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Various Sensing Techniques in Cognitive Radio Networks: A Review

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Abstract

Cognitive radio networks (CRN) is IEEE 802.22 standards, also known as 5-G wireless technology. CRN carries primary users (PU) or licensed users and secondary users (CR) or un-licensed users. In this paper, we have presented an overview of CRN, further we discuss CRN functions. There are various sensing techniques which we classify and discuss, and further analyze the issues related to CRN. Finally, we conclude that each sensing technique has its own advantages and dis-advantages.

Keywords: *Cognitive Radio Network, Primary user, Cognitive Radio User, Spectrum Sensing, SNR*

I. Introduction

In present era wireless communication is going in big way and cognitive radio network is one of the future based technologies in wireless communication system. The concept of cognitive radio was first proposed by Joseph Mitola III at KTH (the Royal Institute of Technology in Stockholm) in 1998. Cognitive radio (CR) is an intelligent wireless communication system, which is aware of its surrounding environment, learns from the environment and adapts its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters in real time. A cognitive radio comes under IEEE 802.22 WRAN (Wireless Regional Area Network) standard and has ability to detect channel usage, analyze the channel information and make a decision whether and how to access the channel. The U.S. Federal Communications Commission (FCC) uses a narrower definition for this concept: “Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, and access secondary markets”. The primary objective of the cognitive radio is to provide highly reliable communication whenever and wherever needed and to utilize the radio spectrum efficiently. Static allocation of the frequency spectrum does not meet the needs of current wireless technology that’s why dynamic spectrum usage is required for wireless networks. Cognitive radio is considered as a promising candidate to be employed in such systems as they are aware of their operating environments and can adjust their parameters. Cognitive radio can sense the spectrum and detect the idle frequency bands, thus secondary users can be allocated in those bands when primary users do not use those in order to avoid any interference to primary user by secondary user. In cognitive network literature, primary user and secondary user are considered as shown in Figure 1. The primary user is licensed user that has been allocated a band of spectrum for exclusive use. The secondary user is unlicensed user that does not have allocated band of

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spectrum. We use spectrum sensing techniques to detect the presence of primary user licensed signal at low SNR.

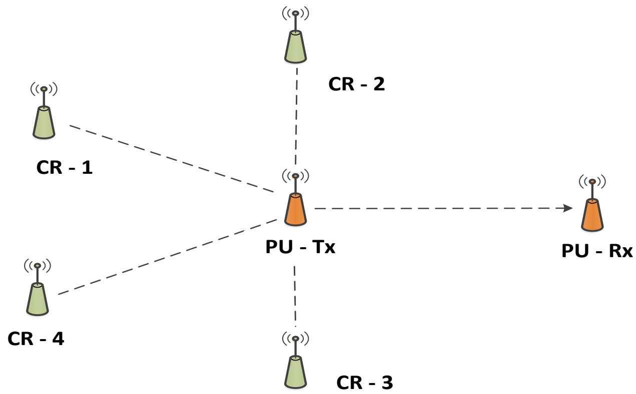

Figure 1. Cognitive Radio Network (CRN)

The rest of the paper is organized as follows: Section II presents spectrum sensing methodologies to detect PUs presence. Section III describes cognitive radio network function. Section IV presents the sensing techniques. Section V presents the issues in cognitive radio networks. Finally, Section VI concludes the paper.

II. Spectrum Sensing Methodologies

CRs utilize unused channel of PU's signal and spectrum sensing mechanism allows them to determine the presence of a PU. In transmitter detection based technique, CR determines signal strength generated from the PU. In this method, the locations of the primary receivers are not known to the CRs as there is no signaling between the PUs and the CRs. To detect PU signal, there are following hypothesis for received signal:

$$x(n) = \begin{cases} w(n), & H_0 \quad (1) \\ s(n)h(n) + w(n), & H_1 \quad (2) \end{cases}$$

Where, *x(n)* shows signal received by the CR user, *w(n)* shows additive white gaussian noise, *s(n)* is PU signal, and *h(n)* indicates channel gain.

