A Survey of Advanced Spectrum Sensing Techniques in Cognitive Radio Networks

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Abstract*: *Radio spectrum resource demand has increased extraordinarily due to emerging broadband wireless applications which have resulted to critical spectrum shortage problem. Cognitive radio technology is promising technology that can effectively use unutilized licensed spectrum and can solve spectrum shortage problem. Spectrum sensing is the key element of cognitive radio network to find unused spectrum. Hence effective and accurate spectrum sensing is compulsory for cognitive radio network. Cooperative spectrum sensing and Non-Cooperative spectrum sensing are two basic types of spectrum sensing. In Non-Cooperative spectrum sensing, spectrum sensing is performed individually by each cognitive radio node whereas in Cooperative spectrum sensing, spectrum sensing activity is performed in a group. This paper is a survey of various advanced spectrum sensing techniques. This paper covers basics of spectrum sensing along with its classification and challenges of spectrum sensing.

***Keywords*: Cognitive radio, Spectrum sensing, cooperative spectrum sensing, non-cooperative spectrum sensing.**

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I. INTRODUCTION

The use of wireless communication enabled devices has increased tremendously due to its multiple advantages. Due to its widespread use the demand of radio spectrum has increased heavily. The governmental agencies which are handling these wireless networks uses fixed channel assignment strategy to allot channel for the user. In this traditional technique spectrum access is given to licensed user dedicatedly. The biggest disadvantage of this fixed channel assignment strategy is inefficient spectrum utilization.

According to Federal Communications Commission (FCC) allocated spectrum to users are 15 % to 85 % free [1]. After recognizing the shortage of radio spectrum problem, the FCC is thinking of allowing access of licensed frequency band to unlicensed users on non-interfering basis with legitimate user. The efficiency of spectrum utilization can be increased if unlicensed user access licensed frequency band when licensed frequency band is idle without interfering licensed user. This technique is called Opportunistic Spectrum Sharing (OSS).

Cognitive radio (CR) is a promising technology which aims to solve the problem of ever-increasing spectrum demand and inefficient spectrum utilization. In Cognitive Radio first step is to search available frequency bands using spectrum sensing method for unlicensed secondary users (SU). When licensed primary user (PU) is not utilizing the spectrum band, they are considered as idle or available. The unused Primary licensed bands are called as spectrum hole or white space. In second step idle channels will be allocated to unlicensed secondary users using dynamic spectrum access. Whenever legitimate user wants to access licensed band, SU immediately has release the licensed frequency band [2, 3].

Basically spectrum sensing methods are classified in two types - Cooperative spectrum sensing and Non-cooperative spectrum sensing. In Cooperative spectrum sensing, spectrum sensing decision is made by Fusion Center on the basis of sensing information gathered from every cooperating cognitive radio node. In distributed cooperative sensing method CR nodes communicate with each other to decide presence or absence of primary users.

In Non-cooperative spectrum each CR node senses spectrum individually. Energy detection, Matched filter detection, Cyclostationary feature detection method are non-cooperative spectrum sensing methods. The Energy detection method is very popular since it is easy to implement and it does not require any prior information about primary signal. The Matched filter detection method requires prior knowledge of primary signal and it also maximizes SNR for accurate decisions. In Cyclostationary feature detection method primary user presence is recognized by realizing periodicity in the received signal. This method requires a prior knowledge of the signal, but it performs well under low SNR regions.

The rest of the paper is organized as follows. We will discuss basics of cognitive radio technology under section II. Section III consists of various spectrum sensing methodologies and classification of spectrum sensing methods. Advanced spectrum sensing methods along with

challenges in spectrum sensing will be in Section IV. In V section, we will conclude the article with conclusion.

II. COGNITIVE RADIO TECHNOLOGY OVERVIEW

The cognitive cycle which shows fundamental cognitive tasks is shown below [4].

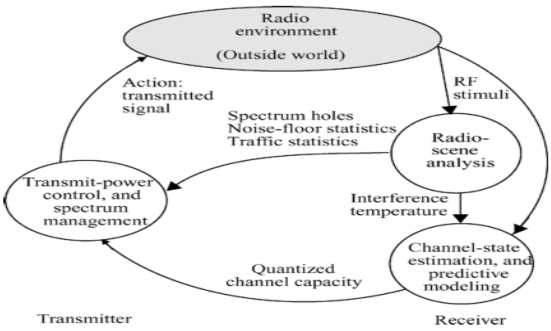

Figure1. Basic Cognitive cycle [3]

Cognitive radios are basically an extension of software defined radios [5]. Cognitive process is basically performed in three steps which start with the sensing of RF stimuli. Three Cognitive steps are

1. Radio – scene analysis, which detects spectrum holes

2. Channel Identification, which estimates channel state information and predicts channel capacity

3. Dynamic spectrum access management and transmit power control.

These three steps constitute a cognitive cycle. Cognitive radios can be considered as intelligent due to its awareness and ability to sense the radio environment.

