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Performance Enhancement for Cognitive Radio

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Abstract: Cognitive Radio (CR) is an emerging technology which provides a way to overcome the problems associated with the limited bandwidth. CR promises to fulfill the usage of limited spectrum for the innovative exposure for the mankind and also for the development in the field of research. It uses the unlicensed band when the Primary User (PU) is not actively using it for its own purpose. This intelligent technology makes use of the unlicensed band and also make sure that it will not interference the primary user whenever PU demands for its own licensed band. Spectrum sensing is the one of the most important function of CR. The main aim of this paper is to get the knowledge about the techniques of spectrum sensing and also summarize the pros and cons of each technique in details. The simulations are done to show the relationship between the different parameters in the energy detection method. The improvement has done by applying different modulation technique and also by increasing the SNR value up to desire level.

Key words: Cognitive Radio (CR), Primary User (PU), energy detection, cyclo-stationary feature detection, matched filter

INTRODUCTION

As the world is moving into the era of development. This can be achieved only by the motivation towards the innovation of the new trendy technologies and can be done by the help of the researcher who needs the spectrum for the experiments so that their work proved worth for the society as well as for the academic purpose. All this requires the band which is becoming expensive day by day to meet the necessity of everyone. For this reason, only the cognitive radio comes in the picture to facilitate the need of spectrum. CR works for increasing the usage of the limited spectrum by providing many applications and services which comes under wireless sensor network. It has been observed by the FCC that in the particular location or in the different time >70% of the licensed spectrum is vacant and can be utilize for the other research purpose. At the certain time of period when the spectrum is not in use can be compensated by the secondary user known as cognitive radio. Cognitive radio has the ability to change its parameter according to the environment and adapt very quickly without any interference to the primary user. The most important characteristics which attract the researcher to work upon cognitive radio are:

Capability: It is the major factor of CR is the way it senses the radio environment continuously and chooses the best path for transmission or communication. The optimum way is selected to achieve the QoS and make sure it should not trouble the primary user at any point of time.

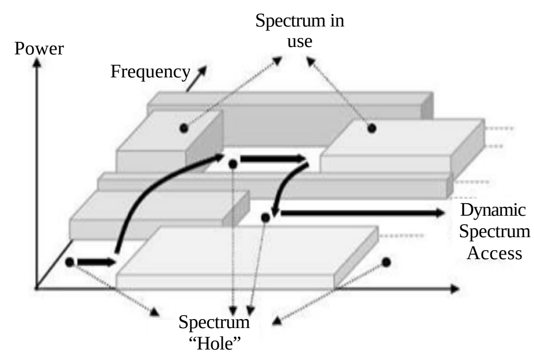

Fig. 1: Spectrum hole concept

Reconfigurability: CR has the intelligent features that it can change accordingly for the other use. CR is designed in such a way that it can be used for transmit and receive at different frequencies and utilize various transmission access supported by its hardware design (Akyildiz *et al*, 2006):

- The initial work of the CR is to continues sense for the unused spectrum and chooses the best spectrum for the transmission of the signals (Fig. 1)

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- Once the spectrum sensing is done the next important step is to manage the unused spectrum which is called as spectrum management
- The spectrum is found by secondary user and utilizes the band until the primary user demand for it. This is called as spectrum sharing
- Spectrum mobility is the final step of CR is to vacant the PU's band and immediately move to the other spectrum available

MATERIALS AND METHODS

Main functions of CR: The main functions of the cognitive radio are as follows:

- Spectrum sensing
- Spectrum Management
- Spectrum sharing
- Spectrum mobility

These are the most important functions of cognitive radio which performs at the different OSI layers and together results in the communication. Spectrum sensing: This is the first step in the cognitive radio transmission to observe the radio environment continuously and gives the best possible way after sensing the whole environment and also keeps the track on the frequency of the primary user visiting the spectrum at which particular time slot. Sensing of the spectrum continuously will consume the energy but it is essential to sense it regularly so that the best path can be achieved. Spectrum Sensing can lead to two important parameters in the cognitive radio:

False detection: This false detection will occur when actually PU is absent but CR fails to identify the unused band for the transmission.

