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Spectrum Sensing Methods for Cognitive Radio: A Survey

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Abstract: One of the most challenging issues in cognitive radio systems is spectrum sensing. Spectrum sensing is a key function of cognitive radio to prevent the harmful interference with licensed users and identify the available spectrum for improving the spectrum's utilization. The paper explains the spectrum sensing concept and its various forms.

Keywords: Cognitive radio, Spectrum sensing techniques

I. INTRODUCTION

The RADIO spectrum, which is needed for wireless communication systems, is a limited resource. To support various wireless applications and services in a noninterfering basis, the *fixed spectrum access* (FSA) policy has traditionally been adopted by spectrum regulators, which assign each piece of spectrum with certain bandwidth to one or more dedicated users (Primary users). And only the assigned (licensed or PU) users have the right to use the allocated spectrum, and other users are not allowed to use it, regardless of whether the licensed users are using it or not. As spectrum is a limited resource, unlicensed users may use the spectrum when primary user not using that spectrum. To do so SU are required to capture or sense the radio environment, and a SU with such a capability is also called a *cognitive radio* (CR) or a CR user. The spectrum sensing is the focal point of CRs allowing them to detect vacant spectrum holes and use them without harmful interference to other CRs or licensed users.

A cognitive radio can sense spectrum and detect "spectrum holes" which are those frequency bands not used by the licensed users or having limited interference with them (Fig. 1).

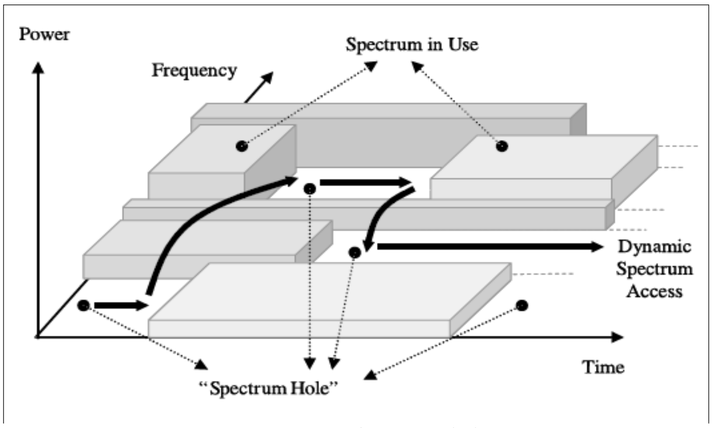

Fig.1 Concept of spectrum hole.

II. SPECTRUM-SENSING TECHNIQUES

The spectrum sensing methods can be broadly classified as:

- Receiver detection methods

- Transmitter detection methods
- Cooperative sensing methods.

Transmitter Detection Spectrum Sensing Methods
The *transmitter detection* methods assume that a primary user is *transmitting* information to a primary receiver when a secondary user is sensing the primary channel band [1-6]. The presence of the primary transmission can be extracted by a secondary user by two possible approaches, i.e.:

- Blind sensing and
- Signal specific sensing

Blind sensing
The blind spectrum sensing methods do not require any a priori knowledge of the received signal and they base their decision on the received signal power samples. These methods are further classified into being:

- Energy detection based [7] or
- Eigenvalue detection based [8,9].

Energy detection
The energy detector estimates the signal power in the channel band where the primary transmission is occurring and compares that estimate with a predefined threshold.

Advantages of energy detection
Energy detection are the implementation simplicity and the low computational complexities. Furthermore, as in most general cases of spectrum sensing no a priori information for the primary transmission is known to the secondary user, the energy detection is often the only possible solution for spectrum sensing.

However, this technique has several drawbacks.

Disadvantages of energy detection
The decision threshold is subject to variations with the SNR, the energy detector cannot distinguish between a user signal and interference, the energy detector cannot operate without accurate knowledge of the noise (noise uncertainty), the energy detector is not effective for spread (i.e. wideband) signals etc.

