SPECTRUM SENSING IN COGNITIVE RADIO NETWORKS: QOS CONSIDERATIONS

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ABSTRACT

The rapidly growing number of wireless communication devices has led to massive increases in radio traffic density, resulting in a noticeable shortage of available spectrum. To address this shortage, the Cognitive Radio (CR) technology offers promising solutions that aim to improve the spectrum utilization. The operation of CR relies on detecting the so-called spectrum holes, the frequency bands that remain unoccupied by their licensed operators. The unlicensed users are then allowed to communicate using these spectrum holes. As such, the performance of CR is highly dependent on the employed spectrum sensing methods. Several sensing methods are already available. However, no individual method can accommodate all potential CR operation scenarios. Hence, it is fair to ascertain that the performance of a CR device can be improved if it is capable of supporting several sensing methods. It should obviously also be able to select the most suitable method. In this paper, several spectrum sensing methods are compared and analyzed, aiming to identify their advantages and shortcomings in different CR operating conditions. Furthermore, it identifies the features that need to be considered while selecting a suitable sensing method from the catalog of available methods.

KEYWORDS

Cognitive Radio; Spectrum Sensing; Qos

1. INTRODUCTION

In general, the Radio Frequency Spectrum (RFS) is statically divided into licensed and unlicensed bands. While the use of the former is restricted to authorized operators, the unlicensed bands are available for use by the public, only subject to transmission constraints [1]. As such, the unlicensed bands may get heavily congested. On the other hand, several studies and measurements conducted around the world have indicated that the licensed RFS bands can be underutilized [2].

From a technical perspective, the Cognitive Radio (CR) concept is a promising technology to achieve an efficient utilization of RFS. The concepts for CR models were introduced in 1999 by Joseph Mitola [3]. In these models, the operators licensed to use some particular frequency bands are considered as the Primary Users (PUs). Whereas, the unlicensed participants are referred to as the Secondary Users (SUs). The CR model is based on the realization that a PU may not fully utilize its licensed bands, leaving parts of its spectrum unoccupied. These unoccupied white spaces, or holes, relate to use, or more correctly the lack of use, in terms of frequency, time, or

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space and location. An SU can utilize these holes in addition to the unlicensed bands that it may typically use.

To achieve their objectives, CR systems are dependent on the execution of a sequence of several functions, the so-called CR cycle. A typical CR cycle was proposed by Mitola [3]. This is illustrated in Figure 1.

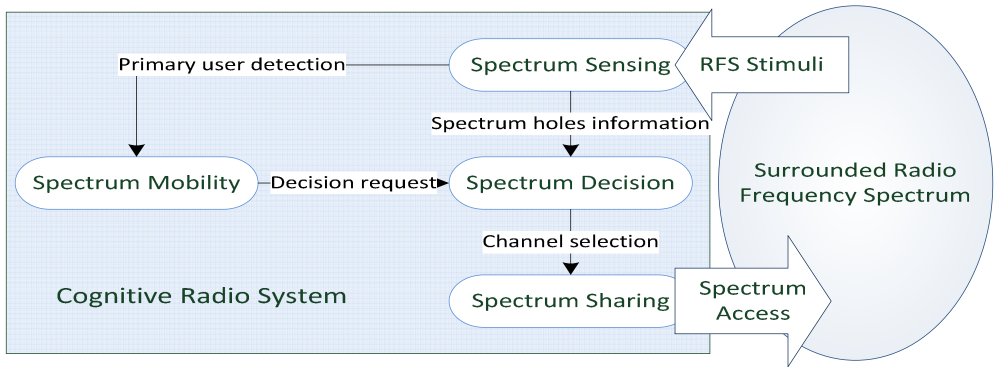

Figure 1. Basic CR cycle

The main functions of this CR cycle are spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility. More specifically, an SU should be able to perform the following [4]:

- Spectrum sensing: sense the surrounding RFS to determine spectrum holes and to detect the presence of the relevant PU.
- Spectrum decision: analyze and decide which spectrum hole is the most suitable for satisfying the application requirements.
- Spectrum sharing: share the available spectrum holes with other SUs as fairly as possible.
- Spectrum mobility: seamlessly switch to another suitable spectrum hole to avoid interference with a detected PU that may wish to start using its licensed spectrum.

