Survey: A Comparison of Spectrum Sensing Techniques in Cognitive Radio

A.M. Fanan, N.G. Riley, M. Mehdawi, M. Ammar, and M. Zolfaghari

***Abstract* —** In the present day Cognitive Radio has become a realistic option for solution of the spectrum scarcity problem in wireless communication. One of the most challenging issues in cognitive radio systems is spectrum sensing concepts, which is considered an extremely well researched topic. In this paper we compare three main classes of spectrum sensing techniques (Energy detection, matched filtering and cyclostationary) analysis in terms of time and spectrum resource consumed required prior knowledge and complexity. We then rank the three classes according to accuracy and performance.

***Keywords*—** Cognitive Radio, Cyclostationary, Spectrum Mobility, Spectrum Sharing.

I. Introduction

TODAY, wireless communications systems become ever more constrained by availability of spectrum, due to an increasing demand of higher data transmission rates and channel capacity, while the wireless networks are regulated by government policy. Historically, the spectrum bands have been assigned to license holders for long term and over large geographic areas, which led to spectrum scarcity for potential new spectrum users. Such issues can be addressed in wireless networks by using cognitive radio technology even if all spectrum bands are allocated for licensed users. According to the report of Federal Communications Commission (FCC), "A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. This interaction may involve active negotiation or communications with other spectrum users and/or passive sensing and decision making within the radio. The majority of cognitive radios will probably be SDRs, but neither having software nor being field reprogrammable are requirements of a cognitive radio"[1]. The majority of cognitive radios will probably be SDRs, but neither having software nor being field reprogrammable are requirements of a cognitive radio"[1].

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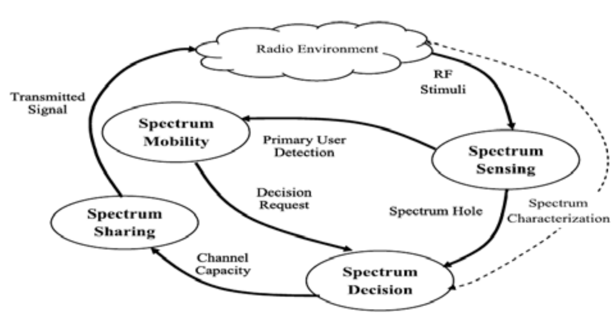
The FCC report has shown the most of measurement studies obvious that the vast majority of licensed spectrum unutilized across many time and frequency slots [2]. The main idea of cognitive radio technology is to reuse or share the spectrum, which is licensed to the primary users (PU) and then allow secondary User (SU) to exploit and communicate over unused spectrum in precise time and specific location. It is also seeking to maintain efficiency and reliability in spectrum use. Cognitive radio is considered an intelligent wireless communication system which can be aware and learn from the environment and then adapt new states to deal with incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier frequency, and modulation strategy) [2][3].

This paper is organized as follows. Firstly, the various functions of cognitive radio are presented; Spectrum sensing, spectrum decision, spectrum mobility and spectrum sharing. Spectrum sensing techniques are classified and then advantages and disadvantages are extracted. Finally the comparisons among spectrum sensing techniques are discussed by using six criteria: time and spectrum resource consumed required prior knowledge, complexity, accuracy and performance.

II. Cognitive Radio Functions

CR has been divided into four main functions to provide the capability to use or share the spectrum and to achieve the primary objectives, efficient utilization of spectrum. Also highly reliable communications when and where needed. Fig 1 show the cycle of the cognitive radio as secondary radio system which involve spectrum Sensing, spectrum mobility, spectrum decision and spectrum sharing.[4]

Fig 1: Cognitive radio cycle [5], [6]



Spectrum Sensing is main key of CR which senses the radio environment continuously to explore unutilized frequency bands which can be exploit by CR [7]. In addition, the spectrum sensing also is defined by [8] “as the task of finding spectrum holes by sensing the radio spectrum in the local neighborhood of the cognitive radio receiver in an unsupervised manner”. Consequently, the main goal of spectrum sensing is to give more opportunities to CR users whose can temporarily access over the unoccupied spectrum for transmission without interference to the licensed (primary) users. **Spectrum Decision** is an operation that based on the spectrum sensing which provides sensing information to cognitive radio, operating frequency and its corresponding technical parameters. To enhance the satisfaction of quality of service without causing excessive interference the CR can be used data from policy database. Therefore, the CR networks need to decide which suitable spectrum bands can be used by secondary user. This process will implement by spectrum decision [3], [4], [9]. **Spectrum Mobility -** The definition of spectrum mobility in this paper is suggested in [3] as: "maintaining seamless communication requirement during the transition to better spectrum". Furthermore, to implant this process, the spectrum mobility in CR networks is divided into two parts, spectrum handoff and connection management. The spectrum handoff means transfer continuous data transmission from current spectrum to unused spectrum. As a consequence due to PU arrival, hence the SU should leave the licensed spectrum immediately. Thus, the handoff process yielded to transmutation delay. Consequently, the connection management will manage and adjusts protocol stack parameters to compensate handoff delay [10]. **Spectrum Sharing -** Wherein, the spectrum holes can be used by a number of secondary users, A key challenge of the cognitive radios (CRs) is how to "achieve balance between its self-goal of transferring information in efficient way and altruistic goal to share the available resources with other cognitive and non-cognitive users"[4]. Hence, it can be said, Scheduling of using spectrum holes among CR users will contribute to prevent excessive interference to primary users and between secondary users.

