissions, which is what the cognitive radio frequencies will make use of. The sensing phase detects the activity of the available and unavailable spaces. The monitoring phase should ensure that there is no interference pattern in the second users. The monitoring is real time and requires accurate detection of the white spaces [2]. The sensing of the spectrum phase is followed by the recognition of the white space with a suitable frequency that has highest quality (using QoS). There are several other requirements that should be met by the available white space before it can be considered suitable for the transmission. If both primary and secondary users are busy in transmission, the secondary users are allowed to change the frequency band using the requirements [2]. Noise levels, losses, and error rates are usually considered as the parameters to analyze the quality of the frequency available. It is important to note that the frequency specifications are available for all the users (primary and secondary). It is the design of the cognitive radio that ensures that a suitable frequency (after checking the parameters) can be allocated for secondary users[2]. The spectral efficiency in a conventional radio network is not used appropriately. The use of the same spectrum for several communications is the advantage of the cognitive radio.

There are several capacity limitations and the techniques which are usually different when a design for a cognitive radio is proposed. The spectrum utilization is considered to be the best in cognitive radio. The technical information about the channels, messages, and node shares is critical in terms of the design and spectrum utilization[2]. The three approaches usually preferred about the side information on the cognitive radio are – underlay, overlay and interweave. There are specific characteristics for these three approaches. This survey paper lists, describes and classifies the technical details of the radio spectrum of the cognitive radio topic.

Working of the Cognitive radio

The new technology (cognitive radio) should satisfy the following conditions – smart utilization of the information in the frequencies, be compatible with the channel conditions, do not disturb the exiting channels/frequencies, and offer high quality transmission. The three types of the channel information used by the cognitive radio are overlay, underlay, and interweave [6]. There is a possibility that interference occurs due to the introduction of the new channels and frequencies. If the interference due to the new users is lower than the average of the frequencies, underlay occurs. In overlay, the newer frequencies improve the quality of the existing frequencies together. In the interweave type, the unused and left-over spectral gaps of the system are utilized by the new frequencies. These three types of network approaches are usually used by the cognitive radio to accommodate the new frequencies in the existing frequency spectrum [6].

Underlay – The first paradigm of the cognitive radio which is defined by the knowledge of the interference between the new and the existing frequencies. In this understanding, the primary and secondary users refer to existing and cognitive radio respectively. The specific requirement is that the interference that is caused by the no cognitive frequencies is below the threshold when compared with their cognitive counterparts. The difference should be below the threshold value to facilitate the transmission of both the transmissions. There are different ways of achieving this goal. The use of multiple antennas that direct the cognitive and non-cognitive signals away from each other is one way. The second method is to use a wide bandwidth that ensures spreading of the cognitive signals below the noise level and beaming them at the receiver end. These methods ensure that the interference remains a low level and ensures that the signals are not overlapping and causing any issues in transmission[1]. It is also possible to design the transmitter of the cognitive signal to keep the power at the output minimal to maintain the threshold level. With this mechanism as the fundamental concept, it is safe to interpret that the underlay method can be used only for short range communications by the cognitive signals. The major reason is the limitation of power. The underlay method is used by different users for different unlicensed bands[1]. The interference temperature is the metric used as the standard for the analysis of the underlay radio. [6] This metric defines the power of the radio frequency by the antenna during transmission. This power can be used to check if the interference is above or below the limit of threshold. This can be visualized as follows. The average power received (in terms of interference) is approximately equivalent to the power constraint at the transmitter which is considered secondary. Signal-to-Noise Ratio (SNR) can be used to measure the value and the level of interference. It is important to note that if the interference value is at its maximum, the cognitive signals cannot be transmitted due to the limitation of the threshold value. The maximum power value thus remains below the predetermined level. The quality of service in case of underlay method is such that it is the average of all the powers of the transmitters (cognitive). The peak transmission power is first determined, and then the zero-transmission level. It is possible that different users of the cognitive band are assigned different priorities. This facility allows the users to have different types of channels transmitting different data using the same type of cognitive bands.

Interference

A simple case of transmitters and receivers, two in number, is explained in figure 2. Whenever the encoder t needs to send the messages Mt to the receiver Wt, an n length codeword is used. The rate is represented by Rt. The same case is represented in figure 2.