Detecting the presence of a PU, or more precisely finding out whether the PU is using its allocated spectrum or not, is an essential task for a CR device. On one hand, this fundamental task requires improving sensing accuracy by avoiding false positive results while detecting the presence of a PU. On the other, the employed sensing technique should achieve a high detecting probability of the available spectrum holes. The nature of the electromagnetic signals makes accurate sensing a complicated process. More specifically, the Signal to Noise Ratio (SNR), the multipath fading of the PU signals, and the changing levels of noise can significantly affect the sensing accuracy [5, 6]. Moreover, imperfect spectrum sensing can result in increased transmission error rates, for both the PU and the SUs [7]. Such errors may contribute to the degradation of the quality of the services provided by a PU and SUs. Noticeably, any QoS degradation that can be attributed to the CR technology can potentially harm the progress of the CR-based solutions. In this paper, the main features and limitations of the prevalent spectrum sensing methods are examined. Furthermore, the key aspects that should be involved in selecting the appropriate sensing method are highlighted and discussed.

The remainder of this paper is organized as follows. Section II presents the background and motivation for this work. The effects of the sensing operation on the QoS of the applications running over CR networks are described in Section III. Several sensing approaches are discussed and evaluated in Section IV. Factors that may help in selecting the proper sensing techniques are outlined in Section V. The last section gives the conclusions and points to the potential future expansion of the reported work.

2. MOTIVATIONS

Most of the previous reviews of spectrum sensing techniques are mainly focused on the operation, accuracies, complexities, and implementation issues [8-11]. For instance, the relation between the sensing accuracy, and the speed, i.e., sensing time, and frequency, i.e., repeating the sensing, are the primary focus of the authors in [8]. They aim to achieve an optimal spectrum sensing performance with the capability of flexible tuning between the speed and frequency. However, they find that the available state-of-art sensing technologies do not offer a possible trade-off between complexity and accuracy. In contrast, other reviewers consider the characteristics of the PU signal as the main factor for selecting a proper sensing method [9]. Nevertheless, other factors should be considered for more adaptive sensing and improved performance.

In general, the dominant approach is about how to find an optimal sensing method for all possible CR operation requirements. However, none of the proposed sensing methods is suitable for all possible sensing situations, conditions and technologies of CR systems. This study shifts the focus to another approach where a CR device supports a range of various sensing methods. Thus, the proper sensing technique can be selected based on the real-time requirements. This approach implies the need for a real-time mechanism to select the most suitable sensing method. In this paper, various sensing methods are studied toward finding the relevant selection criteria that should be considered when designing such as real-time selection mechanism.

3. SENSING OPERATION IMPACT ON APPLICATIONS' QOS IN CR NETWORKS

As shown in Figure 2, the operation of a CR can be divided into repeated cycles of the sensing period. The sensing period T effectively represents the time interval where sensing is repeated. It also represents the communication frame in CR. During the sensing time t, a CR device obtains information from its environment. After the sensing time, the CR device can decide to transmit data on the same channel or in a new vacant channel, i.e., a spectrum hole.

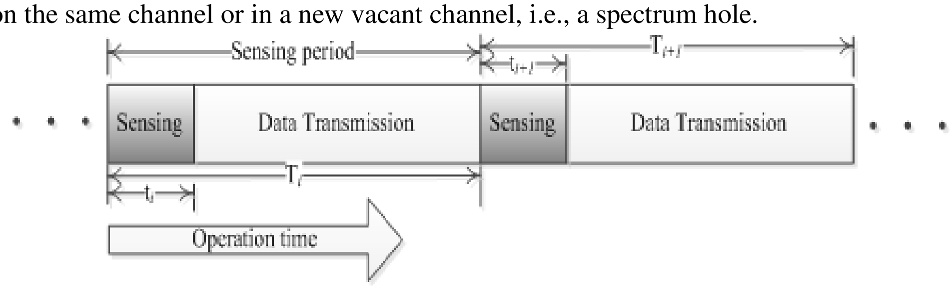

Figure 2. Simple structure of CR frames based on sensing operation

The decision taken by the CR device is based on the sensing outcome, i.e., the presence or absence of the PU. The transmission starts after the sensing time until the next sensing period, also called the CR communication frame. The transmission time (T-t) depends on the sensing time t and the frame time T that is based on the design of how frequent the sensing will be conducted. Thus, sensing frequency is 1/T. The sensing time t and the frame time T can be designed to be fixed for all frames or could be designed to vary based on the design goals [12]. Typically, the sensing operation should be limited and less frequent as much as possible without affecting the sensing accuracy [13].