In a practical scenario, there can be a large number of cognitive radio nodes, which forms cognitive radio network. But basically a cognitive radio network has three basic constituents

1. Station/Mobile Station (STA/MS)

2. Access Point/Base Station (AP/BS)

3. Backbone network/Distribution system.

Cognitive radio network system architectures are divided into two types

1. Infrastructure-based Network

Several nodes, called stations/Mobile station (STA_i/MS) connect to, access points/Base station (AP/BS). Stations are terminal with access mechanisms to the wireless medium and radio contact to the access point [6]. STA/MS having CR capability can communicate with another device only through the AP/BS. The STA/BS and AP/BS which are within the same radio coverage form a Basic service set/cell (BSS). A distribution system/Backbone network connects several BSSs/cells via AP/BS to form a single network.

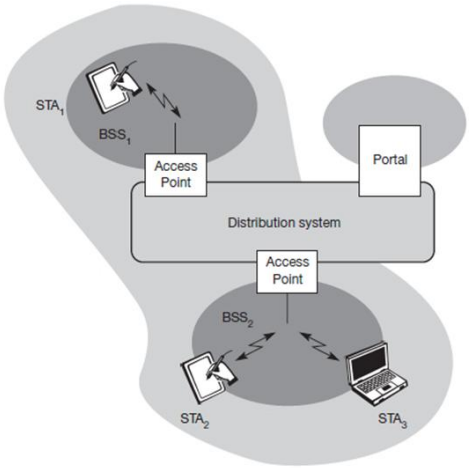

Figure 2. Architecture of Infrastructure-based Cognitive Radio Network [18]

2. Ad-hoc Network

AP/BSs are not needed in Ad-hoc cognitive radio networks. Independent BSSs (IBSS) are formed between STA/MS. STA/MS establish links between them using various communication protocols [6].

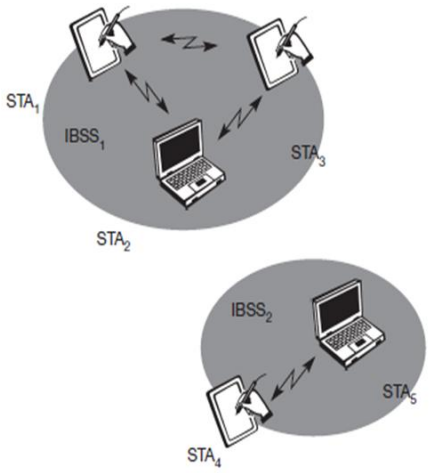

Figure 3 Architecture of Ad-hoc cognitive radio network [6]

III. BASIC SPECTRUM SENSING TECHNIQUES AND ITS CLASSIFICATION

The key element in cognitive radio network is spectrum sensing. Ensuring the accurate spectrum sensing is a very important problem which needs to be addressed. In CRN, SUs are permitted to access licensed band on non-interfering basis to PUs. It is very important for CRN to distinguish between PU signals and SU signals to ensure proper operation of the network. There are two basic types of spectrum sensing.

A. Cooperative spectrum sensing

In cooperative sensing, all cooperating CR nodes individually perform spectrum sensing operation. Fusion center (FC)/Base station (BS) decides the frequency band for

sensing. The result of spectrum sensing performed by each CR node is reported back to FC/BS where received sensing information is processed. In last, FC/BS decides presence of primary user [7, 8].

Advantages of cooperative sensing – 1) Accurate spectrum sensing 2) It solves to hidden node problem.

Disadvantages of cooperative sensing – 1) Increased sensing time.

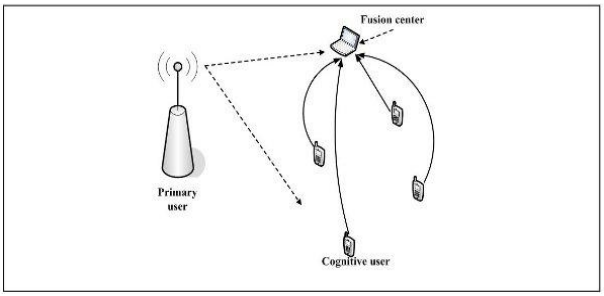

Figure 4. Cooperative spectrum sensing architecture

B. Non-cooperative spectrum sensing

In this technique, each cognitive radio node senses spectrum individually and decides independently about the presence of primary signal in a specified frequency band. There are three types of non-cooperative spectrum sensing, which is summarized in a following table.

