Advanced Intelligent Spectrum Sensing Techniques For Cognitive Radio Networks

Gorakh Prasad Yadav, Mr. Vaibhav Purwar

Abstract— **The growing demand of wireless applications has put a lot of constraints on the usage of available radio spectrum which is limited and precious resource. Cognitive radio is a promising technology which provides a novel way to improve utilization efficiency of available electromagnetic spectrum. Reliable spectrum sensing is one of the most crucial aspects for the successful deployment of cognitive radio (CR) technology. Spectrum sensing in CR is challenged by a number of uncertainties, which degrade the sensing performance and in turn require much more time to achieve the targeted sensing efficiency. Cognitive radio technology promises a solution to the problem by allowing unlicensed users, access to the licensed bands opportunistically. A prime component of the cognitive radio technology is spectrum sensing. Many spectrum sensing techniques have been developed to sense the presence or not of a licensed user.**

Index Terms— **Cognitive radio networks, Spectrum sensing, Energy detection, Cyclostationary detection, Matched filter.**

I. INTRODUCTION

Cognitive radio (CR) technology is a new way to compensate the spectrum shortage problem of wireless environment. The demand forradio spectrum increases proportionally with the number of users, and thus causes a significant increase in spectrum utilization. The major hurdle in the current spectrum scarcity is the fixed spectrum assignment. This spectrum shortage has a deep impact on research directions in the field of wireless communication. It enables much higher spectrum efficiency by dynamic spectrum access. It allows unlicensed users to utilize the free portions of licensed spectrum while ensuring no interference to primary users' transmissions. Cognitive radio arises to be tempting solution to the spectral congestion problem by introducing opportunistic usage of the frequency bands that are not heavily occupied by licensed users. FCC define cognitive radio as, "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, access secondary markets". Hence, one main aspects of cognitive radio is related to autonomously exploiting locally unused spectrum to provide new paths to spectrum access.
2. Cognitive radios possess the ability to observe their communication environment and adapt the parameters of their communication scheme to maximize the spectrum, while minimizing interference to the primary users [1]. Its [2],

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asserts that CRs must continuously sense the spectrum in use in order to detect re-appearance of a primary user. This and other functions of CRs are contained in the basic cognitive cycle shown in Figure 1.1.
3. When implemented, the CR undergoes the various phases of the cognitive cycle. Thus specifying how the radio learns, as well as responds (adapts) to its operating environment [2]. From this cycle, the radio receives information (senses) it's operating environment by performing direct observation; searching and identifying spectrum holes.
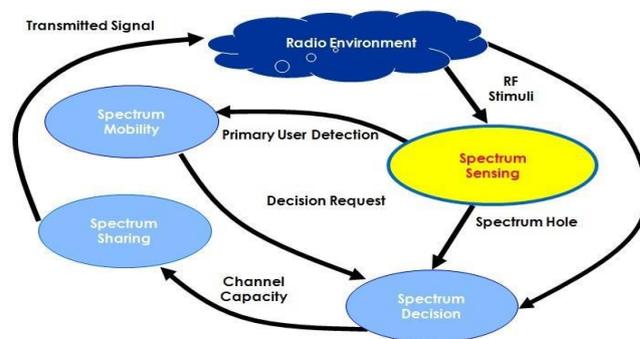

Figure 1 The Cognitive cycle

The information obtained is then analysed to ascertain characteristics of the environment; i.e. to estimate the spectrum holes. Based on this evaluation, the radio determines its alternatives; selecting an option in a way that improves the evaluation carried out previously [3]. The radio then employs these observations and decisions to improve its operation. As seen from the figure, the initial phase of the cognitive cycle consists of the sensing process. Hence, it is evident that reliable spectrum sensing is the most critical function of the cognitive radio process [4]. By sensing and adapting to the environment, a cognitive radio will possess the ability to fill in the spectrum holes and serve its users without causing harmful interference to the primary user. Ultimately, a spectrum sensing scheme should give a general picture of the medium over the entire radio spectrum. This allows the cognitive radio network to analyze all parameters (time, frequency and space) in order to ascertain spectrum usage [5]. Cognitive radio (CR) is a key technology for dealing with the current underutilization of spectrum [6]. The CR network allows CR users or secondary users (SUs) to access a spectrum which is not in use by a licensed user or primary user (PU). The most essential task of a CR network is to detect the presence or absence of a PU in order for the SU to use the licensed band efficiently and to avoid interference in the PU vicinity. The process of PU detection is called spectrum sensing. Currently, spectrum sensing techniques focus on PU transmitter detection. The local sensing techniques considered to be important are energy detection, matched filter detection, and cyclostationary detection [7]. Energy detection needs less sensing time but performs poorly under