Increasing the sensing time t and conducting the sensing more frequently, i.e. decreasing T, lead to an increase in the probability of correct detection of the PU's presence. In turn, this leads to more protection to the PU from interference by CR users and more utilization of the spectrum. On the other hand, this leads to less data transmission rate and hence to QoS degradation for SUs.

The degradation can be measured by several parameters such as throughput, delay and MAC layer process overhead [14]. Therefore, designing the sensing time and frequency of sensing operation should take into account the trade-off between protecting the PU's QoS and improving the QoS of SUs.

4. SENSING METHODS

The main challenge facing the sensing methods is how to improve the spectrum sensing performance by mainly increasing the positive detection probability and decreasing the false detection probability. A sensing technique with a higher positive detection probability provides more protection to PU. A CR user with a lower probability of false detection of the presence of the PU has more chance to use the available spectrum holes. Therefore, the user has more chance of achieving a higher throughput on the CR network. The design of a sensing technique is constrained by an acceptable level of false detection [15]. Additionally, improving sensing performance is challenged by a range of trade-offs and various constraints such as application requirements, hardware capability, complexity and required infrastructure [16].

In general, a sensing method that uses surrounding RFS information collected by the CR device only is called a local sensing. If the SUs do not exchange their surrounding RFS information gathered by local sensing, then this sensing is referred to as non-cooperative sensing. In this paper, the sensing methods are classified mainly into three categories: methods with no prior information required, based on prior information and based on SUs cooperation.

4.1. No Prior Information Required (Blind Sensing)

No prior information about the PUs' signal is necessary for the sensing methods under this category. However, prior information about the noise power of the targeted spectrum may be required for better performance. Otherwise, a reasonable estimation of the noise power is used instead. Two well-known blind sensing methods are energy detection and covariance-based detection.

4.1.1. Energy Detection

Also known as radiometry or periodogram, energy detection is the most common method for spectrum sensing because of its low implementation complexity and computational overhead [5]. In this method, the energy detector is used to detect a narrowband spectrum and then the observed signal energy level is compared with a predefined threshold. Thus, the channel is occupied by the PU if the detected signal energy is over the threshold. Otherwise, it is considered unoccupied, i.e., a spectrum hole. Because of this simplicity, this technique requires the shortest sensing duration t per frame compared to other common sensing technologies [17].
Generalizing the use of this method faces several challenges as a consequence of its simplicity. Firstly, selection of the threshold used for detection is an issue when the channel noise level is unknown or uncertain over time [18]. Secondly, under low SNR, it is hard to differentiate between modulated signals, including signals of other SUs, noise, and interference, resulting in poor detection performance [5]. Lastly, an energy detector is ineffective in detecting spread spectrum signals [19].

4.1.2. Covariance-based Detection

This method is based on comparing the covariance of the detected signal and the covariance of the noise where statistical covariance matrices of signal and noise are usually different [20]. The main improvement of this method is to overcome the energy detection shortcoming. In particular, it can distinguish between signal and noise in a low SNR, and without any prior information about the PU's signal and channel noise. This detection improvement is achieved at the expense of adding a computational overhead in computing the covariance matrix of the received signal samples [11]. In addition to increasing complexity, other drawbacks of the energy detection are still present in the covariance-based detection.

These sensing methods work with no prior information about the PU signals. They have a limited performance particularly for spread spectrum and in situations where other SUs are sharing the spectrum. Research is ongoing to improve the blind sensing approach in terms of performance and required sensing time, such as in [21, 22].

4.2. Prior Information Required

Methods belonging to this category rely on partial or full information about the PU's transmission signal to be able to differentiate it from other signals and noise.