Missed detection: In the process of sensing the environment sometimes it happens that even the PU is present but CR fails to identify it so this is known as missed detection.

Spectrum management: Spectrum sensing refers to the way to choose the best route to meet the required purpose of the user. CR needs to analyze, store, represent and organize the data which is obtained from the first step and forward the same to the other CR network to achieve QoS show in Fig. 2.

Spectrum sharing: Once the cognitive radio sets its own transmitting frequency it will acknowledge to the receiver end about its band chosen for the communication to be established.

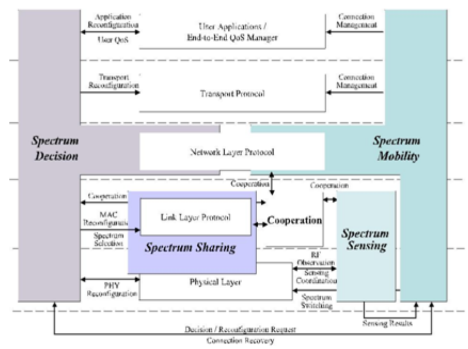

Fig. 2: Spectrum management of the CR

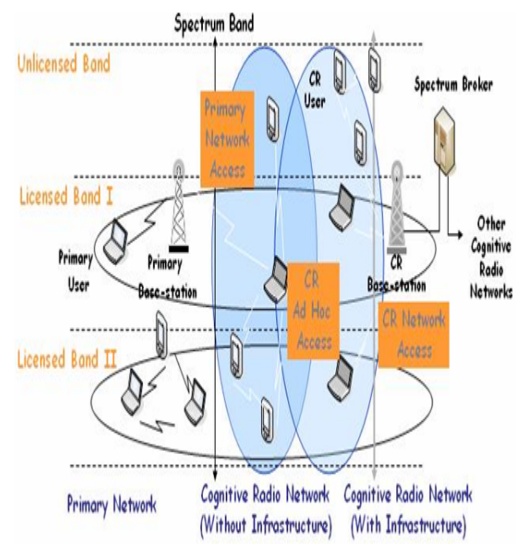

Fig. 3: Cognitive radio architecture

Spectrum mobility: This step is well known as handover in the wireless communication. It provides the rapid switching of the CR from the unlicensed band to the other vacant band when PU is back to its own band. CR needs to shift to the other band in such a way that the transmission should not be failed to gain best QoS.

Architecture of cognitive radio: Present wireless network architectures provide combination of both spectrum policies and communication technologies (Banerjee and Karmakar, 2012). In the present radio spectrum some of the portion is for the licensed band and rest of it is unlicensed band (ISM) show in Fig. 3.

The blocks in the architecture of CR network is classified in two segments primary network and the other is cognitive radio.

Primary network: Primary user: A primary user is the authorized user to access the licensed band for its own purpose. Primary user has all the access via base station which controls every function of the primary user as per the demand of the user. Primary base band: It has the fixed infrastructure network blocks for the specific technologies with licensed band and called as primary base band. For example, in Wi Max network, fixed number of transceiver, BTS are present to provide the connectivity.

Cognitive radio network; cognitive radio user: Secondary user or CR user are not having the access to operate on licensed band so some other ways are carried out for these users to provide connectivity with other network. Cognitive Radio base station: Cognitive radio also has the fixed infrastructure components to provide the one hop connectivity to the CR users which do not have the license of the spectrum. Spectrum broker: This is a center part of the network which facilitates the ability to share the network among the different CR networks to avoid wastage of bandwidth.

Appication of cognitive radio: With its innovative properties and functions cognitive radio can be used in other fields such as:

Leased network: In leased network, the primary network may give the leased network to CR users to access its licensed band like rent for some moment to utilize it without creating any interference in the communication of primary user.