low signal-to-noise ratio (SNR) conditions. One of the well-known coherent detection techniques in the field of spectrum sensing is matched filter detection. Cyclostationary detection provides reliable detection but is computationally complex. The probability of detection (Pd) and the probability of false alarm (Pf) are the metrics for the detection performance of spectrum sensing. The probability that an SU declares the presence of a PU when the spectrum is occupied by the PU is called the probability of detection, whereas the probability that an SU declares the presence of the PU when the spectrum is idle is called the probability of false alarm. The probability of miss detection (Pm) indicates the probability that an SU declares the absence of a PU when the spectrum is occupied. The probability of miss detection is simply, $Pm = 1 - Pd$. In view of the fact that false alarms reduce spectral efficiency and miss detection causes interference with the PU, generally it is vital for optimal detection performance so that the maximum probability of detection is achieved subject to the minimum probability of false alarm [8]. The matched filter is optimal if structure of PU waveform is known. If deployment of CR is limited to operate in few PU bands then matched filer is the best choice. However, the implementation cost and complexity will increase if more PU bands are considered because dedicated circuitry is required for each primary licensee to achieve synchronization [9]. Practically, it is not possible to devote circuitry for each PU licensee. However, matched filter can be considered for most frequent sensed channels to get optimal sensing results with minimum sensing time if PU waveform is known. This approach can be very healthy for CR applications for disaster management; smart grid, and so on to get reliable sensing results with minimum sensing time. Many improved local sensing schemes are proposed in [10 -17], including our own fuzzy logic-based and SNR-based adaptive spectrum sensing for improved local sensing. In the proposed scheme, channels with known PU waveform will be sensed by matched filter detection and rest of the channels by the detectors which do not need dedicated circuitry and prior knowledge of PU waveform.

1.1 Overview of Cognitive Radio Concepts

The cognitive radio concept was first introduced in [18], where the main focus was on the Radio Knowledge Representation Language (RKRL) [19]. A few formal definitions of Cognitive Radio exist; the two most complete are given by Haykin and Thomas in [20] respectively: Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

1. Highly reliable communications whenever and wherever needed;
2. Efficient utilization of the radio spectrum."

"A Cognitive Radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates."
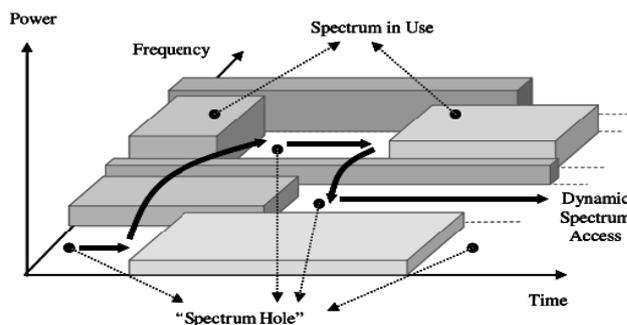

Figure 2 Spectrum hole concept

The ultimate objective of CR is to obtain the best available spectrum band through cognitive capability and recon-figurability. In order to take advantages of CR techniques we must find the unused portions of the spectrum also known as spectrum holes or white spaces [21]. Figure 2 shows the spectrum hole concept. In this figure we can observe the detection of the white spaces by real time sensing the wideband channel followed by the selection of the more suitable frequency bands. Finally, the multiple spectrum access coordination with other SUs who finally vacate the channel when a PU needs to transmit.

1.2 Cognitive Radio Tasks

The cognitive cycle consists of the following tasks:
1. Spectrum Sensing: Detects unused spectrum and shares the spectrum without negative interfering with other users.
2. Spectrum Analysis: Captures the best available spectrum to meet user communication requirements.
3. Spectrum Management and Handoff: Enables SUs to choose the best frequency band and hop among multiple bands according to the time varying channel characteristics to meet the different Quality of Service (QoS) requirements.
4. Spectrum Allocation and Sharing: Provides a fair spectrum scheduling method between coexisting SUs and PUs.