4.2.1. Cyclostationarity Feature Detection

This method is based on distinguishing the PU signal from noise, interference, and other signals by identifying its cyclostationarity features [23, 24]. These cyclostationarity features are associated with the signal modulation type, carrier frequency, and data rate. Hence, the CR device needs sufficient prior information about these unique characteristics of the PU signal. Based on this information, it can perform a cyclostationarity analysis on the detected signal to identify matched features [9]. For this method to perform better than the energy detection method, an adequate number of real-time sample sets in the frequency domain need to be collected. As a consequence, better performance accrues more complexity and sensing time at the expense of the available throughput [9].

4.2.2. Correlation Detection

Sensing based on correlation is also known as waveform-based sensing or coherent sensing. In this method, the expected correlation or coherence between signal samples is identified to detect the PU signal based on previous knowledge about its waveform patterns [9]. The accuracy of the sensing increases when the length of the known signal pattern of the PU is increased [25]. The main drawback of this method is related to the large amount of information required for signal patterns of the PUs to achieve a high performance that is not practical for all CR systems.

4.2.3. Radio Identification Based Sensing

This method is based on having apriori information about the transmission technologies used by the PU. In the radio identification stage of the method, several features of the received signal are exploited and then classified to determine if the signal demonstrates the PU signal technology [26]. Fundamentally, the feature extraction and classification techniques are used in the context of European Transparent Ubiquitous Terminal (TRUST) project [27]. For collecting the signal features, the radio identification method may use one of the known sensing techniques, such as the energy detection method [9]. The radio identification improves the accuracy of the energy detection to some extent with complexity implication. The achieved precision is dependent on the signal features and classification techniques used to identify the presence of the PU.

4.2.4. Matched Filtering

The matched filtering method achieves a higher detection probability in a short detection time, compared to other methods that are similarly based on prior information [28, 29]. Hence, under this classification, this method is considered as the best sensing method. The collected signal is passed through a filter that will amplify the possible PU signal and attenuate any noise signal. The filter makes the detection of the presence of the PU signal more accurate [29]. The filter, which is known as a matched filter, has to be tuned based on some features of the PU signal. These characteristics include the required bandwidth, operating frequency, the modulation used and frame format [9]. One of the disadvantages of this method is in implementation where different PUs signal types require different dedicated hardware receivers. This requirement makes the method impractical to implement and also leads to higher power consumptions if the method is implemented based on current hardware technologies.

Figure 3 shows a comparison between non-cooperative sensing methods, based on accuracy and complexity metrics. Table 1 shows more comparison factors between local sensing methods.

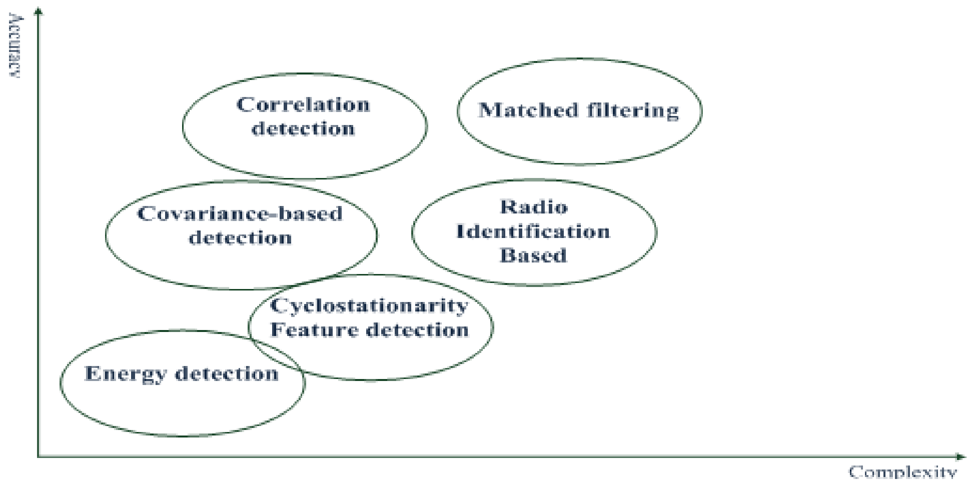

Figure 3. Sensing method complexity versus accuracy

Table 1. Comparison between local sensing methods

Sensing method	Sensing time	Robustness against SNR	Detection Performance	Complexity	Prior information required
Matched filter	High	High	High	High	High
Radio Identification Based	Medium	Medium	Medium	High	Medium
Correlation	High	High	Medium	Medium	Medium
Cyclostationarity Feature detection	High	High	Low	Medium	High
Covariance	Medium	Medium	Low	Medium	None
Energy detection	Low	Low	Low	Low	Low