Cognitive mesh radio: The broadband connectivity can be achieved by providing the mesh network which are growing very fast in wireless domain as a cost effective technology (Akyildiz *et al*., 2005). High throughput is the only demand needed by the mesh topology to deploy in the network.

Emergency network: Cognitive radio network can be served for the public safety and disaster management also. At the time when required CR acts as the ad-hoc network which provides temporary connectivity (Stine, 2005).

Military network: Nowadays military radio environment make effective utilization of cognitive radio (Stine, 2005). CR networks can empower the military radios to select Intermediate Frequency (IF) bandwidth, modulation schemes and coding schemes, adjusting to the variable radio environment at the frontend.

Spectrum sensing methods: The biggest hindrance in the path of CR success is the spectrum sensing. In the spectrum sensing it is very essential to detect the hole in the spectrum band for identifying the presence of PU. It is important to find out the sensing techniques which have less mean detection time to identify the presence or absence of the secondary user. Since, it is tedious work for CR to know about of the transmission channel between the primary user and the secondary user (Haykin *et al*., 2009).

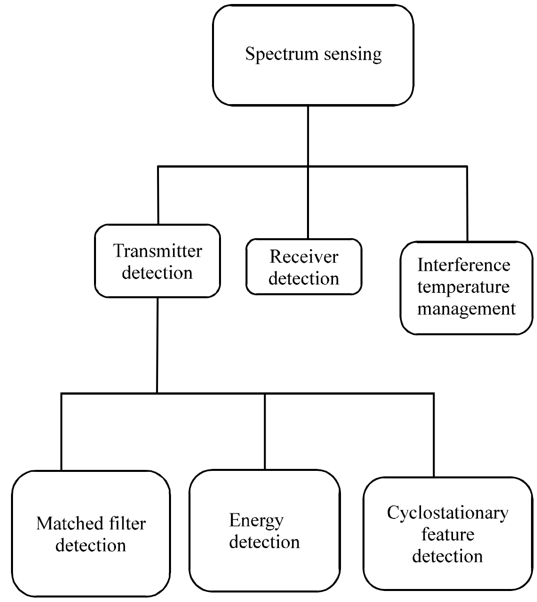

Fig. 4: Spectrum sensing techniques

These are the some of the sensing techniques based on the transmitter detection, receiver det+ection and the interference temperature detection. In the transmitter detection the common techniques for detection are matched filter detection, Cyclo-stationary detection and energy detection show in Fig. 4.

Transmitter detection: In this detection it is required to keep the track on the primary user that are transmitting the signals at any time in the environment. Hypothesis model for transmitter detection is defined as the signal received by the secondary user (Ghasemi and Sousa, 2005):

$$r(t)=\{n(t) \text{ if } H_0 n(t)+hs(t) \text{ if } H_1\}$$

Where:

- $r(t)$ = The received signal by CR
- $s(t)$ = The transmitting signal of primary user
- $n(t)$ = The Additive White Gaussian Noise (AWGN) in the environment and h is known as the gain of the channel
- H_0 = The null hypothesis
- H_1 = The presence of transmitting signal show in Fig. 5

Table 1: Comparison of the different sensing techniques

Spectrum sensing techniques	Advantages	Disadvantages
Energy detection	Prior knowledge of PU is not required	Performs at low SNR
Cyclo-stationary detection	Performance is better than ED	Sensing time is high
Matched filter detection	Improved SNR	Need of prior information is needed

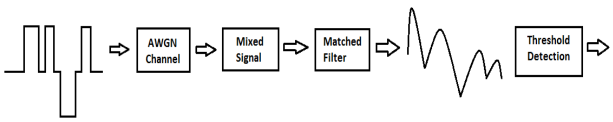

Fig. 5: Block diagram of matched filter

Matched filter: The matched filter is used for maximizing the output signal to noise ratio at the receiver end for better results (Haykin *et al*., 2009) in the presence of the noise in signal. It basically increases the signal strength without increasing the noise in that signal.