H_0 and H_1 are the sensing states for absence and presence of signal respectively. H_0 is the null hypothesis which indicates that PU has not occupied channel and H_1 is the alternative hypothesis. It can define in following cases for the detected signal.

- Declaring H_1 under H_0 hypothesis which leads to Probability of False Alarm (P_f).
- Declaring H_1 under H_1 hypothesis which leads to Probability of Detection (P_d).
- Declaring H_0 under H_1 hypothesis which leads to Probability of Missing (P_m).

Now, working and implementation of three primary transmitter detection techniques are briefly described.

III. Cognitive Radio Network Functios

Basically, a cognitive radio should be able to quickly jump in and out of free spaces in spectrum bands, avoiding pre-existing users, in order to transmit and receive signals. There are four basic functions of cognitive radio networks, Spectrum sensing, Spectrum sharing/allocation, Spectrum mobility/handoff, and Spectrum decision/management.

- **Spectrum sensing:** It detects all the available spectrum holes in order to avoid interference. Spectrum sensing determines which portion of the spectrum is available and senses the presence of licensed primary users.
- **Spectrum decision:** It captures the best available vacant spectrum holes from detected spectrum holes.
- **Spectrum sharing:** It shares the spectrum related information between neighbor nodes.
- **Spectrum mobility:** If the spectrum in use by a CR user is required for PU, then CR leaves present band and switches to another vacant spectrum band in order to provide seamless connectivity.

Many of the licensed air waves are too crowded. Some bands are so overloaded that long waits and interference are the norm. Other bands are used sporadically and are even underused. Even the Federal Communications Commission (FCC) acknowledges the variability in licensed spectrum usage. According to FCC Report, 70% of the allocated primary user licensed spectrum band remains un-used called white space/ spectrum hole at any one time as shown in Figure 2. This fluctuating utilization results from the current process of static allocation of spectrum, such as auctions and licensing, which is inefficient, slow, and expensive. This process cannot keep up with the swift pace of technology. In the past, a fixed spectrum assignment policy was more than adequate. However, today such rigid assignments cannot match the dramatic increase in access to limited spectrum for mobile devices. This increase is straining the effectiveness of traditional, licensed spectrum policies. In fact, even unlicensed spectrum/bands need an overhaul. Congestion resulting from the coexistence of heterogeneous devices operating in these bands is on the rise. Take the license- free industrial, scientific, and medical (ISM) radio band. It is crowded by wireless local area network (WLAN) equipment, Bluetooth devices, microwave ovens, cordless phones, and other users. Devices, which are using unlicensed bands, need to have higher performance capabilities to have better job managing user quality of service (QoS). The limited availability of spectrum and the non-efficient use of existing RF resources necessitate a new communication paradigm to exploit wireless spectrum opportunistically and with greater efficiency. The new paradigm should support methods to work around spectrum availability traffic jams, make communications far more dependable, and of course reduce interference among users. The present shortage of radio spectrum can also be blamed in large part on the cost and performance limits of current and legacy hardware. Next generation wireless technology-like software defined radio (SDR) may well hold the key to promoting better spectrum usage from an underlying hardware/ physical layer perspective. SDR uses both embedded signal processing algorithms to sift out weak signals and reconfigurable code structures to receive and transmit new radio protocols. However, the system-wide solution is really cognitive radio.

In a typical cognitive radio scenario, users of a given frequency band are classified into primary users and secondary users. Primary users are licensed users of that frequency band. Secondary users are unlicensed users that opportunistically access the spectrum when no primary users are operating on that frequency band. This scenario exploits the spectrum sensing attributes of cognitive radio. Cognitive radio networks form when secondary users utilize “holes” in licensed spectrum for communication. These spectrum holes are temporally unused sections of licensed spectrum that are free of primary users or partially occupied by low-power interferers. The holes are commonly referred to as white or gray spaces. Figure 2 shows a scenario of primary and secondary users utilizing a frequency band.