Eigenvalue detection
The eigenvalue-based detection does not need any information on the noise level and SNR and can be used for detection without knowledge of the signal, the channel and the noise power. The detector makes decision of presence of a primary signal based on a covariance matrix constructed by computing the autocorrelation of the signal from one antenna or by constructing the covariance matrix between the samples from different antennas. Eigenvalue detectors overcome the noise uncertainty difficulty and keep the advantages of the energy detection. The detector shows good performances in terms of probability of false alarm and probability of detection, when detecting time correlated signals. Although it performs better than the energy detector, it has much higher computational complexity.

Signal specific sensing
The signal specific spectrum sensing methods require a priori knowledge of the transmitted signal. As a result, they yield higher complexity and computation power than the energy detection methods. But, their main advantage, compared to the energy detectors, is the fact that they do not require any a priori knowledge of the noise power. The signal specific methods can be further classified as:

• Matched filter detection [10]

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• Cyclostationary feature detection [11]
• Waveform-based sensing [12] and
• Radio identification—based sensing [13].

Matched filtering
The matched filtering is an optimal way to detect signals in communication systems. The main advantage of this technique is that it can provide high processing gain in short time, however the drawback is the need for prior knowledge of some information for the primary transmission (e.g. modulation order, pulse type etc.), high power consumption and perfect synchronization requirements.

Cyclostationary feature detection
The cyclostationary feature detection uses the cyclostationary feature inherently present in many wireless communications signals. This feature means that the statistical properties of the transmitted signal (e.g. the mean value or the autocorrelation function) change periodically as functions of time. The cyclostationarity is either produced by modulation or coding or is intentionally incurred in order to aid the spectrum sensing. The cyclostationary feature detection is a promising technique able to extract signal features in the background of noise (since the noise is usually wide sense stationary) and, thus, be more effective than energy detection. Its main drawbacks are the need for prior knowledge of specific transmitted signal parameters and the high computational complexity.

Waveform-based sensing
The waveform-based sensing method relies on the correlation of the received signal with a copy of itself. The advantages of the method lie in the short sensing time and the operation at low SNR values. However, the major drawback of the method is the necessity of knowing longer sequences of the transmitted signal for increased detection performance.

Radio identification-based sensing
The radio identification—based sensing is a method that combines several spectrum sensing techniques. It allows good knowledge of the spectrum utilization, but yields complex computations as a result of the combinations of the different sensing methods.

Receiver Detection Spectrum Sensing Methods
The receiver detection approaches assume that a primary user is receiving information from a primary transmitter when a secondary user is sensing the primary channel band. They rely on the fact that the primary user in a receiving mode is not passive, i.e. it produces leakage of electromagnetic waves. The secondary users can detect the *Local Oscillator (LO) leakage power* when the primary user is receiving information and, as a result, detect the primary user [14]. It is obvious that the receiver detection relies on the energy detection technique previously described. The advantages of the receiver detection approaches over the transmitter detection approaches lie in the ability to locate the primary user, locate the exact primary channel band in use and the high probability to find free spectrum even in high density of primary receivers. However, the disadvantages lie in the need for a highly sensitive energy detector, the price of the architecture, the near-far problem etc.

Cooperative Spectrum Sensing Methods
The cooperative detection strategies for spectrum sensing rely on information exchanges among secondary users. The exchanged information can facilitate the detection of spectrum holes and increase the efficiency of the spectrum sensing. It must be stressed that the secondary users may sometimes also exchange minimal information with the primary ones [15-17].

Also, the information exchange must be accompanied by defining a control channel used for rendezvous of secondary users and their information exchanges. Based on the amount of the shared information, the cooperative detection strategies can be further classified as:

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• Partial cooperation approaches and
• Total cooperation approaches.

Partial cooperation approaches

The partial cooperation approaches refer to a scenario where the secondary users detect the primary channel by using some of the techniques elaborated in the Sect. 2.1 (usually energy detection) either independently or with the aid of some local cooperation with nearby secondary users. The detection information is then sent to a common controller which is also a secondary user (sometimes named as spectrum broker or a fusion center). The common controller is responsible to decide upon the spectrum availability for secondary users' transmissions.