A cognitive radio networks is created intelligently to be monitor and aware to the changes in its surrounding sensitively, which makes spectrum sensing a vital task among other CR tasks. Spectrum sensing is facing a number of challenges to apply sensing methods; these challenges are represented in some factors that have negative impacts on spectrum detection [3]. Firstly, signal-to-noise ratio (SNR) might be very low detection. Secondly, there are two issues of wireless channels that make the spectrum sensing is complicated, time dispersion and multipath. Finally, the noise power might be uncertainly to detect the holes in the spectrum band, due to noise level that might change within location and time. Spectrum sensing has widely investigated by vast majority of researchers [2], [11]. The main challenge of cognitive radio is the spectrum sensing which need to detect spectrum holes in radio environment for secondary users. In [12], [13], [14] the spectrum sensing is divided into three various schemes in terms of system performance a full Sensing scheme, which need to sense the target spectrum in each activation, thus all the available spectrums are sensed by CR users to exploit a suitable and available spectrum. Secondary, “a restricted sensing scheme, that users only sense the spectrum in their ideal resource set” [12]. Finally, a minimum sensing scheme, in this case, the users can communicate over the suitable spectrum holes directly without sensing.

Nowadays, there are some spectrum techniques already involved in current wireless standards, which have some features of cognitive radio such as IEEE 802.11K, Bluetooth and IEEE 802.22. For instance, the Bluetooth use the adaptive frequency hopping (AFH) to reduce the interference between wireless system, so AFH contain sensing algorithm to decide if there is device present in band or not to avoid them [16].

III. Spectrum Sensing Techniques

The various spectrum sensing techniques 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 Fig 2.

A-Non-cooperative spectrum sensing

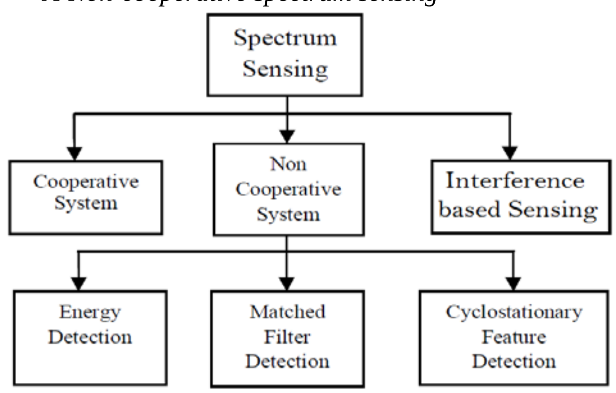


Fig. 2 Spectrum Sensing Techniques [15].

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 [2], [3], [4], [16], [17]. The most advantages of using energy detection, low computational cost, easy implementation, less complexity and does not need any prior knowledge of primary user 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 [3], [4], [5] [7], [17]. 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 [18]. 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 [16], [17], [19].

2-Matched Filter Detection(MFD)

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 [3], [4], [17]. 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 [2], [7], [15]. 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[2], [16]. 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 [15], [20]. Another advantage, it has high processing gain and high accuracy compared with other techniques [15]. Also it is the optimal detection performance [17]. 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 [16]. Match filter requires a dedicated receiver for every signal type of primary user [15]. Also the MFD needs a perfect knowledge of primary user signal [5]. The implementation complexity of sensing unit is impractically large [16], [21].

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 performance and high accuracy in the MFD at the expense of cost and complexity that are increased obviously as illustrated in Fig 3.a and Fig 3.b.