II. SPECTRUM SENSING

Cognitive radio (CR) technology solves the issue of spectrum underutilization in wireless communication better way. Cognitive radios are designed in order to provide highly reliable communication for all users of the network, wherever and whenever needed and to facilitate effective utilization of the radio spectrum to its maximum extent. This observation has lead the regulatory bodies to search a method where secondary (unlicensed) systems are allowed to opportunistically utilize the unused licensed bands commonly called them as white spaces. CR network can change its transmitter parameters based on interaction with environment in which it operates. A major challenge in cognitive radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and come out of the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary users. This method is called spectrum sensing. Spectrum sensing and estimation is the fast and major step to implement cognitive radio system. So many ways are there, and other way of categorizing the spectrum sensing and estimating methods are by making group into model based parametric method and period gram based non-parametric methods. Other way of classification depends on the need of spectrum sensing as stated below Spectrum Sensing for Spectrum Opportunities. The detection of primary users is

verified based on the received signal at Cognitive radio users. This method includes matched filter (MF) based detection, covariance based detection, energy based detection method, radio identification based detection, waveform based detection, cyclostationary based detection scheme, radio identification based detection and random Hough Transform based detection.

2.1 Spectrum Sensing Techniques

Sensing spectrum is the most important factor of cognitive radio, which is important step that needs to be performed for communication to take place. A number of techniques have been developed for detecting whether the primary user is present in a particular frequency band of the spectrum. Some of the most common schemes employed for Spectrum Sensing are

i)   Energy Detection
ii) Cyclostationary Feature Detector
iii) Matched Filter Detection

Among the above three methods energy detection is popular till now, but the major problem with energy detection method is that the poor performance under low SNR conditions and also no proper difference between primary users and noise. Rather the MF maximizes the SNR the electromagnetic radio spectrum we have is a limited natural resource and getting crowded day by day due to increase in wireless devices and apps. Also, the conventional approach to spectrum management is very easy in the sense that each wireless operator is assigned an exclusive license to operate in a certain frequency spectrum. With most of the useful radio spectrum already allocated, so it is difficult to find vacant bands to either to enhance existing ones or to encourage new service.

2.2 Classification of Spectrum Sensing Techniques

The various spectrum sensing techniques [24] were proposed to identify the presence of primary user signal and what extent to exploit that single by secondary user when the primary user is absence. The most popular spectrum sensing techniques are classified under three major categories Non-Cooperative detection, Cooperative detection and Interference based detection as shown in Figure 3.
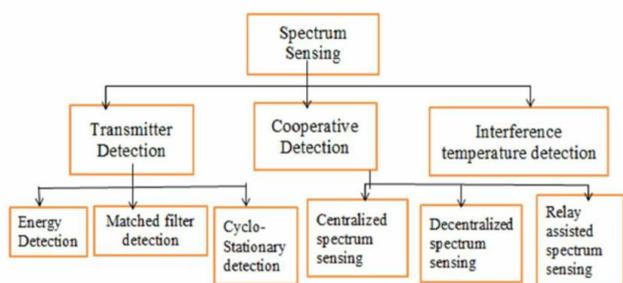

Figure 3 Spectrum Sensing Techniques

2.2.1 Non-cooperative spectrum sensing This form of spectrum sensing also known as single-user sensing (or local detection), and occurs when a cognitive radio acts on its own. There are various non-cooperative spectrums sensing technique. For e.g., matched filter, energy detection and cycloystationary detection.

(1) Energy Detection (ED)

The energy detection is a non-coherent detection technique, the primary user detection and its statistics does not need any prior knowledge of the primary user signal to determine whether the channel is occupied or not. Consequently, it is considered the one of simplest techniques of spectrum sensing to detect primary user transmitter [24]. The most advantages of using energy detection, low computational cost, easy implementation, less complexity which depend only on the power of PU signal whether the signal present or absence, these advantages makes energy detection the simplest method to detect primary user signal. In contrast, in this technique the signal detection is depend on comparing power of the received signal to the threshold level, whereas threshold level rely on the noise floor which can be estimated but the signal power is difficult to estimate as it changes relying on two factories distance between primary user and cognitive radio another factor is ongoing transmission characteristics [25].