If the sampled output is greater than the threshold level then H_1, the spectrum is occupied by PU transmitter. This shows the details of the matched filter which has sensing time faster than other techniques, that requires zero samples to achieve the given targets. Matched filter demand for the previous information about the primary user like the modulation type, channel, type of fading etc. and addition to that it also requires the coordination between the PU transmitter and the CR user which is difficult to achieve.

Advantages: Matched filter takes less detection time because it needs zero samples to achieve the given limited probability of detection.

Disadvantages: This filter requires the prior information of the PU user and also demands for the adjustment between the PU user and the CR user. If the data collected is not accurate then the performance degrades. CR could needs a separate receiver for every PU (Haykin *et al*., 2009).

Energy detection: Energy detection is the simplest technique which is used for the sensing of the spectrum. This is adopted when the CR does not have the prior knowledge about primary user (Ghasemi and Sousa, 2008). In the energy detection the presence or absence of the primary user is based on the energy of the received signal show in Fig. 6. The Energy detection also requires the zero samples for a given detection probability ($1/SNR^2$). If CR needs to identify the week PU signals (-10 to 40 db) then the energy detector will suffer the longer detection time as compared to the matched filter. As it is known that the energy detection is only based on the signal-to-noise ratio of the given received signal, its performance degrades at the changeable noise power. If the noise power is changed at any point of the time during the sensing then energy detector will fail to perform as the SNR is less than the threshold value, this is known as SNR walls.

Table 2: Parameters used

Parameters	Values
Length of the signal	10000.00
Probabilityof false detection (Pf)	0.01
Number of simulation	1000.00

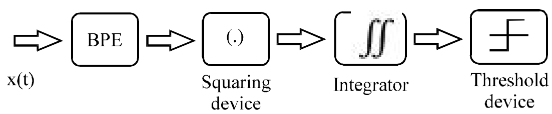

Fig. 6: Block diagram of energy detection

Advantages: This filter doesn't demand for any prior knowledge of the PU user. It also ignores the structure of the given received signal. It is simple method as compared to other methods.

Disadvantages: Sensing time taken by this filter is quite high. Performance level will degrade if the noise power becomes uncertain in nature. Energy detection can't be used as to distinguished between the primary user's signals and the CR user's signals Table 2.

Cyclo-stationary feature detection: This detection determines the presence of the primary user in the given spectrum by extracting all the necessary features such as pilot signal, cyclic prefix, symbol rate, spreading codes and modulation type from its local observation (Ghasemi and Sousa, 2005). Cyclo-stationay feature detection is complex but its accuracy is good in detection of the primary user in the radio environment and its sensing time is also longer show in Fig. 7.

Advantages: The major advantage of Cyclo-stationary feature detection is its flexibility to the uncertain to the noise power.

Disadvantages: Its computation is complex and also requires long sensing time show in Fig. 8. The figure shows the different techniques of spectrum sensing and its accuracy with its complexity in performance. Table 1 displays the performance comparison of different sensing techniques.

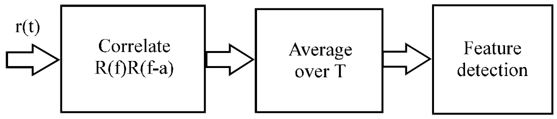

Fig. 7: Block diagram of cyclo-stationary detection

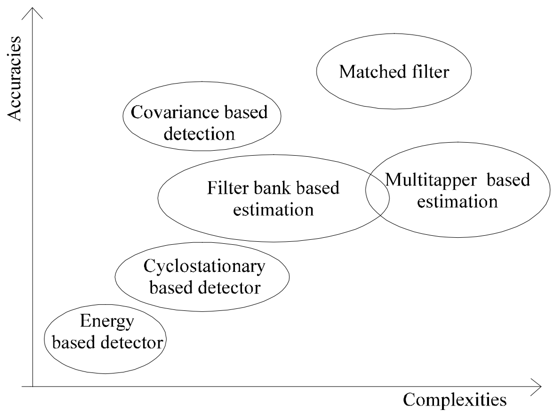

Fig. 8: Sensing accuracy and complexity of techniques (Subhedar and Birajdar, 2011)

Receiver detection: To overcome the problems in the transmitter detection, the receiver detection is proposed. In receiver detection all the topologies provide reduced detection time as compared to the transmitter detection. The scenarios which are present in cooperative techniques are decentralized uncoordinated technique, centralized coordinated techniques and decentralized coordinated techniques.

