Optimization of Spectrum Sensing in Cognitive Radio Network using Cooperative Relay Channel

[1]Aparna Singh Kushwah, [2]Kartik Mehra
[1,2]Dept. of Electronics and Communication, UIT-RGPV, Bhopal, Madhya Pradesh, India

Abstract
Cognitive radio is an emerging technology for the opportunistic use of under-utilized spectrum. It promises to change the future technological trends forever if employed properly. Spectrum sensing is the major function of a cognitive radio network. This paper proposes a new strategy to optimize the overall performance in cooperative spectrum sensing. Optimization strategy is proposed in order to optimize the overall performance by varying the SNR. We consider optimization of cooperative spectrum sensing with energy detection to minimize the total error rate. Here we derive optimal voting rule for optimal value of cognitive radios. The effects of spectrum sensing technique type that used locally at each CR, the local SNR and the total number of cooperated CRs on the optimal fusion rule are found. The Energy Detector (ED) spectrum sensing technique is used as local spectrum sensing techniques. Here, different error levels are founded by varying the SNR values to find the optimal number of CRs for minimizing the error levels.

Keywords
Cognitive Radio, Spectrum Sensing, Total Error Rate

I. Introduction
The electromagnetic radio spectrum is a licensed resource. They are carefully managed by governments and authorities to provide secure and reliable wireless communication. Now a day the wireless service providers buy the license for one or more spectrum bands. And only its users known as primary user (PUs) are allowed to access these channel and use there. Examples of licensed technology are global system for mobile communications (GSM), worldwide interoperability for microwave access (WiMax) and Long Term Evolution (LTE). On the other hand, unlicensed cognitive users with lower priority are defined as secondary users (SUs).Due to the increased number of user's demand of wireless spectrum increases and spectrum scarcity problem arises. It leads to inefficient channel utilization. To, solve this problem concept of cognitive radio emerges.

The Federal Communication Commission (FCC) defines cognitive radio as follows: a radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters for modifying interference, facilitate interoperability, and access secondary markets. In Cognitive Radio (CR) network, a SU can access spectral resources of a PU, if the primary user is not using it. However the SU has to vacate the frequency band as soon as the PU becomes active so that negligible (or no) interference is caused to the PU.

Such opportunistic access of the PU resources by the SUs is called as dynamic spectrum access. A SU can opportunistically utilize different spectrum holes corresponding to different PUs. In order to satisfy its bandwidth requirement without causing interference to the PUs as shown in fig. 1.

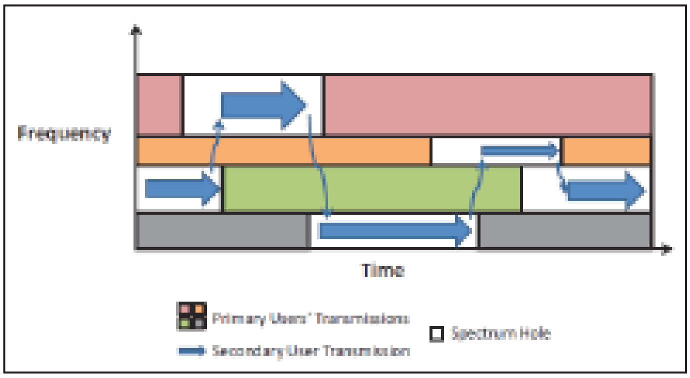

Fig. 1: In Cognitive Radios, Secondary Users (SUs)

Opportunistically use the spectrum not used by the primary users. Spectrum sensing is a key enabler for dynamic spectrum access in cognitive radios. It is the task of obtaining awareness regarding the radio spectrum as well as identifying idle spectrum. It enables the SUs to explore and exploit the unused PU spectrum. In addition it is crucial for managing the level of interference caused to the PUs of the spectrum. Spectrum sensing can be done by an individual SU and is called as single-user sensing or local detection. Single-user sensing becomes difficult in challenging propagation environments like multipath fading, Doppler spread, and shadowing. In such a scenario a SU has to distinguish between a white space, where there is no primary signal, and a deep fade, where it is hard to detect the primary signal. Cooperative Sensing (CS), where different SUs collaborate to detect the presence of a PU, provides diversity gains to tackle the fading and shadowing effects. CS also helps to increase the SNR gain and network coverage.