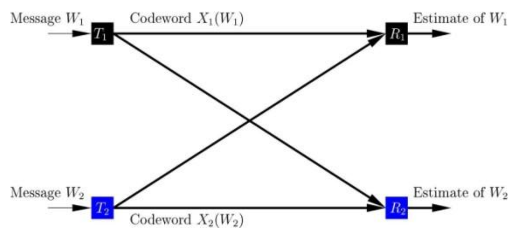

Fig. 2. Interference channels [6]

Overlay- The major difference between the underlay and overlay is that the overlay type allows the simultaneous use of both non cognitive and cognitive users. Both the users can transmit data without interference. It is also possible that only two users are present and the data of one user is hidden from the others. It is important encode the information in such a way that the transmission of the non-cognitive user is not interfering with the cognitive counterpart. The cognitive user should be aware of the type of information transmitted by the non-cognitive user to ensure that the interference does not occur. In the case where the information of one channel known by another, the practical issues arise which may be fatal to the entire communication system. This is a possibility when the two channels are close to each other. In case of any combination of issues such as the delay or retransmission, the issues grow large enough to fail the communication. Different types of encoding techniques are used to encode the cognitive and non-cognitive information to ensure the transmission is seamless and no interference occurs.

Interweave- The above-described overlay approach requires the knowledge of the information sent by the non-cognitive channel to transmit the data without interference. This is a major channel when it comes to different applications. As the proximity of the channels increase, the interference and the issues caused by the channels delay and degrade the quality of the signal. Encoding methods, On the other hand, are important to isolate the message from either channels and also maintain the SNR for proper reception. Interference is the parameter that is central in this discussion. The methods and strategies used to transmit the information by avoiding the interference and transmit over the gaps is the concept of Interweave method. Both the cognitive and non-cognitive transmissions can be achieved when the information of the non-cognitive transmission is available. The presence and the details of the transmissions of the non-cognitive systems is the essential part of the interweave method. The issues of user detection of the non-cognitive system are complex because of the signal fading. The noise value of the system also increases when the data from the unlicensed channels and frequencies adds to the existing signal band. Another issue in detecting the non-cognitive data is that it is not a constant value. It is dynamic over time. The signal value keeps fluctuating. The detection method should be such that the data is checked over a period of time at regular intervals of time. One effective method to detect the users is by sensing the undelivered transmissions. The false negative values are also considered during the calculations. The dynamic nature also means that the signal value could be so less it is often perceived as non-existent.

Spectral Sensing-

The cognitive radio can be designed well after the channels have been sensed and analyzed. The above-described techniques of overlay, underlay, and interweave works well only if the spectrum has been sensed and analyzed for the available frequencies. There are different sensing methods used in the research. The sensing phase involves the scanning of the spectrum gaps and the presence of users in the spectrum [4][8].

Interference Temperature

An important method senses the temperature due to the interference by the primary and the secondary users. The existence of the primary users is detected by sensing the frequencies. The power of the transmitter is limited so that no interference is caused, which can be measured by the noise at the interference [10]. This method has not been successful because limiting the frequency and thus the power of the signal is not practical, which may lead to signal losses and the low quality of transmission. It is also possible that any other undesirable noises causing interference appears. Therefore, the radio frequency power is measures at the reception which is then transmitted to the receiver. The interference [24] temperature is the measure of the power at the receiving antenna. Energy of the signal is the parameter detected in this type of sensing. This method is the easiest of all and does not require any information of the primary signals [7]. This method has a certain disadvantage because of the lack of knowledge of the data of the signals. It is possible that the sensing has high number of false positives due to the inaccurate calculation of the noise value. On the other hand, if the signal quality is weak, the uncertainty of the calculation in high. This method also fails to distinguish between the primary signal and signals from the other sources, which is a possibility in case of several signals [15]. Spectrum Sensing – Spectrum sensing ensures that many parameters of the transmission are determined and the details of the available spectrum [26] are also calculated. Basically, this method checks for the available frequency gap satisfies the requirements for efficient transmission of the cognitive radio. This type belongs to the feature detection category of spectrum sensing. The density of the spectrum and the features that are used to define a high-quality signal is used as a parameter. The characteristics of a primary signal are defined in the design, which is the input for the feature detection mechanism [3] [5]. This method is complex than the power detection, but offers robustness against the noises. This method is efficient in determining the interference pattern at low signal strength because there are many other parameters used to determine the presence of the signal. It is also possible that this method can detect different signals and differentiate the primary signals from other available signals. This method requires the knowledge of the characteristics of the primary signals. Although efficient, this method requires complex design process especially characterizing the signals based on the features that are exclusive to the particular system designed [14]. Matched filtering – Another method that uses the pattern of the waveform of the signal to check the different signals and differentiate the primary from secondary. Coherent detection mechanism is employed in this method to ensure that the primary signal and the secondary signal waveforms are distinguished. The signal match is detected and compared with the required signal to check the presence of the primary signal. This method is simpler in comparison because the details of the signal are stored and a comparison is made which requires fewer samples. It is also robust in case of noises and low-quality signals. The design is however complex because this method requires a thorough analysis of the signal which can be used for comparison.