This technique also comes which its own disadvantages that is CR need to perform the sensing of the radio environment only at the particular interval of time as sensed information changed frequently in cognitive radio due to the function of CR which involves spectrum mobility, channel impairments.

Interference based detection: In this type of detection CR Users operate at the underlay (UWB) like approach. In the interference based detection the interference can be monitored at the transmitter side through the radiated power, location and the frequency of the particular operators Fig. 9 (Hossain *et al*., 2009). The main idea to fix the upper interference limit for the required frequency band in the specific location so that the CR users are unable to emit any kind of harmful interference. The drastic need for the spectrum based services, rapid technical development in the area of radio system demands for the unique methods which concentrate on the actual RF environment and interaction between the transmitter and the receiver.

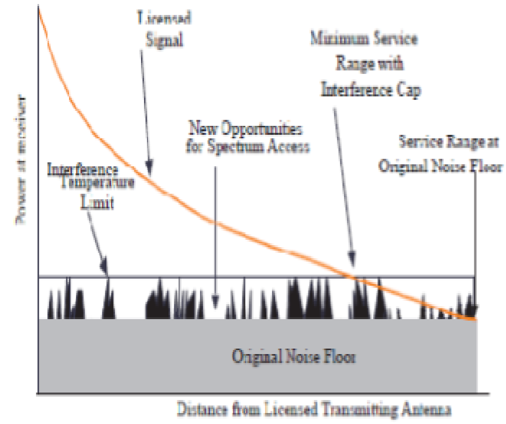

Fig. 9: Interference temperature models

System model: For sensing the primary signals a formulated hypothesis is mentioned as:

$$X(t) = \begin{cases} n(t) & \text{if } H_0 \\ n(t) + hs(t) & \text{if } H_1 \end{cases}$$

Where:
$x(t)$ = The received signal by CR
$n(t)$ = The Additive White Gaussian Noise (AWGN)
$s(t)$ = The transmitting signal and h is the channel gain
H_0 = The null hypothesis
H_1 = The presence of the primary user

The Energy received by the receiver is given as:

$$E\sum_{N=1}^{N}|x(t)|^2$$

Where:
E = The energy received at the receiver side
N = The number of the samples

The probability of detection and probability of false alarm are given by the mathematical formula as:

$$Pf = P(E < \lambda) = Q\left(\frac{\lambda - N\sigma_w^2}{\sqrt{2N\sigma_w^4}}\right)$$

$$Pd = P(E > \lambda) = Q\left(\frac{\lambda - N(\sigma_w^2 + \sigma_w^2)}{\sqrt{2N(\sigma_s^2 + \sigma_w^2)}}\right)$$

The probability of missed detection is given as:

$$Pm = 1 - Pd$$

Where:
λ = The threshold value which is compared with the received energy to identify the presence or absence of the σ_w PU

Q = The Marcum Q-function
σ_s = The signal variance
σ_w = The noise variance

Simulation environment: All the simulation in the energy detection technique is carried in MATLAB tool. Some of the necessary assumptions are made in order to achieve the results. The important parameter is the noise present in the system, the AWGN (Additive White Gaussian Noise) with zero mean and variance 1 is used for the simulation purpose. For the ROC curve which shows the relationship between the Probability of detection (Pd) and Probability of false alarm (Pm) the SNR value which is taken is 0.10. The Monte Carlo simulation is used for result analyses.