TABLE 1: NON-COOPERATIVE SPECTRUM SENSING TECHNIQUES

Spectrum sensing technique	**Functionality**	**Advantages**	**Disadvantages**
Energy Detection (Radiometer) [9, 10]	It is non-coherent detection method. It is used when prior knowledge of signal is unavailable. Three sections of radiometer consist of BPF, squaring device and integrator.	1. Short sensing time 2.Less computational and implementation complexity	1. Requires long sensing time to achieve accurate results 2. Under low SNR performance degrades
Matched filter detection (Coherent detector) [11, 12]	It consists of BPF, matched filter and Threshold comparator. Convolution of unknown signal and filter takes place in matched filter.	1. Low sensing time 2. It maximizes signal to noise ratio for accurate decision.	1. Requires prior knowledge of primary signal 2.High computational complexity
Cyclostationary Feature detection [10, 13]	Primary user detection is done by accomplishing the periodicity of the received primary signal	1.Good performance low SNR	1.High computational complexity

IV. ADVANCED SPECTRUM SENSING TECHNIQUES AND CHALLENGES OF SPECTRUM SENSING

a. Double threshold based Cooperative Sensing

In this method presence of primary user is decided on the basis of previous spectrum sensing history and comparison of two thresholds with test statistic [14]. Also AND rule to is employed for the detection primary user signal. This method, single threshold based detection and double threshold based are compared using probability of detection and probability of false alarm performance matrices. In case of uncertainty of decision number of times re-sensing performed, SNR and number of samples etc. parameters are also compared. Then final decision about the presence or absence of primary user is made. The advantage of this method is the good accuracy of spectrum sensing.

b. Phase frequency detector (PFD) based spectrum sensing

This method locates spectrum holes based on comparison of frequency with the help of Phase frequency detector (PFD). The basic work of PFD is to detect the frequency and phase difference between two input signals [15]. The block diagram of PFD based spectrum sensing is given below.

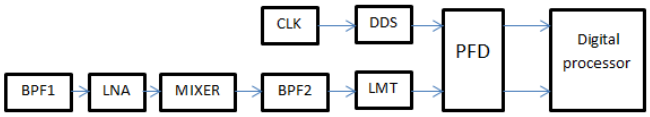

Figure 5 PFD based spectrum sensing [15]

The block diagram has following sections- BPFs, Low noise amplifier (LNA), Local oscillator (LO), Ref. Clock, Limiter, PFD and Digital processor. This method has a fast spectrum sensing time along with good accuracy. Complexity of the system is high.

c. Alternative selection based detection method for spectrum sensing

An alternative selection based method is a combination of energy detection method and covariance absolute value (CAV) detection method [16]. The Energy detection method is widely used because it is easy to implement, but it also suffers from noise. CAV method is based on autocorrelations or statistical covariance of the received signal [17]. For highly correlated signals the CAV method is quite efficient. The Combination of these methods has improved performance of overall system compared to energy detection and CAV method alone.

d. Cooperative Maximum to Minimum Eigenvalue (MME) sensing method for Energy efficiency

In this method energy efficiency is achieved by finding optimal values of probability of a user wait or handoff to another channel while PU utilizing current channel. Cooperative MME spectrum sensing method performance is better than Energy detection method as it is does not depend on the uncertainty of noise [18, 19].

- *Challenges of spectrum sensing*

1. Spectrum sensing time – Secondary user must free licensed band on the arrival of Primary user. So it is very important for a CR node to sense the presence of PU signal within short time.

2. Hidden terminal problem – Shadowing is the basic cause of the hidden terminal problem. A Hidden terminal may cause collision and unnecessary delay for transmission.

3. Security – Security issues are very important for cognitive radio networks for its smooth operation. Various types of attackers e.g. PUE attack, Jamming attack, Eavesdropping attack, etc. leave adverse impact on network performance [20,21]. Hence security becomes very important issue to address.

V. CONCLUSION

Very important part in the cognitive radio is an accurate spectrum sensing which finds unused frequency bands or white spaces. Various methods can be employed to detect vacant licensed band. In this article alongwith basic sensing methodologies few advanced spectrum sensing methods are also discussed. By analyzing all these spectrum sensing methods we can conclude that the non-cooperative spectrum sensing doesn't produce accurate spectrum sensing results as probability of misdetection is more. Cooperative spectrum sensing method gives an accurate spectrum sensing also it solves few problems like hidden terminal, false alarm detection, but energy consumption is more. Hence few advanced spectrum sensing techniques are employed to solve these issues. Still, there are few challenges of spectrum sensing which needs to be addressed. So it is a potential research area for the researchers to work and sort out the challenges of spectrum sensing.