III. ANALYSIS

The spectrum analysis is another important phase of the cognitive radio characteristics [23]. The critical action performed in this stage is the detection of the white spaces in the spectrum through which any portion of frequency that is not being utilized for transmission by other users of the spectrum is effectively detected for the transmission [31]. The other action of this phase is that the users who were already transmitting or using the spectrum will effectively continue their operation through the same channel as before. The analysis stage ensures that there is no interference between the existing and the new unused spaces detected. The secondary users will be allowed to choose the frequencies that suit their requirement. This phase is critical as the selection process determines the efficiency of the system [9]. The summary of the results can be explained in three steps – Dynamic allocation, reasoning, and adaptation.

- **Dynamic allocation** – Dynamicallocation is used in which the primary users are given highest priority [9]. If the primary users request the band which is allocated to the secondary users, as per the design, the primary users can take the secondary users' frequency [11]. The secondary users may then choose the frequency that is free to use after sensing the frequencies. The design also allows the sharing of the frequency allocation between primary and secondary users. This approach allows the best use of the frequency spectrum by all the users. This phase also marks the rapid characterization of the frequency bands allocated for the primary and secondary users.

- **Reasoning** – The next phase is the reasoning phase in which the best response strategy will be determined for the allocation of frequencies. Once the analysis of the frequency band has been completed successfully, the details of the allocation are shared by the design to the secondary users. Different algorithms are used to sense and work on the determination of the frequencies. At this stage, the comparison, selection, and the reasoning process of frequencies is performed [12]. The efficiency of the system is determined by the design of this algorithm. There are several parameters of a user which can be used to determine if the secondary user can be allocated a frequency.

The smartness of the design is in this phase. Advanced machine learning methods can also be used to analyze the parameters. The most important factor is that the primary and secondary users should not be the source of any interference in the system. On the other hand, no unused frequency should be free despite the parameters allowing the allocation. This phase also includes the allocation of frequency after all the parameters have been found to be suitable.

- **Adaptation** – After the reasoning phase, the frequencies are to be allocated with new parameters to the new transmission [19]. This phase is the last phase in the life cycle of the cognitive radio. This Phase also marks the end of one cycle of the cognitive radio. Both the primary and secondary users are using the respective frequencies at this point [21]. The new users need to adapt to the changes whereas the primary users should not be disturbed, and no interference should be caused. The transmission and reception action of both primary and secondary users can continue in this phase for as long as required. Ideally, the interference should not occur, transmissions should be noise free and SNR maintained high. Once the transmission is complete, the cycle goes back to the sensing phase in which the unused frequencies are sensed for next phase. This cycle is repeated as long as the secondary users require transmission frequencies.

IV. CONCLUSION

Cognitive radio is an emerging technology with applications in several different fields. The research in this field is limited and required importance at the survey level. This survey paper describes the basic functioning of the cognitive radio, the network paradigms, and the sensing mechanisms. The most important parts of the cognitive radio and the functionality of the same have been well described. The design of a cognitive radio is the next step. Sensing, Analysis, Reasoning, and Adaptation phases are discussed completing all the phases of the cognitive life cycle. The details presented in this paper offer insights to the researchers in the field. The findings also present different cases and mechanisms on how cognitive radio can be utilized efficiently by using various mechanisms for sensing and transmission. The findings are generic in nature and can be applied to any applications of cognitive radio. Cognitive design is specific to the application and is considered the future scope of the design.

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