There are numerous examples found in the literature that deal with the partial cooperation approaches to spectrum sensing and various enhancements in terms of finding the optimal local secondary node information to be collected and optimal decision making at the common controller side. They usually differ according to the implemented mechanism for data processing in the common controller which may be based on *voting* or *various statistical combinations* of the gathered data. Voting schemes, e.g. [18,19], perform decision making upon the collected spectrum occupancy decision from every secondary user. It elaborates the cluster-collect-forward scheme based on secondary users' own confidence, i.e. the common controller collects information about the sensed spectrum only when the secondary users are confident about their sensing results. This scheme provides 65 to 95% transmission energy saving compared to traditional broadcasting schemes. It proves that the optimal fusion role at the fusion center is the half-voting rule if energy detection is used by the secondary users locally. If all secondary users have identical energy detectors and the received signals are modeled as correlated log-normal random variables, then a Linear-Quadratic (LQ) fusion strategy based on a deflection criterion that takes into account the correlation among the nodes proves to significantly outperform other fusion strategies under the mentioned assumptions [20].

Instead of voting, another approach to optimal partial cooperation strategy is to make various statistical combinations of the gathered data from the secondary users. It shows a linear combination of local test statistics from individual secondary users at a fusion center (i.e. the common controller) method. The result is to either optimize the probability distribution function of the global test statistics or maximize the global detection sensitivity under constraints on false alarm probability [21]. Furthermore, it shows an approach where a Maximal Ratio Combining (MRC) and Equal Gain Combination (EGC) is being used at the fusion center as they are able to provide close to optimal solutions in low SNR regions (which is a common scenario in the context of cognitive radio) over the hard combination technique [22]. Therefore, it introduces a new softened hard combination scheme with two-bit overhead for each user that achieves a good tradeoff between detection performance and complexity.

The collected information by the common controller under partial cooperation must be robust against Byzantine failures which require specific data fusion techniques. Most of the existing data fusion techniques rely on using a fixed number of samples, but there are also techniques that use a variable number of samples [23].

Total Cooperation

The total cooperation approaches to spectrum sensing refer to a scenario where all secondary users operate in an ad-hoc manner using optimal transmission parameters. This means that the secondary users cooperatively sense the spectrum in order to reduce the detection time of spectrum holes and increase the agility of the secondary users. The coordination among the secondary users in this case aids the control of the uncertainty that limits the ability of a cognitive radio network to reclaim a band or not, which is actually caused by the presence/absence of secondary users. It can be shown that the degree of coordination among the secondary nodes in total cooperation approaches can vary based on the coherence times and bandwidths involved, as well as the complexity of the detectors themselves [24,25].

There are several total cooperation approaches to spectrum sensing found in the literature. Due to their versatile nature, it is not easy to provide a unified classification. However, all of them usually employ *relaying schemes* [26] or *various* *mathematical transformations* [27] of the received data. For example, it uses relaying based on the Amplify-and-Forward (AF) cooperation protocol in order to reduce the detection time. Multiple secondary users are used to infer on the structure of the received signals using Random Matrix Theory (RMT). The secondary users share information among them making the scheme not dependable on the knowledge of the noise statistics or its variance, but relying on the behavior of the largest and the smallest eigenvalue of random matrices.

Further on, the benefits of total cooperation approach for a simple two user cooperative cognitive network is elaborated in [28]. The improvement in agility is shown by exploiting the inherent asymmetry in the network. The same authors extended their work on total cooperation approaches to spectrum sensing in [29] to account for a multiuser single carrier network. They have found the sufficient conditions under which asymptotic agility gain is achievable and developed a pairing protocol that ensures asymptotic agility gain with probability equal to one. The authors in [30-38] show that the total cooperation approach can increase the throughput of the secondary users while limiting the interference to the primary users.

III. CONCLUSION

Spectrum is a very valuable resource in wireless communication systems, and it has been a focal point for research and development efforts over the last several decades. Cognitive radio, which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage, has become an exciting and promising concept. One of the important elements of cognitive radio is sensing the available spectrum opportunities. In this paper various methods for spectrum sensing are discussed. Spectrum opportunity and spectrum sensing concepts are re-evaluated by considering different dimensions of the spectrum space. The new interpretation of spectrum space creates new opportunities and challenges for spectrum sensing while solving some of the traditional problems. Various aspects of the spectrum sensing task are explained in detail spectrum sensing methods are discussed.