RESULTS AND DISCUSSION

In the energy detection as the SNR value is being changed the Probability of false alarm (Pf) and Probability of detection (Pd) will be change accordingly. SNR is directly proportional to the probability of detection as the SNR will increase the probability of the detection will also increase linearly or vice versa. This simulation is done under the AWGN (Additive White Gaussian Noise) with zero mean and variance as 1. The SNR value is kept as 0.10 which is -10dB. The graphs that are plotted shows the relationship between the different parameters that are essential for the energy detection methods the important factors are the probability of missed detection (Pm), probability of false alarm (Pf) and probability of detection(Pd). Under various SNR values.

Figure 10 shows the ROCs curve for the energy detection when the SNR is set to be 0.1. both the theoretical value as well as the simulation values are shown in the above graph.

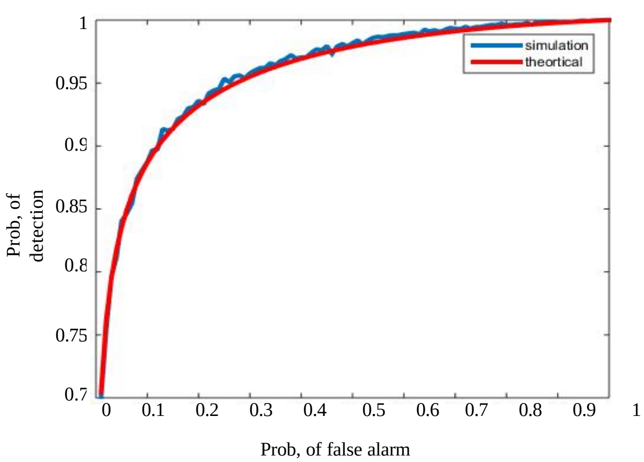

Fig. 10: ROC of energy detection

Figure 11 as the SNR value is being decrease from 0.16 to 0.10 the probability of detection will decrease from the 0.95-0.7. So as the SNR and probability of detection are directly proportional to each other. According to the simulations as the probability of detection will increase the probability of the false alarm will also increase simultaneously as shown in the Fig. 12. Both are directly proportional to each other's. In Fig. 12, the different modulation techniques are implemented on the energy detection in the presence of AWGN channel. The graph is plotted between the probability of detection and SNR (dB). The probability of detection is linearly increasing with the SNR values show in Fig. 13. The results show that the relationship between the probability of missed detection vs. SNR (dB) value at different modulation technique under the AWGN channel.

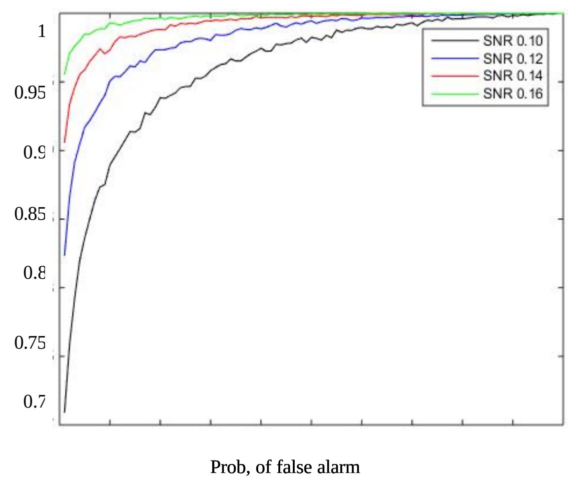

Fig. 11: Probability of detection vs. probability of false alarm at different SNR values