4.3. Based on SU Cooperation

The main principle of this approach is that SUs share their local sensed information of the spectrum. The use of sensed information from all SUs can produce a more accurate sensing outcome than relying solely on local sensing. The hidden transmitter problem is an example of the issues that may prohibit a CR from detecting the presence of a PU. The cause of this problem is the fading and shadowing of the signals from a PU, although it is within the transmission range of the CR [9]. However, when cooperated SUs are spatially distributed, it helps to overcome the hidden PU problem and other limitations of local sensing [30]. Sensing cooperation can also reduce the local sensing cost, e.g., sensing time duration and energy consumption while maintaining sensing quality by scheduling the sensing operation among cooperative SUs [31].

The sensing method used by an individual SU can be based on one of the sensing methods for local sensing, such as energy detection and cyclostationarity feature detection [10].

In some environments, cooperative sensing may lose its advantages as far as an individual SU is concerned. For instance, increasing the local sensing frequency in individual high mobility SUs is more efficient, in terms of sensing accuracy and overhead, than to cooperate with other SUs [19]. In cooperative sensing, the improvement of sensing is more noticeable when the number of cooperative SUs is increased. However, involvement of more SUs will increase the cooperation overhead in terms of the amount of data exchange and the time required for the exchange [32].

The cooperative approaches can only be used when SUs are able and willing to collaborate. Also, a SU may not always find other cooperative SUs within its transmission range. Therefore, the CR devices should not solely rely on cooperative sensing approaches. They should be able to use a fitting local sensing method and resort to cooperative sensing, only when an enhanced performance is possible.

5. FACTORS FOR SELECTING THE FITTING SENSING METHOD

Selecting the best sensing method for a particular cognitive radio operation condition depends on several factors. Based on the discussions in previous sections, notable factors are summarized below:

5.1. CR Device Capability

A CR device designed with limited hardware resources and power capacities will not be able to support a wider range of sensing methods. Some methods require sophisticated hardware components and higher power consumption, e.g. the matched filter method, compared to simple ones such as the energy detection method. An ideal CR device should be able to be reconfigured on-the-fly to support a broad range of sensing methods. In practice, a CR device's actual capability will limit the range of sensing methods that can be supported.

5.2. Qos Required for Applications Running on the CR Device

The QoS requirements differ based on the applications running on a CR device. The sensing delay and transmission throughput vary from one sensing method to another within the same conditions. As a result, the sensing operation used on a CR device has a direct impact on the QoS of an application running on the device, mainly in terms of the throughput and delay. As sensing is a repetitive operation, a CR device should be able to select a proper sensing method with the least impact on the QoS of the running application. Other operational requirements must also be taken into account. For example, the PU protection should have a higher priority than the QoS requirements of a CR user.

5.3. Apriori Information

The extent of information available about the characteristics of the PUs and the communications media is a major factor influencing the selection of a proper sensing method. For instance, insufficient information about the PU signals, excludes the use of matched filter method.
The CR device should be able to change the sensing method based on the information that becomes available about the PU signal or the SNR of the targeted spectrum by sensing.

5.4. Level of Protection Required for PU

The selection of the sensing method must be considered with regard to the degree of protection necessary for the PU. They may vary depending on available frequency bands and types of services. For instance, analog TV service is more robust against interference than digital TV service [16]. Hence, a sensing method that provides less protection, i.e., lower PU detection probability, should only be used when the PU is more tolerant of interference such as in analog TV services.

5.5. The CR Network Mode and Capability

The network mode and capability are important factors to CR systems to make a decision between cooperative and non-cooperative sensing approaches. In CR networks with infrastructure and centralized topology, a method based on cooperative sensing is more suitable than that based on local sensing only. Hence, the capability of such a CR network depends on how much management ability can provide for white space determination to its CR devices. Furthermore, the capacity of a CR network relies on how much information the network can gather and provide to its CR users about the PU signals and the ambient spectrum.