II. Cooperative Spectrum Sensing
The performance of a local detector degrades in the presence of propagation effects such as shadowing and fading caused by multipath. These channel conditions may also result in the problem of hidden node. Where a secondary transceiver is outside the listening range of a primary transmitter but close enough to the primary receiver to create interference. This is known as hidden terminal problem. These issues can be overcome using Cooperative Sensing (CS).Where neighbouring yet geographically distributed SUs cooperate in sensing a common PU transmission. It is achieved by exchanging sensing information among them before making a final decision. Most of the CS schemes stem from the field of distributed detection. Fig.2 shows an example of CS, where N SUs sense listening channels for the PU signal activity and send the sensing information on reporting channels to the fusion center (FC) or to the common receiver, it makes the final decision. It is very unlikely that all the channels between the PU and the SUs will be in a deep fade simultaneously. Thus cooperative detection helps in mitigating the channel effects through multipath diversity. Other benefits of cooperative detection include improved detector performance, increased coverage, simplified local detector design, and increased robustness to non-idealities. Therefore, CS has generated lot of interest in the cognitive radio literature.

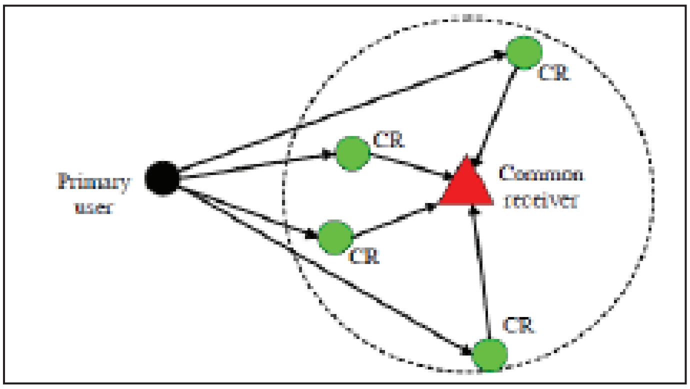

Fig. 2: Spectrum Sensing Structure in a Cognitive Radio Network

There are mainly two types of cooperative spectrum sensing:

A. Centralized Approach

In this method, there is a central node within the network that collects all the sensing information from the neighbouring sense nodes within the network. It then process and analyzes the collected information and then determines the frequencies which are used and cannot be used. The cognitive radio central node can also organize the various cognitive radio users to undertake different measurements at different times.

B. Distributed Approach

In distributed approach of cognitive radio cooperative spectrum sensing there is no central or master node for all controlling operations. Instead communication exists between the different nodes and they are able to share sense information. However this approach requires for the individual radios to have a much higher level of autonomy and setting themselves up as an ad-hoc network.
Hidden terminal problem makes spectrum sensing more critical to implement. This problem is due to environmental conditions and creates the problems like multipath fading, shadowing. Due to this there may be a wrong interpretation of secondary user and loss of information occurs. So to remove this problem and to achieve efficiency in spectrum sensing, cooperative spectrum sensing is used.

Cooperative spectrum sensing will go through two successive channels:

- Sensing channel (from the PU to CRs) and
- Reporting channel (from the CRs to the common receiver).

1. Advantages of Cooperative Spectrum Sensing:

(i). Hidden Terminal Problem is Reduced

By using cooperative sensing system, it is possible to reduce the hidden terminal problem because a greater number of receivers will be able to build up a more accurate scenario of the transmissions in the area.

(ii). Increase in Agility

An increase in the number of spectrum sensing nodes by cooperation enables the sensing to be more accurate and better options for channel moves to be processed. There by providing an increase in agility.

(iii). Reduced False Alarms

Due to multiple nodes performing the spectrum sensing, channel signal detection is more accurate and this reduces the number of false alarms.

2. Disadvantage of Cooperative Spectrum Sensing

Significant disadvantage of cooperative spectrum sensing are:-

(i). Control Channel

For the different elements within the cognitive radio cooperative spectrum sensing network to communicate, a control channel is required. This will take up a proportion of the overall system bandwidth.

(ii). System Synchronization

It is normally necessary to provide synchronization between all the nodes within the cognitive radio cooperative spectrum sensing network. Accurate spectrum sensing requires a longer period of time than a rough sense to see if a strong signal has returned. By adapting the sense periods, channel throughput can be maximized. But there is a greater need to maintain synchronization under these circumstances.