REFERENCES

[1] QT. Vien, HX, Nguyen, R. Trestian, P. Shah, O. Gemikonakli, "A hybrid double-threshold based cooperative spectrum sensing over fading channels", In: Proceedings of IEEE Transactions on Wireless Communications, pp. 1821-1834, 2016.
[2] GS. Rathore, S. Bharatula. "Efficient multi stage spectrum sensing technique for cognitive radio networks under noisy condition", In: Proceeding of International Journal of Applied Engineering Research, pp: 1831-1835, 2017.
[3] M. Jia, X. Wang, F. Ben, Q. Guo, X. Gu, "The fractional-step spectrum sensing algorithm based on energy and covariance detection", In: Proceeding of IEEE, 2015.
[4] S. Yao, Z. Zhang, "Spectrum sensing algorithm based on estimated covariance matrix MME detection" In: Proceeding of IEEE 2nd International Conference on Information Science and Control Engineering, pp, 926-930, 2015.
[5] A. Bagwari, GS. Tomar. "Adaptive double-threshold based energy detector for spectrum sensing in cognitive radio networks" In: Proceeding of Taylor & Francis International Journal of Electronics Letters, pp. 23-32, 2013.
[6] Y. Wang, Y. Li, F. Yuan, J. Yang,"A Cooperative Spectrum Sensing Scheme Based on Trust and Fuzzy Logic for Cognitive Radio Sensor Networks" In: Proceeding of International Journal of Computer Science Issues, Vol. 10, No 1, pp.275-279, 2013.
[7] Huifang Chen, Ming Zhou, Lei Xie, Xu Jin. "Fault-Tolerant Cooperative Spectrum Sensing Scheme for Cognitive Radio Networks" In: Proceeding of Springer Wireless Press Communication, pp. 2379–2397, 2012.
[8] NT. Nhan, I. Koo, "A cluster-based selective cooperative spectrum sensing scheme in cognitive radio" In: Proceeding of Springer EURASIP Journal on Wireless Communications and Networking, pp. 1-9, 2013.
[9] H. Urkowitz, "Energy detection of unknown deterministic signals" In: Proceedings of IEEE, pp. 523–531, 1967.
[10] Y. Zeng, YC. Liang, "Eigenvalue based spectrum sensing algorithms for cognitive radio" In: Proceedings of IEEE Transactions on Communications, 2009.
[11] Y. Zeng, YC. Liang, "Eigenvalue based spectrum sensing algorithms" In: Proceedings of IEEE P802.22 Wireless RANs, 2006.
[12] A. Sahai, D. Cabric, "Spectrum sensing: Fundamental limits and practical challenges" In: Proceedings of IEEE, 2005.
[13] AV. Dandawate, GB. Giannakis, "Statistical tests for presence of cyclostationarity" In: Proceedings of IEEE Transactions on Signal Processing, pp. 2355–2369, 1994.
[14] H. Tang, "Some physical layer issues of wide-band cognitive radio systems" In: Proceedings of IEEE international symposium on new frontiers in dynamic spectrum access networks, pp. 151–159, 2005.
[15] T. Ycek T, H. Arslan,"A survey of spectrum sensing algorithms for cognitive radio applications" In: Proceeding of IEEE Communications Surveys & Tutorials, pp. 116–160, 2009.