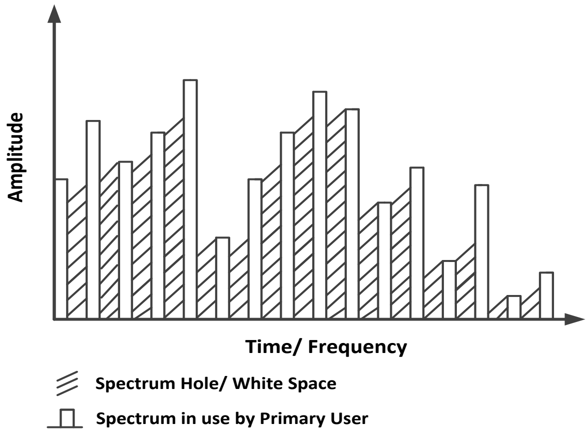

Figure 2. CRN Concepts: Spectrum Holes

In the other cognitive scenario, there are no assigned primary users for unlicensed spectrum. Since there are no license holders, all network entities have the same right to access the spectrum. Multiple cognitive radios co-exist and communicate using the same portion of spectrum. The objective of the cognitive radio in these scenarios is more intelligent and fair spectrum sharing to make open spectrum usage much more efficient. It will help in utilizing the unused channels and also use spectrum efficiently, also includes the better channel assignment and management policy.

IV. Spectrum Sensing Techniques

Cognitive radio attempts to discern areas of used or unused spectrum by determining if a primary user is transmitting in its vicinity.

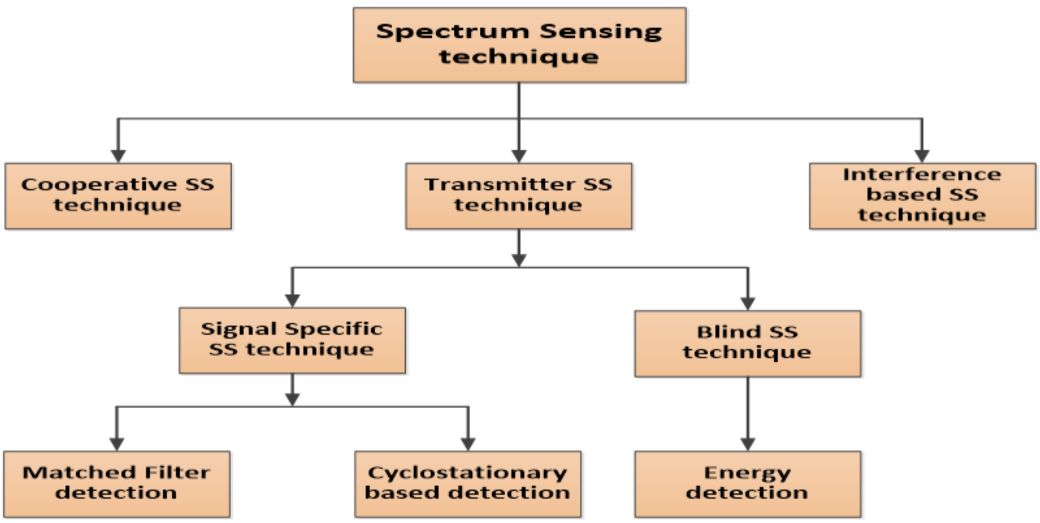

Figure 3. CRN Spectrum Sensing Techniques

The aim of the cognitive radio is to use the natural resources efficiently including frequency, time, and transmitted energy. Cognitive radio technologies can be used in lower priority secondary systems that improve spectral efficiency by sensing the environment and then filling the discovered gaps of unused licensed spectrum with their own transmissions. Unused frequencies can be thought as a spectrum pool from which frequencies can be allocated to secondary users (SUs) and SU can also directly use frequencies discovered to be free without gathering these frequencies into a common pool. In addition, CR techniques can be used internally within a licensed network to improve the efficiency of spectrum use. In cognitive radio network the cognitive radio users monitor the radio spectrum periodically and opportunistically communicate over the spectrum holes

As shown in Figure 3 there are basically three types of spectrum sensing techniques for detecting PU licensed spectrum band [1-3].