(iii). Suitable Geographical Spread of Cooperating Nodes

In order to gain the optimum sensing from the cooperating nodes within the cognitive network, it is necessary to obtain the best geographical spread. In this way the hidden node syndrome can be minimized and the most accurate spectrum sensing can be gained.

III. Cooperative Spectrum Sensing (CSS)

In cooperative spectrum sensing, binary hypothesis decision from each CR i.e. one bit decision (1 standing for the presence of licensed user, 0 stands for absence of licensed user) is forwarded to fusion centre. At the fusion centre, all 1-bit decisions are combined according to any one of the logic rule (AND Logic, OR Logic, and M-OUT-N Logic), a global decision will be taken; this final decision can be in favour of H_1 or H_0.

$$Y = \sum_{j=1}^{N} D_j \begin{cases} \geq m, & H_1 \\ < m, & H_0 \end{cases} \qquad (1)$$

Where H_1 and H_0 are decisions taken by fusion Centre that the primary user is transmitted or not transmitted respectively. Threshold m is an integer representing m-out of-N logic. From above the inference it can be seen that the AND logic corresponds to m=N and OR logic corresponds to m=1.

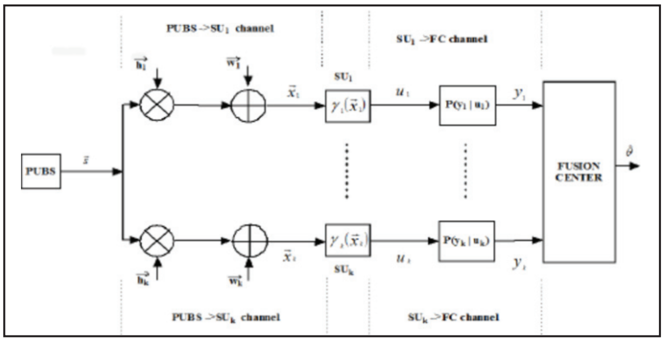

Fig. 3: Block Diagram for System Model of Cooperative Spectrum Sensing (CSS) Technique with K SUs (Sensors), one FC and one PU. Final Decision is made at the FC.

IV. Proposed Methodology

A. System Model

We consider a cognitive network with K number of CR's. One primary user and one fusion center (i.e., common receiver). The spectrum sensing is done by each CR independently. The decision taken by CR is sent to the fusion center and the fusion center will decide whether the primary user is present or not. To determine this we are considering two hypotheses: The received signal will be

$$x_i(t) = \begin{cases} w_i(t) \\ h_i(t)s(t) + w_i(t) \end{cases} \quad (2)$$

When the signal is received at the ith CR in timeslot t, s(t) is the PU signal. $h_i(t)$is the complex channel gain of the sensing channel between the PU and ith CR. $w_i(t)$ is the Additive White Gaussian Noise (AWGN). We assume that the sensing time is lesser than the coherence time of the channel. The coherence time is the time duration over which the channel impulse response remains constant. So $h_i(t)$ will be time invariant ($h_i(t) = h_i$) i. e., time independent. Also we assume that during sensing time, PU does not change its state. We use energy detection technique as PU signal is unknown. For each ith CR by energy detection we found average probability of detection, false alarm, missed detection over AWGN channel with following equations:

$$P_{f,\lambda} = \frac{\Gamma(u, \frac{\lambda_i}{2})}{\Gamma(u)} \quad (3)$$

$$P_{d,i} = Q_u(\sqrt{2\gamma_i}, \sqrt{\gamma_i}) \quad (4)$$

$$P_{m,i} = 1 - P_{d,i} \quad (5)$$

Where λ_i is the energy detection threshold and Y_i is the instantaneous Signal to Noise Ratio (SNR) at the ith CR. Also u is the time-bandwidth product of the energy detector. Γ (a) is the gamma function and Γ (a, x) is the incomplete gamma function.

$$\Gamma(a,x) = \int_x^\infty t^{a-1} e^{-t}\, dt \quad (6)$$

In transmitter detection we have to find the primary transmitters that are transmitting at any given time. We consider a system of one Cognitive Radio (CR), one Primary User (PU) when a signal from PU is transmitted; the received signal by the CR for the detection of PU can be modelled under two hypotheses (H_0 & H_1), is gives as follows