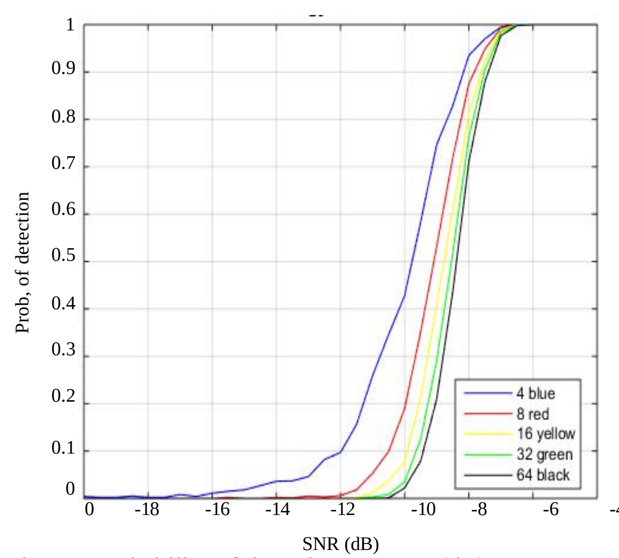

Fig. 12: Probability of detection vs. SNR (dB)

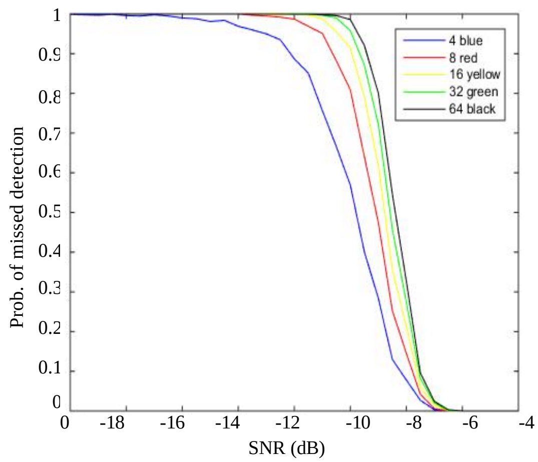

Fig. 13: Probability of missed detection vs. SNR (dB)

CONCLUSION

Cognitive radio technology came as a helper which creates a way out to resolve the issue related of spectrum utilization. With thehelp of the CR, the unlicensed band can be utilized when the primary user is not currently using it. For this purpose, the different techniques are present for spectrum sensing that is searching for the white space in the radio band so that the CR user can make effective use of the bandwidth. Energy detection technique is the simplest way to find out the hole in the spectrum, this method does not demand any kind of prior information about the primary user so computation is easy than other techniques.

REFERENCES

Akyildiz, I.F., W.Y. Lee, M.C. Vuran and S. Mohanty, 2006. NeXt generation dynamic spectrum access cognitive radio wireless networks: A survey. Comput. Networks J., 50: 2127-2159.

Akyildiz, I.F., X. Wang and W. Wang, 2005. Wireless mesh networks: A survey. Comput. Networks, 47: 445-487.

Banerjee, J.S. and K. Karmakar, 2012. A comparative study on cognitive radio implementation issues. J. Comput. Appl., Vol. 74.

Ghasemi, A. and E.S. Sousa, 2005. Collaborative spectrum sensing for opportunistic access in fading environments. Proceedings of the 1st IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks, November 8-11, 2005, Baltimore, USA., pp: 131-136.

Ghasemi, A. and E.S. Sousa, 2008. Spectrum sensing in cognitive radio networks: Requirements, challenges and design trade-offs. IEEE Commun. Mag., 46: 32-39.

Haykin, S., D.J. Thomson and J.H. Reed, 2009. Spectrum sensing for cognitive radio. Proc. IEEE., 97: 849-877.

Hossain, E., D. Niyato and Z. Han, 2009. Dynamic Spectrum Access and Management in Cognitive Radio Networks. Cambridge University Press, Cambridge, UK.

Stine, J.A., 2005. Spectrum management: The killer application of ad hoc and mesh networking. Proceedings of the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks DySPAN-2005, November 8-11, 2005, IEEE, McLean, Virginia, ISBN:1-4244-0013-9, pp. 184-193.

Subhedar, M. and G. Birajdar, 2011. Spectrum sensing techniques in cognitive radio networks: A survey. Int. J. Next Gener. Networks, 3: 37-51.