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Spectrum Sensing for Cognitive Radio

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***Abstract*—Cognitive radio is considered as a promising approach to improve the utilization efficiency of radio spectrum resources. One of the key technologies of cognitive radio is spectrum sensing. A survey of spectrum sensing methodologies for cognitive radio is presented in the paper. The advantages and disadvantages of several spectrum sensing algorithms are analyzed and the challenges of spectrum sensing to be realized are also proposed.**

Keywords-cognitive radio, spectrum sensing, cooperative sensing

I. INTRODUCTION

Traditional fixed spectrum allocation policies results in situations where some radio bands are overcrowded while other bands remain moderately or rarely occupied. According to actual measurement, most of the licensed radio spectrum is poorly utilized [1]. Cognitive radio has been proposed as a potential wireless communication paradigm to improve radio spectrum utilization efficiency [2], [5], [8]. Cognitive radio is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones.

The ultimate objective of a cognitive radio is twofold [5]: provide highly reliable communication for all users of the network, wherever and whenever needed; facilitate efficient utilization of spectrum in a fair-minded and cost-effective manner.

Cognitive radio includes four main functional blocks [3]: spectrum sensing, spectrum management, spectrum sharing and spectrum mobility. Spectrum sensing aims to determine which spectrum is available and to detect the presence of the licensed users (also known as a primary user) when a user operates in a licensed band. Spectrum management is to predict how long the spectrum holes are likely to remain available for use to the unlicensed users (also called cognitive radio users or secondary users). Spectrum sharing is to distribute the spectrum holes fairly among the secondary users, bearing in mind usage costs. Spectrum mobility is to maintain seamless communication requirements during the transition to better spectrum.

Spectrum sensing is believed the most important part to establish cognitive radio networks.

In this paper, we survey the algorithms of spectrum sensing and the challenges to realize. The rest of the paper is organized as follows: section 2 surveys the current typical spectrum sensing technologies and analyzed their characteristics. Section 3 discusses spectrum sensing challenges. Section 4 gives the conclusion of this paper.

II. SPECTRUM SENSING

The spectrum has been classified into three types :black spaces, grey spaces and white spaces by estimating the incoming RF stimuli. Grey spaces and white spaces are candidates for secondary use [5].

A key problem in cognitive radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and quit the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary users. The technique is called spectrum sensing, which is a fundamental problem in cognitive radio.

Generally, spectrum sensing techniques can be divided into three categories: transmitter detection, cooperative detection and interference based detection [3], [6].

A. Transmitter Detection

Transmitter detection is based on the detection of the weak signal from a primary transmitter through the local observation of cognitive radios.

Transmitter detection is non cooperative detection; it can't avoid the hidden terminal problem [3].

Transmitter detection is mainly included matched filter detection, energy detection and feature detection.

1) Matched filter detection

A matched filter is a linear filter designed to maximize the output signal to noise ratio for a given input signal. When secondary user has a priori knowledge of primary user signal, matched filter detection is applied.

a) Advantages of matched filter detection: Matched filter detection needs less detection time because it requires only O(1/SNR) samples to meet a given probability of detection constraint[8].When the information of the primary user signal is known to the cognitive radio user, matched filter detection is optimal detection in stationary Gaussian noise.

b) Disadvantages of matched filter detection: Matched filter detection requires a prior knowledge of every primary

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user, if this information is not accurate, the matched filter performs poorly [3], [7], [8].

2) Energy detection

Energy detection detects the spectrum by measuring the energy of the received signal in a certain frequency band, also called radiometry. It is the most common detection method for spectrum sensing in cognitive radio networks.

a) Advantages of energy detection: Implementation simplicity and comutational complexities low: an energy detector can be implemented similar to a spectrum analyzer by averaging frequency bins of a FFT. Since it is easy to implement, the recent work on detection of the primary user has generally adopted the energy detector. In addition, energy detection is the optimum detection if the primary user signal is not known.

b) Disadvantages of energy detection: The performance of the energy detector is highly susceptible to noise level uncertainty. The noise uncertainty causes problems especially in the case of a simple energy detector because it is difficult to set the threshold properly without the knowledge of the accurate noise level. Secondly, an energy detector cann't differentiates between modulated signals, noise, and interference [3]. The performance of an energy detector in shadowing and fading environments degrades clearly. Moreover, it is hard to select the right threshold for energy detection.