4.1 Cooperative spectrum sensing technique or collaborative spectrum sensing technique.
4.2 Transmitter spectrum sensing technique.
4.3 Interference based spectrum sensing technique.

4.1 Cooperative SS technique

In cooperative detection, multiple cognitive radios work together to supply information to detect a primary user. This technique exploits the spatial diversity intrinsic to a multi-user network. It can be accomplished in a centralized or distributed fashion. In a centralized manner, each radio reports its spectrum observations to a central controller which processes the information and creates a spectrum occupancy map of the overall network. In a distributed fashion, the cognitive radios exchange spectrum observations among themselves and each individually develop a spectrum occupancy map.

Cooperative detection is advantageous because it helps to mitigate multi-path fading and shadowing RF pathologies which increase the probability of primary user detection. Additionally, it helps to combat the dreaded hidden node problem which often exists in ad hoc wireless networks. The hidden node problem, in this context, occurs when a cognitive radio has good line of sight to a receiving radio, but may not be able to detect a second transmitting radio also in the locality of the receiving radio due to shadowing or because the second transmitter is geographically distanced from it. Cooperation between several cognitive radios alleviates this hidden node problem because the combined local sensing data can make up for individual cognitive radio errors made in determining spectrum occupancy. Sensing information from others results in an optimal global decision.

4.2 Transmitter SS Technique

In transmitter spectrum sensing technique, secondary users detect those signals that are transmitted through transmitter. To detect the PU signal, there is a mathematical hypothesis expression for received signal given as

$$x(n) = \begin{cases} w(n), & H_0 \\ s(n)h(n) + w(n), & H_1 \end{cases} \tag{3}$$

In the given expression, *x(n)* shows signal received by each CR user. *s(n)* is the PU licensed signal, $w(n) \sim N(0, \sigma_w^2)$ is additive white Gaussian Noise with zero mean and variance σ_w^2, the channel considered between PU and CR is Rayleigh channel and *h(n)* denotes the Rayleigh fading channel gain of the sensing channel between the PU and the CR user. H_0 known as null hypothesis shows the absence of PU while H_1 is the alternative hypothesis shows that PU is present. Further, transmitter spectrum sensing technique divided into two categories. One is Signal Specific sensing technique, and another is Blind sensing technique.

4.2.1 Signal Specific Spectrum Sensing Technique: It requires prior knowledge of Primary User (PU) signal. The examples are Matched filter detection, and Cyclostationary based detection.

4.2.1.1 Matched Filter Detection: Matched filter detection technique sometimes called coherent detection, which is an optimum spectrum detection method, requires prior information of primary user (PU) and increases SNR (signal to noise ratio). In another word, when primary user signal information, such as modulation type, pulse shape, packet format, etc., is known to a cognitive radio, the optimal detector in stationary Gaussian noise is the matched filter since it maximizes the received SNR. The matched filter works by correlating a known signal, or template, with an unknown signal to detect the presence of the template in the unknown signal. Figure 4 provides a graphical representation of this process. Because most wireless network systems have pilots, preambles, synchronization word, or spreading codes, these can be used for coherent (matched filter) detection. A big plus in favor of the matched filter is that it requires less time to achieve a high processing gain due to coherency. The main shortcoming of the matched filter is that it requires a priori knowledge of the primary user signal which in a real world situation may not be available, and implementation is complex.