REFERENCES

[1] Danijela Cabric, Shridhar Mubaraq Mishra, Rober W Brodrsen, "Implementation Issues in spectrum sensing for Cognitive Radio" ,IEEE, 2004.

[2] Shuai Li ; Haojin Zhu ; Zhaoyu Gao ; Xinping Guan ; Kai Xing ; Xuemin Shen, "Location privacy preservation in collaborative spectrum sensing", IEEE INFOCOM'12, pp. 729-37.

[3] X. Tan, hang,. "A CORDIC-Jacobi based spectrum sensing algorithm for cognitive radio", KSII Trans. Internet and Info. Systems, 2012 Vol. 6, no. 9, pp. 1988-2016.

[4] Simon Haykin, "Cognitive radio: Brain-empowered wireless communications". IEEE Journal on selected areas in communications, 2004, Vol. 23, No. 2, 201-20

[5] J. Mitola, "Cognitive radio for flexible multimedia communications" in Proceedings of MoMuC99, 1999, pp. 3-10.

[6] Jochen Schiller, "Mobile communications". Second edition. 2013 Pearson education Ltd.

[7] Siranjeevi, M,,Karthikeyan, K.V., "A study analysis of cooperative spectrum sensing in cognitive radio network ",IEEE Second International Conference on Science Technology Engineering and Management (ICONSTEM), Jeppiaar Engineering College ,30-31 March 2016, pp 551-555

[8] Ian F. Akyildiz, Brandon F. Lo, Ravikumar Balakrishnan, "Cooperative spectrum sensing in cognitive radio networks: A survey", Physical communication 4, 2011, 40-62.

[9] H. M. Farag, Ehab M, "An Efficient Dynamic Thresholds Energy Detection Technique for Cognitive Radio Spectrum Sensing", IEEE,10th International Computer Engineering Conference (ICENCO), Page(s): 139 – 144

[10] Mansi Subhedar, Gajanan Birajdar, "Spectrum sensing techniques in cognitive radio networks : A survey", International Journal of next-generation networks(IJNGN), 2011, Vol. 3, No. 2.

[11] Xinzhi Zhang, Rong Chai, Feifei Gao, " Matched filter based spectrum sensing and power level detection for cognitive radio network", IEEE Global Conference on Signal and Information Processing (GlobalSIP), 2014, Page(s) : 1267– 1270.

[12] S Kokare, RD Kambale, "Spectrum sensing techniques in cognitive radio cycle", IJETT, 2014, Vol. 9, No. 11.

[13] Amruta V, K. V. Kathikeyan, "Spectrum Sensing Methodologies in Cognitive Radio Networks: A Survey", IEEE International Conference on Innovations in Electrical, Electronics, Instrumentation and Media Technology ICIEEIMT, 2017, Page(s): 306 – 310

[14] Smriti, Chhagan Charan, "Double Threshold Based Cooperative Spectrum Sensing with Consideration of History of Sensing Nodes in Cognitive Radio Networks", IEEE, 2018.

[15] Abdul Ansari, S. M. Gulhane, Thorat Pallavi, "Implementation of PFD based spectrum sensing method in applications of cognitive radio", ICACDOT,2016, I2IT, Pune.

[16] Abdul Rahim, Mruthyunjaya H. S., Vishnamurthy Kedalya K, "An Alternative Selection Based Detection Method for Spectrum Sensing for Cognitive Radio", Third International conference on Advances in computing and communications, 2013.

[17] Y.Zheng and Y.C. Liang, "Spectrum sensing algorithms for cognitive radio based on statistcial covariances" IEEE Transactions on Vehicular Technology, 2014, vol. 58, no. 4,pp. 1804-1815.

[18] Syarifah Putri, Dr. Ir. Sugilhartono, "Energy efficiency in cognitive radio with cooperative MME (Maximum to Minimum Eignevalue) spectrum sensing method", IEEE International seminar on Intelligent Technology and its application, 2015.

[19] Y. Zeng, Y. chang, Liang, "Eigenvalue Based Spectrum Sensing Algorithm for Cognitive Radio", IEEE transactions on communications, Vol. 57, no. 6, June 2009.

[20] Ameer Sameer Hamood, Sattar B. Sadkhan., "Cognitive Radio Network Security Status and Challenges", IEEE Annual Conference on New Trends in Information & Communications Technology Applications, 2017, Pages: 1-6.

[21] Amir Ghasemi, Elvino S. Sousa " Spectrum Sensing in Cognitive Radio Networks: Requirements, Challenges and Design Tradeoffs", IEEE CommnMagazine, April 2008.

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