3) Feature detection

Feature detection captures a specific signature of the primary user signal, such as pilot, segment sync, field sync, or cyclostationarity. Many of the signals used in wireless communication and radar systems possess this property. The idea of the cyclostationary feature detection is to utilize the built-in periodicity of the modulated signal [7].

a) Advantages of feature detection: The main advantage of the feature detection is that it can discriminate the noise energy from the modulated signal energy. Furthermore, cyclostationary feature detection can detect the signals with low SNR .

b) Disadvantages of feature detection: Feature detection requires long observation time and higher computationally complex [3], [7]. In addition, feature detection needs the prior knowledge of the primary users .

B. Cooperative detection

Cooperative detection by combining the observations of several cognitive radio users can be used to improve the performance of spectrum sensing [3], [4], [6], [10].

Cooperative detection can be implemented in a distributed or centralized manner [6].The cooperative schemes can be classified into three regimes according to the cooperative level: decentralized uncoordinated techniques, centralized coordinated techniques and decentralized uncoordinated techniques [10].

1) Advantages of cooperative detection: Lower detection sensitivity requirements. Channel impairments such as shadowing, multipath fading, and building penetration losses high sensitivity requirements on cognitive radios. The sensitivity requirement can be drastically reduced by cooperation detection [3], [4], [6], [11]. Improve the agility of the detection. One of the biggest challenges in cognitive radio is reduction of the overall detection time. Cooperative detection can reduce detection time compared to uncoordinated detection, so it can improve agility of the detection.

2) Disadvantages of cooperative detection: Firstly, cooperation increases the overhead of the cognitive radio network. Secondly, cognitive radio users are usually low cost and low power devices that might not have dedicated hardware for cooperation. Therefore data and cooperation information have to be multiplexed that can cause degradation of throughput for the cognitive user. Lastly, cooperative detection needs control channels[9].

C. Interference based detection

Interference temperature [5] is defined as the temperature equivalent of the total interference present in RF environment for a particular frequency band and a geographic location.

Interference temperature model was introduced by FCC. The model attempts to regulate interference at the receives. As long as the cognitive radio users do not exceed the interference temperature limit, they can use the spectrum band. That is, during the interference based detection, the cognitive radios have to measure the interference temperature and adjust their transmission in a way that they avoid raising the interference temperature over the interference temperature limit.

1) Advantages of interference based detection: Interference based detection can avoid the hidden terminal problem.

2) Disadvantages of interference based detection: Firstly, It's hard to measure interference temperature [5],[12].Secondly,during the inerferced based detection, cognitive radio users can't distinguish between actual signals from the primary users and noise or interference.

III. SPECTRUM SENSING CHALLENGES

A. Spectrum sensing in multi-user networks

Usually, cognitive radio networks lies in environment which consists of multiple secondary users and multiple primary users. In addition, the cognitive radio networks can be co-located with other secondary networks competing for the same spectral resources [3]. Secondary users can interfere with each other in spectrum sensing which makes it more difficult to detect primary users reliably.

Generally, in multi-user networks, cooperative detection is essential. There are several open research challenges in multi-user network operation [13]. What kind of cooperation is really needed to efficiently exploit the spatial diversity? Besides spectrum holes, what information should be distributed (location, transmitted power and frequency of different users)? How to cooperate with other secondary

networks? Do we need to cooperate with primary networks too? How many secondary users cooperative in detection?

B. Hardware Requirements [14]

Spectrum sensing for cognitive radio requires high sampling rate, high resolution analog to digital converters with large dynamic range, and high speed signal processors. If these hardware can't meet the requirements, spectrum sensing will not be implemented.