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(An ISO 3297: 2007 Certified Organization)

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[16] T. Yucek, H. Arslan. "A survey of spectrum sensing algorithms for cognitive radio applications", In: Proceeding of IEEE communications surveys & tutorials, Vol. 11 no. 1, pp. 116-130, 2009.
[17] IF. Akyildiz, BF. Lo, R. Balakrishnan. "Cooperative spectrum sensing in cognitive radio networks: A survey", In: Proceeding of ELSEVIER, pp.40-61, 2011.
[18] T. Manna, IS. Misra. "Collaborative spectrum sensing in real cognitive radio network", In: Proceeding of IEEE, pp.137-142, 2013.
[19] YC. Liang, KC. Chen, GY. Li, P. Mahonen, "Cognitive radio networking and communications: an overview", In: Proceeding of IEEE Transactions on Vehicular Technology, Vol. 60 no.7, pp: 3386-3407, 2011.
[20] CH. Lee, W. Wolf, "Energy efficient techniques for cooperative spectrum sensing in cognitive radios", In: Proceedings of IEEE CCNC, 2008.
[21] W. Zhang, RK. Mallik, KB. Letaief, "Cooperative spectrum sensing optimization in cognitive radio networks", In: Proceedings of IEEE ICC, 2008.
[22] J. Unnikrishnan, VV. Veeravalli,. "Cooperative spectrum sensing and detection for cognitive radio", In: Proceedings of IEEE GLOBECOM, 2007.
[23] Z. Quan, S. Cui, A. Sayed, "An optimal strategy for cooperative spectrum sensing in cognitive radio networks", In: Proceedings of IEEE GLOBECOM, November 2007.
[24] J. Ma, Y. Li, "Soft combination and detection for cooperative spectrum sensing in cognitive radio networks", In: Proceedings of IEEE Globecom, 2007.
[25] R. Chen, JM. Park, K Bian, "Robust distributed spectrum sensing in cognitive radio networks", In: Proceedings of IEEE INFOCOM, 2008.
[26] YW. Jing, ZB. Yu, MQ. Min, CUI Jing Wu & XIE Pei Zhong. "Robust cooperative spectrum sensing schemes for fading channels in cognitive radio networks", In: Proceeding of Springer Science, pp: 348–359, 2011.
[27] A. Sahai, R. Tandra, SM. Mishra, N. Hoven, "Fundamental design tradeoffs in cognitive radio systems", In: Proceedings of TAPAS, 2006.
[28] JN. Laneman, DNC. Tse, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior", In: Proceedings of IEEE Transactions on Information Theory, pp. 3062–3080, 2004.
[29] LS. Cardoso, M. Debbah, P. Bianchi, J. Najim, "Cooperative spectrum sensing using random matrix theory", In: Proceedings of IEEE ISWPC, 2008.
[30] G. Ganesan, Y. Li, "Cooperative spectrum sensing in cognitive radio, part I: Two user networks", In: Proceedings of IEEE Transactions on Wireless Communications, pp. 2204–2213, 2007.
[31] G. Ganesan, Y. Li, "Cooperative spectrum sensing in cognitive radio, part II: Multiuser networks", In: Proceedings of IEEE Transactions on Wireless Communications, pp. 2214–2222, 2007.
[32] K. Lee, A. Yener, "Throughput enhancing cooperative spectrum sensing strategies for cognitive radios", In: Proceedings of 41st annual Asilomar conference on signals, systems, and computers, 2007.
[33] L. Gavrilovska, V. Atanasovski. "Spectrum sensing framework for cognitive radio networks", In: Proceeding of Springer, pp. 447–469, 2011.
[34] H. Sakran, M. Shokair, "Hard and softened combination for cooperative spectrum sensing over imperfect channels in cognitive radio networks", In: Proceeding of Springer, pp. 61–71, 2011.
[35] B. Wild, K. Ramchandran "Detecting primary receivers for cognitive radio applications", In: Proceeding of IEEE, 2005.
[36] M. Lin, AP. Vinod, "A low complexity high resolution cooperative spectrum-sensing scheme for cognitive radios" In: Proceeding of Springer, pp. 1127–1145, 2011.
[37] AT. Hoang, YC. Liang, MH. Islam, "Maximizing throughput of cognitive radio networks with limited primary user's cooperation", In: Proceeding of IEEE ICC, pp. 23-42, 2007.
[38] O. Bakr, B. Wild, M. Johnson, K. Ramchandran, "A multi-antenna framework for spectrum reuse based on primary-secondary cooperation", In: Proceeding of IEEE, 2008.