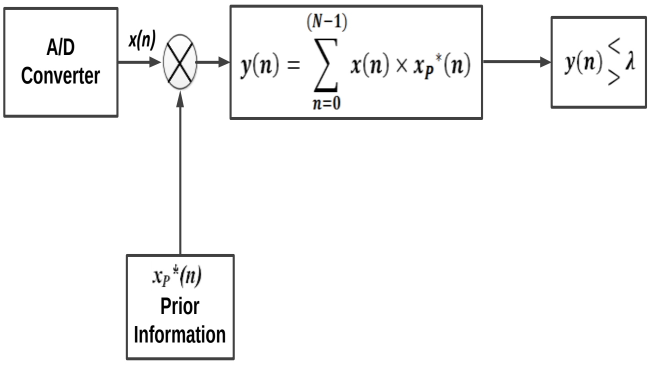

Figure 4. Matched Filter Detector

4.2.1.2 Cyclostationary based Detection: In Cyclostationary based detection; signal is seen to be cyclostationary if its statistics i.e. mean or autocorrelation is a periodic function over a certain period of time. Because modulated signals (i.e., messages being transmitted over RF) are coupled with sine wave carriers, repeating spreading code sequences, or cyclic prefixes all of which have a built-in periodicity, their mean and autocorrelation exhibit periodicity which is characterized as being cyclostationary. Noise, on the other hand, is a wide-sense stationary signal with no correlation. Using a spectral correlation function, it is possible to differentiate noise energy from modulated signal energy and thereby detect if a primary user is present. The cyclostationary detection has several advantages. It can differentiate noise power from signal power, more robust to noise uncertainty and can work with lower SNR. But it requires partial information of PU which makes it computationally complex, and long observation time is required. Figure 5 shows the block diagram of cyclostationary based detector.

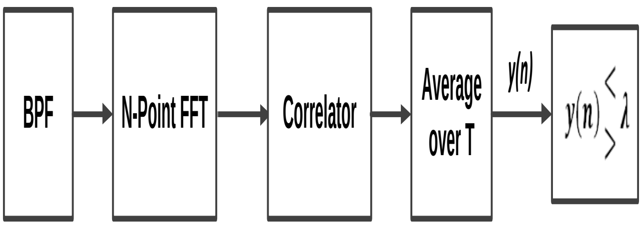

Figure 5. Cyclostationary based Detector

4.2.2 Blind Spectrum Sensing Technique: Blind detection technique does not require prior knowledge of Primary User (PU) signal. Energy detector is the example of this kind of sensing technique.

4.2.2.1 Energy Detection: In Energy detector, if a receiver cannot gather sufficient information about the primary user's signal, such as in the case that only the power of random Gaussian noise is known to the receiver, the optimal detector is an energy detector. Energy detection implementation and computation are easier than others. However, there are some limitations such as, at low SNR its performance degrades, it cannot distinguish interference from a user signal, and it is not effective for signals whose signal power has been spread over a wideband. Figure 6 shows the block diagram of energy detector.

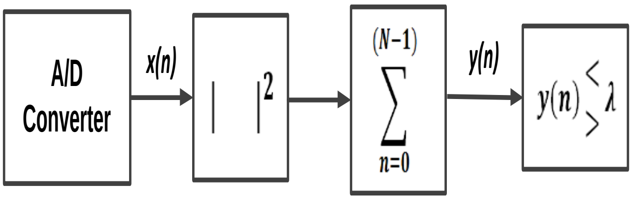

Figure 6. Energy Detector

Now, there are some important parameters related to spectrum sensing performance e.g. probability of detection (P_d), probability of false alarm (P_f), and probability of miss detection (P_m). The probability of detection is the probability of accurately deciding the presence of the primary user's signal. The probability of false alarm refers to the probability that the secondary user incorrectly decides that the channel is idle when the primary user is actually transmitting, and the probability of miss detection refers to the probability that the secondary user missed the primary user signal when the primary user is transmitting.

4.3 Interference based SS Technique

This method differs from the typical study of interference which is usually transmitter-centric. Typically, a transmitter controls its interference by regulating its output transmission power, its out-of-band emissions, based on its location with respect to other users. Cognitive interference-based detection concentrates on measuring interference at the receiver. The FCC introduced a new model of measuring interference referred to as interference temperature. The model manages interference at the receiver through the interference temperature limit, which is the amount of new interference that the receiver can tolerate. The model accounts for cumulative RF energy from multiple transmissions and sets a maximum cap on their aggregate level. As long as the transmissions of cognitive radio users do not exceed this limit, they can use a particular spectrum band. The major hurdle with this method is that unless the cognitive user is aware of the precise location of the nearby primary user, interference cannot be measured with this method. An even bigger problem associated with this method is that it still allows an unlicensed cognitive radio user to deprive a licensee (primary user) access to his licensed spectrum. This situation can occur if a cognitive radio transmits at high power levels while existing primary users of the channel are quite far away from a receiver and are transmitting at a lower power level.