If the PU waveform is unknown, the energy detector is applied on the received signal r(t). An energy detector with bi-thresholds is used for detection in which two thresholds are $\lambda 1$ and $\lambda 2$. The received energy is given by,

$$E = \sum_{K=0}^{j-1} r(K)^2$$

Where, j is determined from the time bandwidth product. If the received energy E is greater than $\lambda 1$, then the presence of a PU is declared. Similarly, if the received signal is less than $\lambda 2$, then the absence of a PU is declared. If the received signal energy is between $\lambda 1$ and $\lambda 2$, it is in the region of uncertainty (RU), and the energy detector is not reliable for PU detection, which is evaluated as

$$\text{Decision} = \begin{cases} 1 & \text{if } E > \lambda_1 \\ RU & \text{if } \lambda_2 \leq E \leq \lambda_1 \\ 0 & \text{if } E < \lambda_2 \end{cases}$$

As a consequence, the selection of an appropriate threshold level caused some drawbacks of the energy detection; threshold is might too low that is makes some noise as primary signal which causing in false alarm. On the other hand, when the threshold is too high, the missed detection will occur because of a weak primary signals will ignore. Therefore the performance of energy detection is depending on the suitable selection of the threshold in the frequency domain. Another disadvantage the accuracy of signal detection is low compared with other techniques.

Energy Detector with Double Thresholds -To overcome noise uncertainty problem, two thresholds are used. This is the region that lies between two thresholds. If detected values lie outside the fuzzy region, it will generate 0 or 1 depending upon the presence or absence of PU signal. In case, the information is ignored, then accuracy of spectrum sensing is compromised. Moreover, if all detected values lie in fuzzy region, then no information is available for taking decision which causes spectrum sensing failure problem. If the decision is taken in cooperative manner, multiple CRs with fusion centre is required, which increases system requirement. In, decision is taken by single user but it considers only difference between measured value and threshold.

(2) Cyclostationary Feature Detection (CFD)

Cyclostationary feature detection needs high computation complexity, the best detection point is determined through simulation analysis on different detection points, and then we intend combination detection method using multiple detection points to obtain better performance. Output validate the effectiveness of the suggested method Cyclostationary feature

detection can be able to have high detection probability under low SNR, actually, it requires high computation complexity. In reality, based on channel and a given location, the licensed users' signal parameters are known and the SNR is changing gradually, so we assume that we can obtain the licensed users' signal type and SNR before making detection. Using of the licensed users' prior knowledge like properties of signal, we only makes detections in some specific frequencies and cycle frequencies, and multiple combine detection points to increase the performance further. And then given the PD required by licensed users, the probability of false alarm (PFA) under different SNRs is implemented. Through the threshold adjustment, we decrease the PFA to make better use of spectrum hole when the SNR is high and increase the PFA to avoid interference to the licensed users when the SNR is low. Also CFD method can distinguish among noise and primary user signal at very low signal-to-noise ratio (SNR) values. In addition, the detection of this method is relies on the inherent redundancy in the primary user transmissions [27]. One of the most advantage, CFD method is represented its ability to identify the modulation scheme.
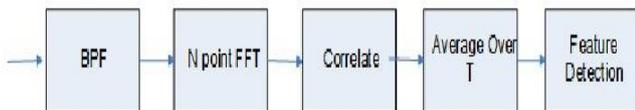

Figure 4 Block Diagram of Cyclostationary Detection

The Cyclostationary Detector Is Applied For A Reliable Decision Of Sensing Accuracy. Researchers Suggest That Cyclostationary Feature Detection Is More Suitable Than The Energy Detector Technique When The Noise Uncertainties Are Unknown [7].

Commonly, The Primary Modulated Waveforms Are Coupled With Patterns Also Characterized As Cyclostationary Features, Like Sine Wave Carriers, Pulse Trains, Repeating Spreading, Hopping Sequences, And Cyclic Prefixes Inducing Periodicity. An SU Can Detect A Random Signal With A Specific Modulation Type In The Presence Of Random Stochastic Noise By Exploiting Periodic Statistics Like The Mean And Auto-Correlation Of A PU Waveform. Features Like Autocorrelation And Mean Are Estimated By Analyzing Spectral Correlation Functions (Scfs). A Block Diagram Of Cyclostationary Detection Using The SCF Is Shown In Figure
4. The SCF, Also Called A Cyclic Spectrum, Is A Two Dimensional Function With A Cyclic Frequency A [28]. In The Spectrum Sensing Scheme, When The Received Energy Is Between λ1 and λ2, Channels Are Sensed By The Cyclostationary Detector.

On the other hand, the CFD takes long time during computation which is considered slightly complex. And also it is the worst when the noise is stationary than energy detection In addition, the cost of this technique is slightly high caused by the partial knowledge which required this method to detect the primary user.