3-Cyclostationary Feature Detection(CFD)

Cyclostationary feature detection (CFD) is a method for detecting transmitted signals of the primary user by suing the CFD of the received signals [2], [3], [16]. Also CFD method can distinguish among noise and primary user signal at very low signal-to-noise ratio (SNR) values [17], [22]. In addition, the detection of this method is relies on the inherent redundancy in the primary user transmissions [16]. One of the most advantage, CFD method is represented its ability to identify the modulation scheme [22]. However, CFD needs partially knowledge of the primary user. And also it can be detect the primary user signal at very low SNR value [17].

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 [2], [4], [7]. In addition, the cost of this technique is slightly high caused by the partial knowledge which required this method to detect the primary user.

Consequently, it can be said, the performance of this technique relies on several factors noise uncertainty, modulation scheme identification and redundancy transmissions of the primary user [4]. Hence, hence the performance improvement of CFD is at the expense of increasing cost and time as shown in the figures 3.a, 3.b.

B-Cooperative Sensing technique

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 sensingf 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.

C-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.

IV. A Performance Comparison of Different Spectrum Sensing Techniques

In this section we compare the performance of three well-known classes of algorithms-energy detectors, matched filter, and the Cyclostationary detection. During the comprehensive study of the spectrum sensing techniques, criteria which directly affect performance and accuracy of each technique were discussed. In particular, these aspects for energy detection, matched filtering and Cyclostationary detection are presented in Fig 3.a and 3.b. A comparison has been made of time, cost, prior knowledge, complexity for each technique (Fig 3.a) and how these aspects impact on the accuracy and performance as shown in Fig 3.b. The performance of comparison has represented in three different values low, medium and high. It can be clearly seen the energy detection has short time, low cost, no prior knowledge and less complexity but correspondingly the accuracy and performance are low because these criteria rely on some factors such as suitable threshold selection and noise stability. It is unrealistic to expect to find these stationary factors in all the times and various places. Whereas, the matched filter technique as illustrated in fig 3.b has good performance and high accuracy but at the expense of increasing the cost, more complexity and requires perfect knowledge to operating these techniques. In contrast Cyclostationary analysis has slightly better performance and possesses higher accuracy than energy detection, but it needs long time, high cost and partial prior knowledge which that make it less complex than the matched filter. Therefore, each of these techniques has advantages and disadvantage where some advantages are at the expense of significant problems which might impact directly on the technique working properly and effectively. Hence, in practice it is necessary to search for an optimum technique which might contain less complexity and high efficiency which is able to adapt its operation to suit prevailing conditions. The overall goal of efficient spectrum sensing is to use the minimum spectrum for the actual sensing task, possibly at the expense of increased processing cost at each terminal.

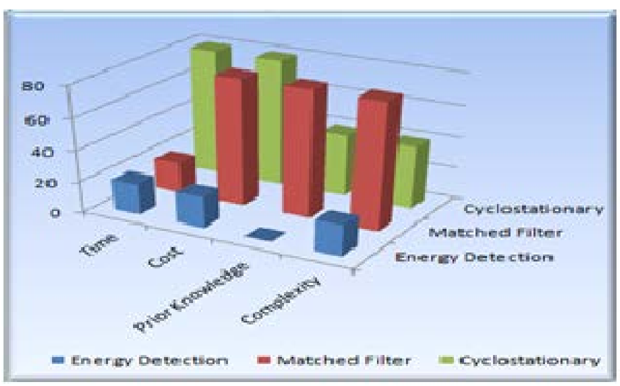


Fig. 3.a Comparison of spectrum sensing techniques

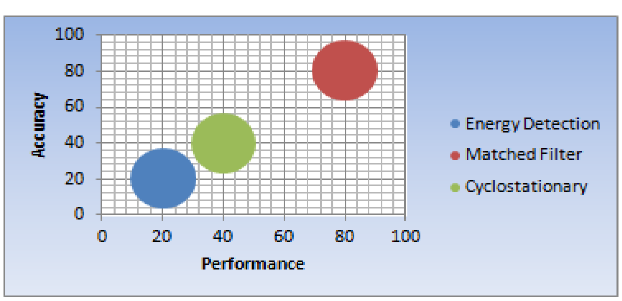


Fig 3.b Performance of the spectrum sensing techniques

V. Simulation Platform for Spectrum Sensing Techniques ED, MF and, CFD

In this section, we have proposed algorithm for the discussed spectrum sensing techniques in the preceding sections. The algorithm computes and compares spectrum sensing techniques based on the probability of detection (Pd) and probability false alarm (Pf). This performance detection is analyzed using (Receiver Operating Characteristics) curves for three different scenario energy detection, matched filter and Cyclostationary detection. Monte-Carlo method is used for simulation.