V. Issues In Cognitive Radio Networks

Cognitive radio network is a future based wireless communication technology. Due to this, there are varies challenges or issues related to cognitive radio networks. In this paper, we are dealing with certain major problems described as

5.1 Spectrum Sensing Failure Problem

In energy detector based spectrum sensing technique, noise uncertainty [4] arises the difficulty in setting the ideal threshold for a CR and therefore reduces its spectrum sensing reliability [5], Moreover this may not be optimum under low SNRs where the performance of fixed threshold (λ_1) based ED can fluctuate from the desired targeted performance metrics significantly.

In Figure 7, *x-axis* shows the power level of signals and *y-axis* shows the signals probability. There are two curves, depicts the primary user (PU) signal and noise curve. According to CRN scheme, it is very easy to detect PU and noise if both signals are separate from each other. Like ED gets PU signal then it shows H_1 i.e. channel is occupied, and if gets noise signal it shows H_0 i.e. channel is un-occupied. But, if PU signal and noise both intersects to each other then it is very difficult to sense desired signals. In Figure 7, the area comes between PU and noise curve or under upper bound (λ_1) and lower bound (λ_2) is known as confused region. In this region using single threshold detection of noise and PU signal is very difficult.

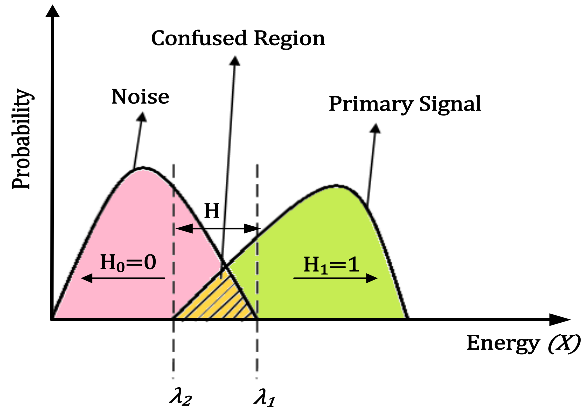

Figure 7. Energy Distribution of Primary user Signal and Noise

5.2 Fading & Shadowing Problem

Multipath fading & shadowing is one of the reason of arising hidden node problem in Carrier Sense Multiple Accessing (CSMA). Figure 8 depicts an illustration of a hidden node problem where the dashed circles show the operating ranges of the primary user and the cognitive radio device. Here, cognitive radio device causes unwanted interference to the primary user (receiver) as the primary transmitter's signal could not be detected because of the locations of devices. Cooperative sensing is proposed in this paper for handling multipath fading & shadowing problem.

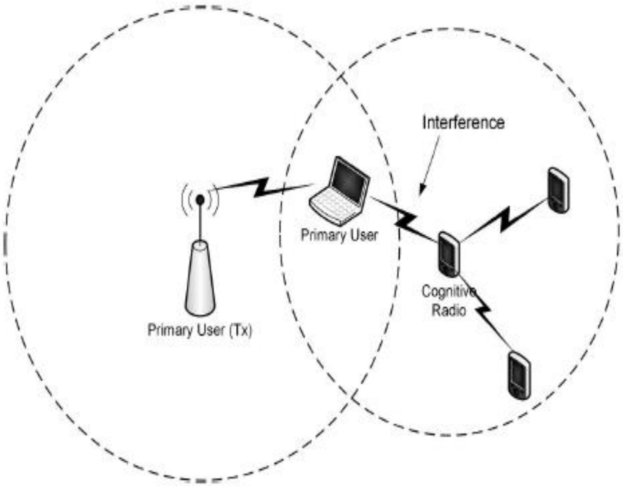

Figure 8. Illustration of Hidden Primary user Problem in CRNs

5.3 Spectrum Sensing Time

The SS time defines the total time taken by CR user to detect PU signal. Suppose SS time is increased then PU can utilize its spectrum in a better manner and the limit is decided that CR can't interfere throughout that much of time. More PUs will be detected if more the SS, due to this the level of interference will be less. The SS time is directly related to the number of samples received by the CR user. The more sensing time is devoted to detecting, the less sensing time is available for transmissions and hence degrading the CR throughput. This is known as the sensing efficiency problem [6] or the sensing-throughput tradeoff [7] in SS.