H_0:y(t) = n(t) PU is absent
H_1:y(t) = h*s(t) + n(t) PU is present

Where y (t) the received signal by secondary users. s (t) is the transmitted signal of the primary user, h is the channel coefficient and n (t) is AWGN with zero mean and σ_2 variance (i.e. N (0. σ_2)). The output is considered as the test statistic to test the two hypotheses H_0 and H_1.
H_1: Corresponds to the presence of both signal and noise We can define three possible cases for the detected signal:

1. H_1 turns out to be TRUE in case of presence of primary user i.e. P (H_1/H_1) is known as Probability of Detection (P_d).
2. H_0 turns out to be TRUE in case of presence of primary user i.e. P (H_0 / H_1) is known as Probability of Missed-Detection (P_m).
3. H_1 turns out to be TRUE in case of absence of primary user i.e. P (H_1/H_0) is known as Probability of False Alarm (P_{fa}).

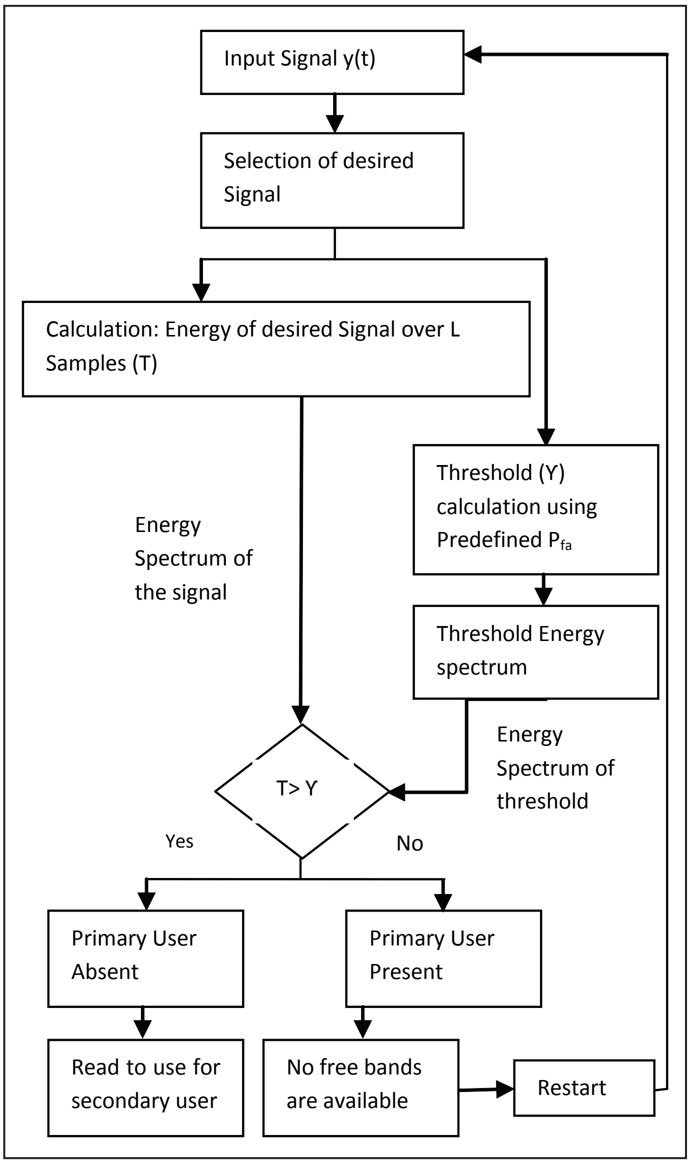

Fig. 4: Flow Chart for Spectrum Sensing Method

This method is used for deciding the absence or presence of primary user with the help of secondary user by sensing the received signal power from the primary user. To do the measurement one energy detector is used. Based on the signal strength of primary user's signal it decides that whether the channel is available for the secondary users or not. For this process secondary user doesn't require the prior information regarding primary user such type of signal, modulation scheme etc. so spectrum sensing using energy detection method is called as a non-coherent detection.
Particle Swarm Optimization (PSO) is a population based random search algorithm developed by Kennedy and Eberhart based on swarm behavior of bird flocking and fish schooling. In PSO, a population, also known as swarm, is initially created based on the search space of a given optimization problem. Each member in the swarm, also referred to as particle, is distributed randomly within the predefined search space. This population will randomly 'fly' through the search space to look for the global optimum. The trajectory of each particle is influenced by the best position personally found so far, which is called personal best (pbest),

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and the best position found by the entire swarm, named as global best (gbest).