The second-order cyclic analyses built-in in modulated signals is used to detect the signals. Because of high complexity of cyclostationary feature detection and so we choose to detect specific frequencies and cyclic frequencies based on the signal's feature to decrease complexity greatly. We collate the detection performance of different points to find the best detection points through simulation analysis and

propose to combination detection method using multiple detection points to get better performance.

(2) Matched Filter Detection (MFD)

The decision making on whether the signal is present or not can be known if we pass the signal through a filter, which will stress the useful signal sig(t) and quash the noise w(t) at the same time. Such a filter which will peak out the signal component at some instant and smother the noise amplitude at the same time has to be designed. This will give a sharp contradiction between the signal and the noise, and if the signal sig (t) is present, the output will come out to have a large peak at this instant. If the signal is missing at this instant, no such peak will appear. This arrangement will make it feasible to decide whether the signal is present or absent with less probability of error. The filter which finished this is called as matched filter. Main intention of the filter is, to minimize the noise component and to maximize the signal component at the same moment. So this is clearly equivalent to maximizing the signal amplitude to the noise amplitude ratio at some instant at the output. It proves more suitable if we go for square of amplitudes. So the matched filter is designed in such a way that it should maximize the ratio of the square of signal amplitude to the square the amplitude of noise.
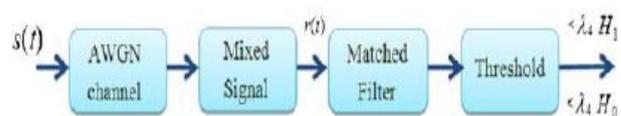

Figure 5 Block diagram of matched filter

Another technique of the spectrum sensing is Matched filter Detection (MFD), which is known as optimum method to detect primary uses when the transmitted signal is known, and also this technique is commonly used in radar transmission. In addition, MFD also is considered as a linear filter designed in digital signal processing (DSP) which is used to maximize the output signal to noise ratio for given input signal [24]. However, a MFD requires demodulation of the primary user signal effectively, as a consequence, this technique requires a perfect prior knowledge of a primary user which is represented in some signal features such as modulation type and order, bandwidth, operating frequency, pulse shaping and frame format. The advantages of this method are represented in the following points: Firstly, The detection process requires short sensing time and low number of samples to meet required level of false alarm or missed detection [24]. Another advantage, it has high processing gain and high accuracy compared with other techniques [24]. Also it is the optimal detection performance. Even though has its advantages, also has some disadvantage, the power consumption of this technique is large in different receiver algorithms witch need to be implemented to detect primary users. Match filter requires a dedicated receiver for every signal type of primary user [24]. Also the MFD needs a perfect knowledge of primary user signal. The implementation complexity of sensing unit is impractically large.

One of the well-known techniques of spectrum sensing for a known PU waveform is matched filter detection. The intuition behind the matched filter relies on the prior knowledge of a PU waveform, such as modulation type, order, the pulse

shape, and the packet format. The matched filter is an optimal linear filter for maximizing the SNR in the presence of additive stochastic noise [19]. The matched filter is equivalent to convolving the received signal r(t) with a time-reversed version of the known signal or template as

$$r(t) * s(T - t + \tau)$$

Where T is a symbol time duration and τ is the shift in the known signal.

Therefore, the performance of matched filter relies on what extent of the availability of perfect prior knowledge of primary users which lead to increasing cost and more complexity. Consequently, the good performances and high accuracy are MFD at the expense of cost and complexity that are increased.

2.2.2 Cooperative Spectrum Sensing

Cooperation is proposed as a solution to problems that arise in spectrum sensing due to noise uncertainty, fading, and shadowing. Cooperative sensing decreases the probabilities of miss-detection and false alarm considerably. In addition, cooperation can solve hidden primary user problem and it can decrease sensing time. In cooperative sensing, several SUs combine their findings to arrive at a more reliable decision. This can be essential in severe fading environments: if the SUs are sufficiently far apart, it is much less likely that they are all in a fading dip. Hence, PMD (and/or PFA) decreases significantly. The final decision of cooperative sensing can be based on hard decisions (e.g. a majority vote), or on soft decisions (including additional information). There will be some trade-off between the final decision quality, the required processing, and the required communication overhead.