Figure 4 show the probability of detection versus probability of miss detection for three different methods. Simulation outcome of spectrum sensing techniques shows in figure (4) point out that the matched filter is the best among the three techniques. Cyclostationary technique is closest to the matched filter and the energy detection is worst among them. In terms of the required processing, the energy detection is the easiest and it is not requires any prior information. However, both the matched filter and cyclostationary, on the other hand, require prior information. For instance the matched filter required fully information and cyclostationary required partially information. This is clearly difficult to implement, as well the will be very expensive and very complicate to build in.

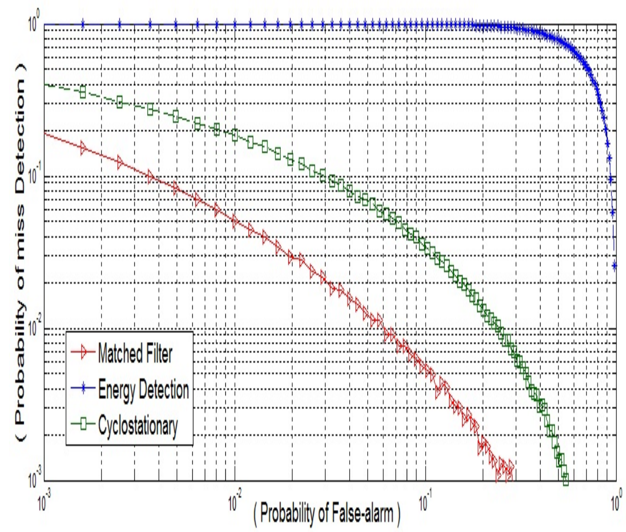


Fig 4 Complementary Roc Curves for various spectrum sensing techniques (ED, MF, CD) with SNR=0

Figure 5 indicates that when SNR increase to 6dB , all the proposed scheme method has high probability of detection and low probability of miss detection compared with SNR=0 dB in figure (4). This not good example since it is will increase the complexity of the system. Alternative solution is to use cooperative sensing which reduce the false alarm and increase agility and has accurate signal detection, this will be our research in future work. [23] In his paper result show that the significant improvement in terms of required average SNR for detection. In particularly, for Pd equal to 0.9, local spectrum sensing requires SNR=16 dB while in cooperative sensing with n=10 only need average SNR of 5dB for individual

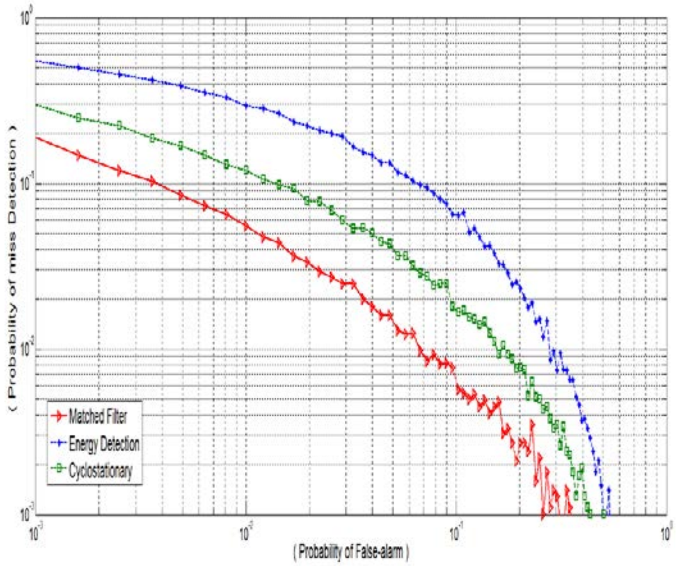


Fig. 5 Complementary Roc Curves for various spectrum sensing techniques (ED, MF, CD) with SNR=6

V. Conclusion

In this paper, we have compared the accuracy and the performance in three various techniques energy detection, matched filter and cyclostatinary by using several criteria such as time, cost, prior knowledge and complexity. It has been found that the performance and accuracy are relies on what extent availability of the prior knowledge for primary user signal. Furthermore, the complexity also increased when spectrum sensing techniques requires more prior knowledge to detect primary user. In contrast, increasing knowledge caused increasing cost and takes long time. Therefore, we need specific technique which might be done in future work by combining the perfect features by using two techniques, whereby possesses minimum prior knowledge of primary user, low cost, short time and less complexity.

References

[1] Federal Communications Commission, “Notice of proposed rule making and order: acilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies,” ET Docket No. 03-108, Dec. 2003.

[2] N.Yadav and S.Rathi, "A comprehensive study of spectrum sensing techniques in cognitive radio," International journal of Advances in engineering & technology, July 2011.