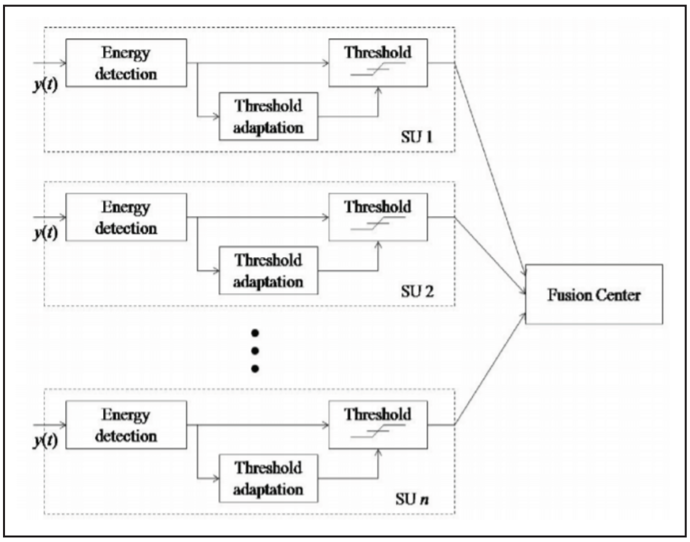

Fig. 5: Block Diagram for Cooperative Spectrum Sensing With PSO-based Threshold Adaptation

$$V_{ij}(t+1) = V_{ij}(t) + c_1 r_1 (y_{ij}(t) - x_{ij}(t)) + c_2 r_2 (\hat{y}_j(t) - x_{ij}(t)) \quad (7)$$

$$x_{ij}(t+1) = x_{ij} + V_{ij}(t+1) \quad (8)$$

Where $v_{ij}(t)$ denotes the velocity of i^{th} particle in j^{th} dimension at t-th iteration, c_1 and c_2 are referred as acceleration constants, r_1 and r_2 are uniformly distributed random values ranging in [0, 1]. $y_{ij}(t)$ is referred as pbest, which is the best position found by the i^{th} particle in j^{th} dimension so far by the t^{th} iteration whereas yˆ j(t) is referred as gbest, which is the best position found by the entire swarm in j-th dimension so far at the t^{th} iteration. $x_{ij}(t)$ denotes the position of i^{th} particle in j^{th} dimension at t^{th} iteration. Another parameter, so-called maximum velocity, V_{max} is imposed to limit the velocity of each particle to ensure exploration within the search space. A pseudocode of PSO is shown in fig. 3 for a given minimization problem.

V. Simulation Result

This section describes the MATLAB-based simulation platform that provides interactive access to check the performance and comparative analysis for energy detection method theoretically as well as practically by varying various Parameters.

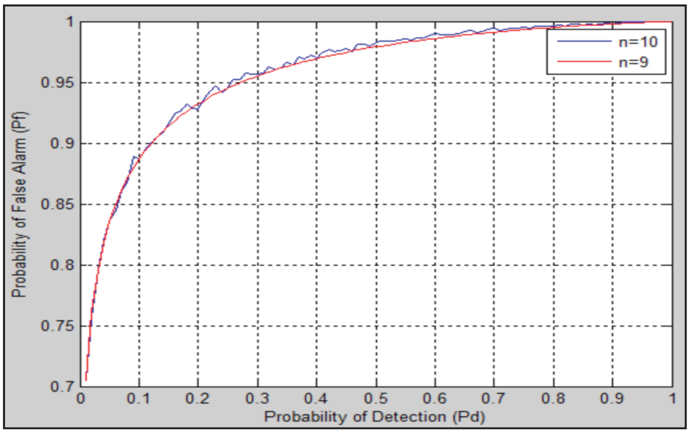

Fig. 4: Plot Probability of Detection (Pd) vs. Probability of False Alarm

In the figure, we found error rate for different threshold values and number of CR's by keeping SNR=10 db. In figure, the error rate is low for n =5 and it is high n =10 and n =1.i.e. with use of 5 CR's out of 10 we can achieve low error rate. This figure explains the optimal rule. This figure explains the optimal rule. That is probability of missed detection and false alarm probability is high if very few or high number CR's are used. So the number of CR's used should be half of total CR's, i.e. for n=5 the probability of missed detection and false alarm probability is low, so cooperative spectrum sensing allocation is done in correct way. Also, by modelling the system, we compare results get from modelling and formulae for n =5.