VI. Conclusion

This paper presented a review study of various spectrum sensing techniques. As we discussed that there are various sensing techniques but three of them are mainly used, named as matched filter, energy detector, and cyclostationary features based detection techniques. Each sensing technique had its own advantages and disadvantages. Matched filter detection improved SNR, but required the prior information of PU for better detection. Energy detection had the advantage that no prior information about PU was required, but did not perform well under low SNR. At other side cyclostationary feature detection performed better than both, but required PU information.

We further discussed and explained the functions of cognitive radio networks. As CRN is one of the hottest research topics in wireless communication that's why there are certain challenges which we had covered and discussed. In future, we will try to resolve challenges of CRN.

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References

[1] Ashish Bagwari, and Brahmjit Singh, "Comparative performance evaluation of Spectrum Sensing Techniques for Cognitive Radio Networks," 2012 Fourth IEEE International Conference on Computational Intelligence and Communication Networks (CICN-2012), pp. 98-105, (**2012**)

[2] D. Cabric, S. M. Mishra, and R. W. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in Proc. 2004 Asilomar Conf. Signals, Syst., Comput., vol. 1, pp. 772–776, **(2004)**.

[3] Yonghong Zeng, Ying-Chang Liang, Anh Tuan Hoang, and Rui Zhang, "A Review on Spectrum Sensing for Cognitive Radio: Challenges and Solutions", EURASIP Journal on Advances in Signal Processing, vol. 2010, pp. 1-15, (**2010**).

[4] Chunyi Song, Yohannes D. Alemseged, Ha Nguyen Tran, Gabriel Villardi, Chen Sun, Stanislav Filin, and Hiroshi Harada, "Adaptive Two Thresholds based Energy Detection for Cooperative spectrum sensing," in Proc. 2010 IEEE CCNC, pp. 1-6, (**2010**) .

[5] R. Tandra, and A. Sahai, "SNR Walls for Signal Detection," IEEE Jour. of Slected Topic in Sig. Proc., vol. 2, no.1, pp. 4–16, Feb. (**2008**).

[6] W. Y. Lee, and I. F. Akyildiz. 2008. "Optimal spectrum sensing framework for cognitive radio networks," IEEE Transactions on Wireless Communications vol. 7, no.10, pp. 3845–3857, (**2008**).

[7] Y. C. Liang, Y. Zeng, E. Peh, and A.T. Hoang. 2008. "Sensing-throughput tradeoff for cognitive radio networks," IEEE Transactions on Wireless Communications vol. 7, no. 4, pp. 1326–1337, (**2008**).

[8] Ashish Bagwari, GS Tomar, "Two-stage detectors with Multiple Energy detectors and Adaptive Double-Threshold in Cognitive Radio Networks", Hindawi International Journal of Distributed Sensor Networks, Vol. 2013 pages 1-8, Aug **(2013).** ISSN- 1550-1329 DOI:10.1155/2013/656495

[9] Ashish Bagwari, GS Tomar, "Cooperative Spectrum Sensing in MEDs Based CRNs Using Adaptive Double-Threshold scheme", Taylors and Francis - International Journal of Electronics, Vol. 101, Issue 4, pp 37-41, Feb **(2014)**. ISSN-0020-7217DOI: 10.1080/00207217. 2014.880953

[10] Ashish Bagwari, GS Tomar, SS Bhadauria, "Multiple Antenna based Cognitive Radio Networks using Energy Detector with Adaptive Double-Threshold for Spectrum sensing", Taylors and Francis International Journal of Electronics Letters, Vol. 101/2 No.2, pp 83-91, Feb (**2001**).