C. Detection capability

One of the main requirements of cognitive radio networks is the very short detection time [6], [8], [11]. But the current proposed detection algorithms are not to be ideal.

D. Security

In cognitive radio networks, wireless devices do not operate in fixed spectrums, but search and find appropriate spectrums to operate in, so some security issues have to be addressed. At first, cognitive radio networks inherit security problems from general wireless networks. Secondly, cognitive radio networks have some new security problems, such as spectrum misusage and selfish misbehaviors; primary user emulation attack and eavesdropping.

E. Interference temperature measurement

Two primary challenges in interference temperature concept are [12]: the determination of the background interference environment and the measurement of the interference temperature. Moreover, current interference model do not consider multi-user.

F. Spread Spectrum Primary Users Detection [7],[14]

Primary users that use spread spectrum signaling are difficult to detect as the power of the primary user is distributed over a wide frequency range even though the actual information bandwidth is much narrower.

IV. CONCLUSION

Spectrums sensing is the key technique in the cognitive radio networks. The advantages and disadvantages of the spectrum sensing are overviewed and the challenges of the spectrum sensing to realize are discussed in the paper.

REFERENCES

[1] FCC, "spectrum policy task force," Tech. Rep., Nov. 2002.

[2] J. Mitola, III and G. Q. Maguire, "Cognitive radio: Making software radios more personal," IEEE Personal Commun., Mag.,vol.6, no.4, pp.13–18, Aug.1999.

[3] I.. F. Akyildiz *et al.*, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey," Elsevier Computer Networks, vol. 50, pp. 2127-2159, Sep. 2006.

[4] S. M. Mishra, A. Sahai and R. W. Brodersen , "Cooperative sensing among cognitive radios," in Proceedings of IEEE International Conference on Communications (ICC'06), Istanbul, Turkey, pp. 1658–1663, June 2006.

[5] S. Haykin, "Cognitive Radio: Brain empowered wireless communications," IEEE Journal on Selected Areas in Communications, vol.23, pp. 201–220, Feb. 2005.

[6] G. Ganesan and Y. Li, "Cooperative spectrum sensing in cognitive radio, part I: two user networks," IEEE Transactions on Wireless Communications, vol. 6, no. 6, pp. 2204-2213, June 2007.

[7] D. Čabrić, S. M. Mishra, and R. W. Brodersen, " Implementation issues in spectrum sensing for cognitive radios," in proceedings of Asilomar Conference 2004, pp. 772–776, Nov. 2004.

[8] A. Sahai, N. Hoven, and R. Tandra, "Some fundamental limits on cognitive radio," in Proceedings of Allerton Conference of Communications,Control and Computing, pp.131-136,Oct. 2004.

[9] H. Sarvanko et al., "Cooperative and noncooperative spectrum sensing techniques using Welch's periodogram in cognitive radios," in Proceedings of First IEEE International Workshop on Cognitive Radios and Advanced Spectrum Management(IEEE CogART'08), Feb. 2008.

[10] L. Thanayankizil, A. Kailas, "Spectrum Sensing Techniques (II): Receiver Detection and Interference Management", 2008.

[11] G. Ganesan and Y. Li, "Cooperative spectrum sensing in cognitive radio, part Ⅱ: Multiuser networks," IEEE Transactions on Wireless Communications, vol. 6, no. 6, pp. 2214-2222, June 2007.

[12] P. J. Kolodzy, "Interference temperature: a metric for dynamic spectrum utilization," International Journal of Network Management, vol..16, pp. 103–113, April 2006.

[13] M. Matinmikko (editor) *et al.,* "Cognitive radio: An intelligent wireless communication system," *RESEARCH REPORT, NO. VTT-R-02219-08*,14.3.2008

[14] T. Yucek, H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," IEEE Communications Surveys and Tutorials,vol.11,no.1, pp.116-130,first quarter ,2009.