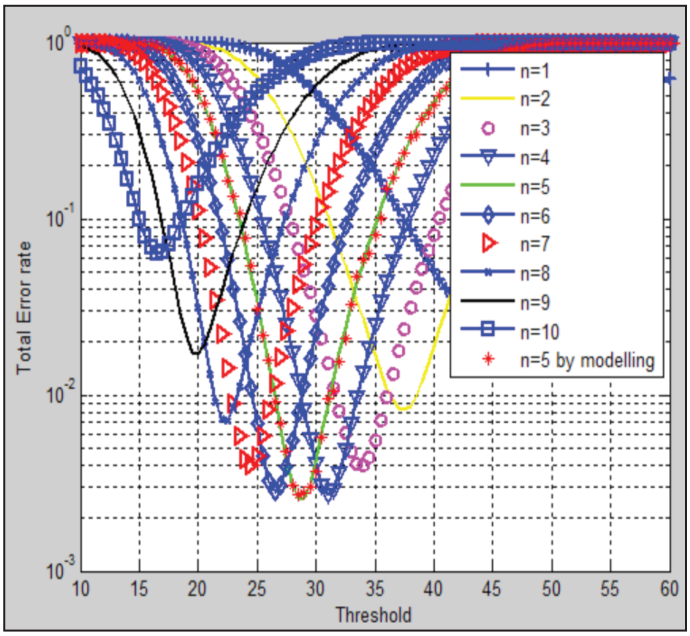

Fig. 5: Total Error Rate of Cooperative Spectrum Sensing in AWGN Channel With 10dB SNR. Optimal Voting rule for n=1, 2,........, 10 and K=10.

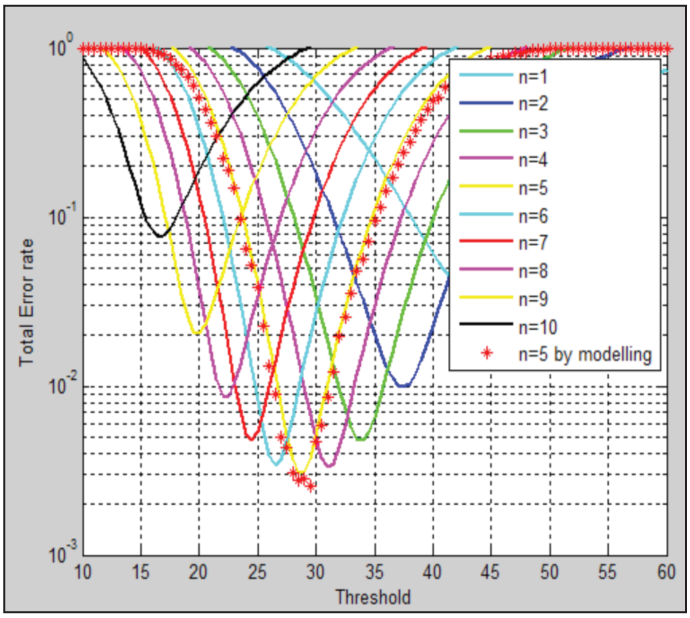

Fig. 6: Total Error Rate of Cooperative Spectrum Sensing in Rayleigh Channel With 10dB SNR. Optimal Voting rule for n=1, 2,........, 10 and K=10.

