Vandana Publications
IJEMR

Volume-7, Issue-3, May-June 2017
International Journal of Engineering and Management Research
Page Number: 537-542

Equal Gain Combining in Cooperative Spectrum Sensing of Cognitive Radio Network: A Review

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ABSTRACT

Reliable detection of the existence of primary users is a primary requirement for the minimization of interference to existing primary networks. Cognitive radio (CR) systems need to detect the presence of licensed primary user (PU) reliably. Spectrum sensing is one of the systems which checks the vacancy of primary user designated to particular frequency spectrum. Cooperation among multiple CRs helps to enhance the reliability of detection of the PU in case of unreliable decision by a single CR due to channel uncertainties. In a real communication environment, the local sensing performance of individual users may severely degrade due to deep fading/shadowing. In this paper, we consider cooperative spectrum sensing (CSS) based on energy detection in cognitive radio networks (CRN) which uses soft combination of the observed energy values from different CRs. More precisely, we study CSS with soft data fusion scheme namely, Equal GainCombining (EGC) that can be implemented at fusion centre (FC). The performance of CSS has been assessed under AWGN Channel.

Keywords-- Cognitive radio, Spectrum Sensing, SNR, radio-frequency spectra, Energy detection, Equal gain combining

I. INTRODUCTION

The radio frequency spectrum is a limited characteristic asset that is divided into spectrum bands. In the course of the most recent century, spectrum bands have been apportioned to diverse services, for example, mobile, fixed, broadcast, fixed satellite, and mobile satellite services. As all the spectrum bands are as of now dispensed to diverse services, most often requiring licenses for operation, a crucial issue confronting future wireless systems is to discover suitable carrier frequencies and bandwidths to take care of the anticipated demand for future services.

With Cognitive Radio being utilized as a part of various applications, the territory of spectrum sensing has become progressively vital. As Cognitive Radio technology is being utilized to provide a method for utilizing the spectrum all the more productively, spectrum sensing is key to this application. The ability of Cognitive Radio frameworks to get to spare sections of the radio spectrum, and to continue observing the spectrum to guarantee that the Cognitive Radio framework does not create any undue interference depends totally on the spectrum sensing components of the framework.

For the overall framework to work viable and to provide the required change in spectrum efficiency, the Cognitive Radio spectrum sensing framework must have the capacity to adequately recognize some other transmissions, distinguish what they are and inform the central preparing unit inside the Cognitive Radio so that the required actions can be taken.

II. COGNITIVE RADIO

Cognitive radio is a type of wireless communication where a transceiver can intelligently distinguish the channels for communication which are being used and which are not being used, and move into unused channels while maintaining a strategic distance from occupied ones. This enhances the utilization of available radio-frequency spectra while interference is minimized to other users. This is an ideal model for wireless communication where transmission or reception parameters of system or node are changed for communication dodging interference with licensed or unlicensed clients.

A. Types of Cognitive Radio

There are two types of Cognitive Radios:

- **Full Cognitive Radio:** Full Cognitive Radio (CR) adapts all transmission parameters to the environment, i.e., modulation format, multiple-access method, coding, as well as centre frequency, bandwidth, transmission times, and so on. A wireless node or network can be conscious of every possible parameter observable. While a fully cognitive radio is interesting from a scientific point of view, it currently seems too complicated for practical purposes.
- **Spectrum Sensing Cognitive Radio:** It only adapts the transmission frequency, bandwidth, and time according to the environment. Detects channels in the

radio frequency spectrum. Fundamental requirement in cognitive radio network is spectrum sensing. Such cognitive radio is also often called Dynamic Spectrum Access (DSA).

B. Characteristics of Cognitive Radio

There are two main characteristics of the cognitive radio and can be defined as:

• **Cognitive ability**: Cognitive Capability characterizes the capacity to catch or sense the data from its radio surroundings of the radio technology. Joseph Mitola initially clarified the cognitive capability in term of the cognitive cycle "a cognitive radio constantly observes nature, orients itself, makes plans, decides, and then acts."

• **Reconfigurability:** Cognitive capacity offers the spectrum awareness, Re-configurability refers to radio capability to change the functions, empowers the cognitive radio to be programmed dynamically as per radio environment (frequency, transmission power, modulation scheme, communication protocol).