6. CONCLUSIONS

The work reported in this paper asserts that none of the available spectrum sensing techniques can achieve perfect solutions for all potential CR operating conditions. Therefore, to improve the performance of CR systems, the relevant devices must be capable of utilizing a catalog of sensing methods. The selection of the most suitable method from the catalog, which is an obvious necessity, is based on a number of factors that have also been identified and discussed in this paper. Our future works will focus on more exhaustive evaluations of these factors and how their fine-tunings can contribute to an improved CR performance.

REFERENCES

[1] L. Cui and M. B. Weiss, "Can unlicensed bands be used by unlicensed usage," Paper for the 41st annual TPRC, September, pp. 27-29, 2013.

[2] K. Patil, R. Prasad, and K. Skouby, "A Survey of Worldwide Spectrum Occupancy Measurement Campaigns for Cognitive Radio," in Devices and Communications (ICDeCom), 2011 International Conference on, 2011, pp. 1-5.

[3] J. Mitola and G. Q. Maguire Jr, "Cognitive radio: making software radios more personal," Personal Communications, IEEE, vol. 6, pp. 13-18, 1999.

[4] J. Marinho and E. Monteiro, "Cognitive radio: survey on communication protocols, spectrum decision issues, and future research directions," Wireless networks, vol. 18, pp. 147-164, 2012/02/01 2012.

[5] Y. Zeng, Y.-C. Liang, A. T. Hoang, and R. Zhang, "A review on spectrum sensing for cognitive radio: challenges and solutions," EURASIP J. Adv. Signal Process, vol. 2010, pp. 2-2, 2010.

[6] A. F. Molisch, L. J. Greenstein, and M. Shafi, "Propagation issues for cognitive radio," Proceedings of the IEEE, vol. 97, pp. 787-804, 2009.

[7] S. Haddadi, H. Saeedi, and K. Navaie, "Channel coding adoption versus increasing sensing time in secondary service to manage the effect of imperfect spectrum sensing in cognitive radio networks," in Communication and Information Theory (IWCIT), 2013 Iran Workshop on, 2013, pp. 1-5.

[8] D. Ariananda, M. Lakshmanan, and H. Nikookar, "A survey on spectrum sensing techniques for cognitive radio," in Cognitive Radio and Advanced Spectrum Management, 2009. CogART 2009. Second International Workshop on, 2009, pp. 74-79.

[9] T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," Communications Surveys & Tutorials, IEEE, vol. 11, pp. 116-130, 2009.

[10] I. F. Akyildiz, B. F. Lo, and R. Balakrishnan, "Cooperative spectrum sensing in cognitive radio networks: A survey," Physical Communication, vol. 4, pp. 40-62, 2011.

[11] D. B. Rawat and G. Yan, "Spectrum sensing methods and dynamic spectrum sharing in cognitive radio networks: A survey," International Journal of Research and Reviews in Wireless Sensor Networks, vol. 1, pp. 1-13, 2011.

[12] P. Yiyang, L. Ying-Chang, K. C. Teh, and L. Kwok Hung, "How much time is needed for wideband spectrum sensing?," Wireless Communications, IEEE Transactions on, vol. 8, pp. 5466-5471, 2009.

[13] C. Kae Won, "Adaptive Sensing Technique to Maximize Spectrum Utilization in Cognitive Radio," Vehicular Technology, IEEE Transactions on, vol. 59, pp. 992-998, 2010.

[14] H. Xin-Lin, W. Gang, H. Fei, and S. Kumar, "The Impact of Spectrum Sensing Frequency and Packet-Loading Scheme on Multimedia Transmission Over Cognitive Radio Networks," Multimedia, IEEE Transactions on, vol. 13, pp. 748-761, 2011.

[15] L. Ying-Chang, Z. Yonghong, E. C. Y. Peh, and H. Anh Tuan, "Sensing-Throughput Tradeoff for Cognitive Radio Networks," Wireless Communications, IEEE Transactions on, vol. 7, pp. 1326-1337, 2008.