[3] V.Saxena and S.J.Basha,”A Survey of various spectrum sensing techniques in cognitive radio networks: Non cooperative systems” Department of ECE, LNCT Indore, RGPV university, 2013

[4] Z.Tabakovic. "A survey of cognitive radio systems," Croatian post and electronic communications agency, 2013.

[5] A.Singh,V.Saxena. "Different spectrum sensing techniques used in non cooperative system", International journal of engineering and innovative technology, Volume1, Issue 2 , February 2012.

[6] I. F. Akyildiz, W.-Y. Lee, K. R. Chowdhury: "CRAHNs: Cognitive Radio Ad Hoc Networks", Ad Hoc Networks, Elsevier, Vol. 7, No. 5, July 2009, pp. 810-836. http://dx.doi.org/10.1016/j.adhoc.2009.01.001

[7] S.Ziafat, W.Ejaz and H.Jamal. "Spectrum sensing techniques for cognitive radio networks: performance analysis," IEEE, 2011.

[8] S.Haykin, D.Thomson and J.Reed, "Spectrum sensing for cognitive radio: The utility of the multitaper method and cyclostationarity for sensing the radio spectrum, including the digital TV spectrum, is studied theoretically and experimentally," IEEE, 2009.

[9] W.Lee and I.Akyildiz,"A Spectrum Decision Framework for Cognitive Radio Networks," IEEE Transactions on mobile computing, vol. 10, no. 2, February 2011.

[10] I.Christian, S.Moh, I.Chung, and J.Lee, " Spectrum Mobility in Cognitive Radio Networks," Chosun University,IEEE Communications Magazine, June 2012

[11] C. K. Chen and W. A. Gardner, “Signal-selective time difference of arrival estimation for passive location of man made signal sources in highly corruptive environments–II:algorithms and performance,” IEEE Transactions on Signal Processing, vol. 40, no. 5, pp. 1185–1197, 1992. http://dx.doi.org/10.1109/78.134480

[12] T.Jiang,D.Grace and Y.Liu, “Cognitive radio spectrum sharing schemes with reduced spectrum sensing requirements,“ Communication Research Group,Department of Electronics University of York, York, YO10 5DD, United Kingdom.

[13] L.Stabellini and M.U.Javed, “Experimental comparison of dynamic spectrum access techniques for wirless sensor networks,“ Wireless@KTH, The Royal Institute of Technology, Electrum 418, SE-164 40 Kista, Sweden, 978-1-4244-2519-8/10/$26.00 ©2010 IEEE.

[14] S.Shobana, R.Saravanan, R.Muthaiah, “Matched Filter Based Spectrum Sensing on Cognitive Radio for OFDM WLANs,“ International Journal of Engineering and Technology (IJET), ISSN : 0975-4024 Vol 5 No 1 Feb-Mar 2013.

[15] B.Mounika,K.R.Chandra,R.R.Kumar, “Spectrum Sensing Techniques and Issues in Cognitive Radio,“ International Journal of Engineering Trends and Technology (IJETT) - ISSN: 2231-5381 Vol4 Issue4- April 2013.

[16] T.Yucek,H.Arslan,“A survey of spectrum sensing algorithms for cognitive radio applications,“ IEEE communications surveys & tutorials, vol. 11,no. 1, first quarter 2009. http://dx.doi.org/10.1109/SURV.2009.090109

[17] I.K.Aulakh,“spectrum sensing for wireless communication networks,“ National Conference on computing, communication and control(ccc-09).

[18] T.Ikuma,M.N.Pour,“A comparison of three classes of spectrum sensing techniques,“ Department of Electrical and computer Engineering-Louisiana state university, IEEE GLOBECOM, 2008.

[19] Worcester polytechnic institute,“Software defined radio system and analysis, laboratory 4: Spectrum Sensing techniques,“ ECE4305,2011.

[20] A.Sahay, N.Hoven and R. Tandra,”Some fundamental limits on cognitive radio. ” In Proc. Allerton conf. ,Monticello, Oct. 2004.

[21] D. Cabric, S. Mishra, and R. Brodersen, “Implementation issues in spectrum sensing for cognitive radios,” in Proc. Asilomar Conf. On Signals, Systems and Computers, vol. 1, Pacific Grove, California, USA, Nov. 2004, pp. 772–776.

[22] P.S.Aparna, M.Jayasheela,“ Cyclostationary Feature Detection in Cognitive Radio using Different Modulation Schemes,“ International Journal of Computer Applications (0975 – 8887) Volume 47– No.21, June 2012.

[23] Geng wang “Performance of Collaborative Spectrum Sensing in a Cognitive Radio System” Master Thesis the university of British Columbia, 2009.