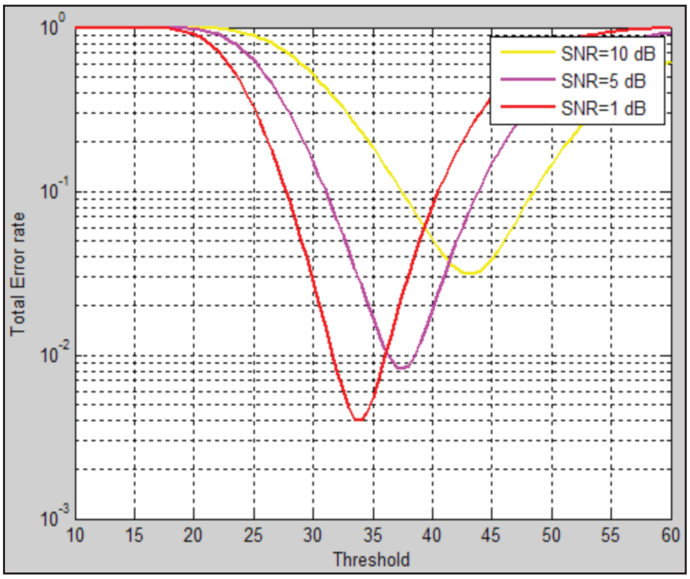

Fig. 7: Total Error Rate of Cooperative Spectrum Sensing in AWGN Channel

VI. Conclusion

We have studied the cooperative spectrum sensing with energy detection using formula and modelling the system. We analyzed the system with optimum voting rule for minimum error rate and K/2 is optimal value. Also, optimization of threshold has been done with minimum values of probability of missed detection and false alarm probability. We analyzed the system, for the less probability of missed detection and false alarm probability so that spectrum allotted correctly to secondary user. We proposed the fast sensing algorithm and calculated least number of CR's a given error bound.

References

[1] M Siranjeevi, K V Karthikeyan,"A study analysis of cooperative spectrum sensing in cognitive radio network", Second International Conference on Science Technology Engineering and Management (ICONSTEM), pp. 551-555, 2016.

[2] Abdelfatah Elarfaoui, Noureddine Elalami,"Optimization of QoS Parameters in Cognitive Radio Using Combination of Two Crossover Methods in Genetic Algorithm", International journal Communications Network and System Sciences, Vol. 6, pp. 478-483, 2013.

[3] Li Gui, Shihong Zou, Xiaofeng Zhong,"Distributed Best-Route Selection for Multi-path Routing in Cognitive Radio Ad Hoc Networks", Institution of Engineering and Technology, Vol. 48, pp. 1630-1632, 2012.

[4] Maninder Jeet Kaur, Moin Uddin, Harsh K Verma, "Optimization of Qos Parameters in Cognitive Radio Using Adaptive Genetic Algorithm", International Journal of Next-Generation Networks, Vol. 4, pp. 1-15, 2012.

[5] Yuan Jinsha, Shi Hongmei,"A Modified Symbol Harry Hrkowitz,"Energy Detection of Unknown Deterministic Signals", Proceeding of the IEEE, Vol. 55, Issue No. 4, pp. 523 – 531, 1967.

[6] Fadel F. Digham, Mohamed-Slim Alouini, Marvin K. Simon,"On the Energy Detection of Unknown Signals Over Fading Channels", IEEE transactions on communications, Vol. 55, No. 1, 2007.

[7] Fadel F. Digham, Mohamed-Slim Alouini, Marvin K. Simon,"On the Energy Detection of Unknown Signal over Fading Channels", Communications, 2003, ICC '03. IEEE International Conference on, Vol. 5, pp. 3575 – 3579, 11-15 May 2003.

[8] Federal Communicated Commission,"Spectrum Policy Task Force", Rep. ET docket no. 02-135, Nov. 2002.

[9] Danijela Cabric, Shridhar Mubaraq Mishra, Robert W. Brodersen, Berkeley,"Wireless Research Center, University of California, Berkeley, "Implementation Issues in Spectrum Sensing for Cognitive Radios".

[10] Marvin K. Simon Mohamed-Slim Alouini,"Digital Communication over Fading Channels", A Unified Approach to Performance Analysis A Wiley-Inter science Publication JOHN WILEY & SONS, INC.

Aparna Singh Kushwah is working as Assistant Professor at the University Institute of Technology, RGPV Bhopal, India since 2005. She received her M.E. degree in Communication Control and Networking from MITS Gwalior in 2006.
She is pursuing Ph.D. from RGPV, Bhopal. Her area of research is cooperative communications. She has published 26 research papers in National, International Journals and Conferences.

Kartik Mehra received the Bachelor of Engineering degree in electronics and communication from UIT-RGPV, Bhopal India. He is pursuing Master of Engineering degree in digital communication from UIT- RGPV, Bhopal India. His research interests are digital signal processing and image processing.