[16] A. Ghasemi and E. S. Sousa, "Spectrum sensing in cognitive radio networks: requirements, challenges and design trade-offs," Communications Magazine, IEEE, vol. 46, pp. 32-39, 2008.

[17] H. Kim and K. G. Shin, "In-band spectrum sensing in cognitive radio networks: energy detection or feature detection?," in Proceedings of the 14th ACM international conference on Mobile computing and networking, 2008, pp. 14-25.

[18] R. Tandra and A. Sahai, "SNR Walls for Signal Detection," Selected Topics in Signal Processing, IEEE Journal of, vol. 2, pp. 4-17, 2008.

[19] D. Cabric, S. M. Mishra, and R. W. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in Signals, Systems and Computers, 2004. Conference Record of the Thirty-Eighth Asilomar Conference on, 2004, pp. 772-776 Vol.1.

[20] Y. Zeng and Y.-C. Liang, "Spectrum-sensing algorithms for cognitive radio based on statistical covariances," Vehicular Technology, IEEE Transactions on, vol. 58, pp. 1804-1815, 2009.

[21] Y. Li, S. Shen, and Q. Wang, "A Blind Detection Algorithm Utilizing Statistical Covariance in Cognitive Radio," International Journal of Computer Science Issues (IJCSI), vol. 9, pp. 7-12, 2012.

[22] K. S. Kumar, R. Saravanan, and R. Muthaiah, "Cognitive Radio Spectrum Sensing Algorithms based on Eigenvalue and Covariance methods," International Journal of Engineering & Technology (0975-4024), vol. 5, 2013.

[23] J. Lundén, V. Koivunen, A. Huttunen, and H. V. Poor, "Spectrum sensing in cognitive radios based on multiple cyclic frequencies," in Cognitive Radio Oriented Wireless Networks and Communications, 2007. CrownCom 2007. 2nd International Conference on, 2007, pp. 37-43.

[24] S. Enserink and D. Cochran, "A cyclostationary feature detector," in Signals, Systems and Computers, 1994. 1994 Conference Record of the Twenty-Eighth Asilomar Conference on, 1994, pp. 806-810.

[25] H. Tang, "Some physical layer issues of wide-band cognitive radio systems," in New frontiers in dynamic spectrum access networks, 2005. DySPAN 2005. 2005 first IEEE international symposium on, 2005, pp. 151-159.

[26] T. Yucek and H. Arslan, "Spectrum characterization for opportunistic cognitive radio systems," in Military Communications Conference, 2006. MILCOM 2006. IEEE, 2006, pp. 1-6.

[27] T. Farnham, G. Clemo, R. Haines, E. Seidel, A. Benamar, S. Billington, et al., "Ist-trust: A perspective on the reconfiguration of future mobile terminals using software download," in Personal, Indoor and Mobile Radio Communications, 2000. PIMRC 2000. The 11th IEEE International Symposium on, 2000, pp. 1054-1059.

[28] S. Shobana, R. Saravanan, and R. Muthaiah, "Optimal Spectrum Sensing Approach on Cognitive Radio Systems," 2013.

[29] S. Shobana, R. Saravanan, and R. Muthaiah, "Matched Filter Based Spectrum Sensing on Cognitive Radio for OFDM WLANs," International Journal of Engineering and Technology (IJET), vol. 5, 2013.

[30] W. Chien-Min, S. Hui-Kai, L. Maw-Lin, L. Yi-Ching, and L. Chih-Pin, "Cooperative Power and Contention Control MAC Protocol in Multichannel Cognitive Radio Ad Hoc Networks," in Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2014 Eighth International Conference on, 2014, pp. 305-309.

[31] X. Dongyue, E. Ekici, and M. C. Vuran, "Cooperative Spectrum Sensing in Cognitive Radio Networks Using Multidimensional Correlations," Wireless Communications, IEEE Transactions on, vol. 13, pp. 1832-1843, 2014.

[32] Z. Yulong, Y. Yu-Dong, and Z. Baoyu, "Cooperative relay techniques for cognitive radio systems: Spectrum sensing and secondary user transmissions," Communications Magazine, IEEE, vol. 50, pp. 98-103, 2012.

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