2.2.3 Interference based detection

Interference management is important in cognitive radio networks since secondary usage is allowed only if the SU interference does not degrade the PU quality of service below a tolerable limit. In this interference model, each primary receiver has an interference temperature limit that defines how much noise and interference it can tolerate to guarantee certain quality of service. This creates spectrum opportunities for the SUs. Using this model, cognitive radios can measure and model the interference environment and adjust their transmission characteristics such that the interference to PU is not above the regulatory limits. However, major drawback of the model is to measure the interference temperature at the primary receivers which is unfeasible in practice. The FCC has abandoned the concept of interference temperature as unworkable. At the same time, the FCC has also encouraged the researchers to solve the problems related to the interference temperature and make it feasible.

In this paper the brief introduction of cognitive radio (CR), overview of CR is discussed and also explains the overview of cognitive radio concepts and tasks. Paper concludes all spectrum sensing techniques determine. Especially spectrum sensing divides non-cooperative spectrum sensing and cooperative spectrum sensing, also determine a part of non-cooperative spectrum with matched filter detection.

REFERENCES

[1] 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, volume 1, pages 772{776 Vol.1, 2004.

[2] Joseph Mitola III. Cognitive Radio-An Integrated Agent Architecture for Software Defined Radio. PhD thesis, PhD Dissertation Royal Institute of Technology (KTH) Stockholm, 2000.

[3] I. F. Akyildiz, L. Won-Yeol, C. V. Mehmet, and M. Shantidev. Next generation/ dynamic spectrum access/ cognitive radio wireless networks; a survey. Computer Networks, 50(2):2127{2159, 2006.

[4] O. Olabiyi and A. Annamalai. Analysis of detection performance of modified periodogram over fading channels. In Consumer Communications and Networking Conference (CCNC), 2012 IEEE, pages 449{453, 2012.

[5] L.S. Cardoso, M. Debbah, S. Lasaulce, K. Mari, and J. Palicot. Spectrum sensing in cognitive radio networks. Cognitive Radio Networks: Architec- tures, Protocols and Standards, 2009.

[6] IF Akyildiz, W-Y Lee, MC Vuran, S Mohanty, NeXt generation/dynamic spectrum access/cognitive radio wireless networks: a survey. Comput. Netw. 50(13), 2127–2159 (2006)

[7] T Yucek, H Arslan, A survey of spectrum sensing algorithms for cognitive radio applications. Commun. Surv Tutor. 11(1), 116–130 (2009)

[8] IF Akildiz, BF Lo, R Balakrishan, Cooperative spectrum sensing in cognitive radio networks: a survey. Phys. Commun. 4(1), 40–62 (2011)

[9] A Ghasemi, ES Sousa, Spectrum sensing in cognitive radio networks: requirements, challenges and design trade-offs. IEEE Commun. Mag. 46(4), 32–39 (2008)

[10] W Ejaz, NU Hasan, MA Azam, HS Kim, Improved local spectrum sensing for cognitive radio networks. EURASIP J. Adv. Signal Process (2012). http:// asp.eurasipjournals.com/content/2012/1/242.

[11] KG Smitha, AP Vinod, PR Nair, in IEEE Proceedings of International Conference on Innovations in Information Technology (IIT). Low power DFT filter bank based two-stage spectrum sensing, (UAE, March 2012), pp. 173–177.

[12] W Ejaz, NU Hasan, HS Kim, SNR-based adaptive spectrum sensing for cognitive radio networks. Int. J. Innov. Comput. Inf. Control. 8(9), 6095–6106 (2012)

[13] S Geethu, GL Narayanan, A novel high speed two stage detector for spectrum sensing. Elsevier Procedia Technol. 6, 682–689 (2012)

[14] S Maleki, A Pandharipande, G Leus, in IEEE Proceedings of International Conference on Acoustic Speech and Signal Processing. Two-stage spectrumsensing for cognitive radios, (USA, March 2010), pp. 2946–2949

[15] PR Nair, AP Vinod, KG Smitha, AK Krishna, Fast two-stage spectrum detector for cognitive radios in uncertain noise channels. IET Commun. 6(11), 1341–1348 (2012)

[16] W Yue, B Zheng, Q Meng, W Yue, Combined energy detection one-order cyclostationary feature detection techniques in cognitive radio systems. J China Univ. Posts Telecommun.

[17] (4), 18–25 (2010) [17] L Luo, NM Neihart, S Roy, DJ Allstot, A two-stage sensing technique for dynamic spectrum access. IEEE Trans. Wirel. Commun. 8(6), 3028–3037 (2009)

[18] J. Mitola and J. Maguire, G.Q., \Cognitive radio: making software radios more personal," Personal Communications, IEEE, vol. 6, no. 4, pp. 13{18, 1999.

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