C. Functions of Cognitive Radio

There are four major functions of Cognitive Radio. Figure 1 shows the basic cognitive cycle:

- **Spectrum Sensing** The principal step of spectrum sensing is that it decides the presence of primary user on a band. The cognitive radio has the capacity to impart the result of its detection with other cognitive radios in the wake of sensing the spectrum. The main objective of spectrum sensing is to discover the spectrum status and activity by periodically sensing the target frequency band.
- **Spectrum Management** Provides the reasonable spectrum schedulingtechnique among coexisting users. The available white space or channel is quickly chosen by cognitive radioif once found. This property of cognitive radio is described as spectrum management.

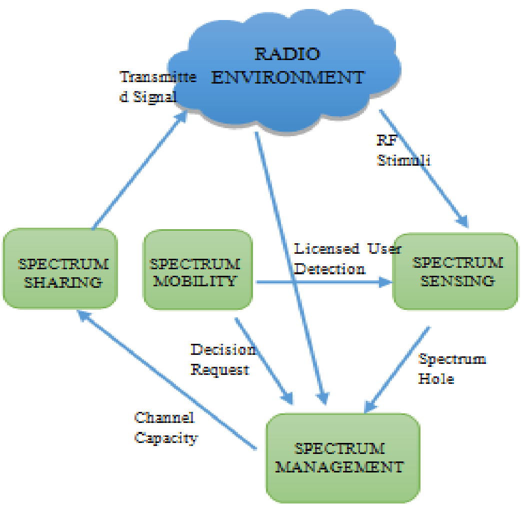

Figure 1 Basic Cognitive Cycle

- **Spectrum Sharing** Cognitive Radio doles out the unused (spectrum hole) to the secondary user (SU) as long as primary user (PU) does not utilize it. This property of cognitive radio is described as spectrum sharing.
- **Spectrum Mobility**When an authorized (Primary) user is detected, the Cognitive Radio (CR) empties the channel. This property of cognitive radio is depicted as the spectrum mobility, also called handoff.

III. SPECTRUM SENSING

Spectrum sensing is the main task in cognitive cycle and themain challenge to the CRs. In spectrum sensing studying the spectrum and find the unusedbands and sharing it while avoiding the spectrum that is occupied by PU. It can be defined as "action of a radio measuring signal feature".From the viewpoint of detection of signals, techniques of sensing can be categorized into twocategories: coherent and non-coherent detection. In coherent detection, the PU signal can becoherently detected by comparing the received signal characteristics with a priori knowledge ofPU signals.

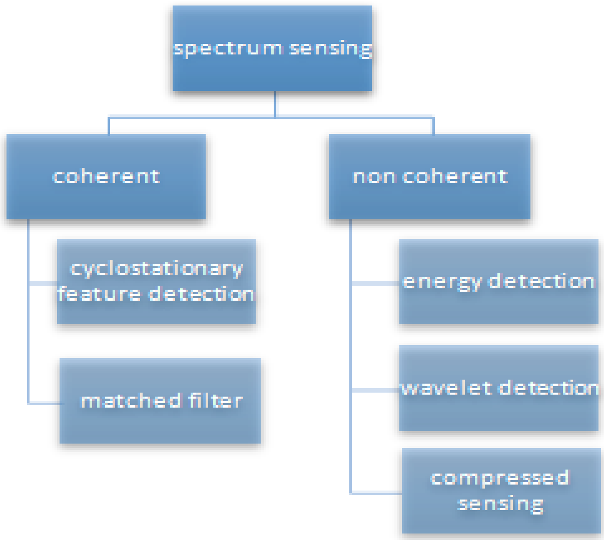

Figure 2Classification of Spectrum Sensing

A. Cooperative spectrum sensing

We consider a cooperative spectrum sensing (CSS) network of N CRs, one primary user (PU) and one fusion center (FC) as shown in Figure below. Multi-path fading is a very important factor which makespectrum sensing less reliable and it cannot be ignored. The improvement in SNR cannot be made by higher transmit power or additional bandwidth because this is against the requirements of next generation systems. Before transmitting any signal, cognitive radio should estimate the power spectral density of the radio spectrum so as to check which bands are in use and which bands are not utilized. However, there might be another user of that spectrum behind the next building, transmitting to a tower on the hill. Because the building is between the users, the cognitive radio user does not receive another user signal and so concludes the spectrum is unoccupied. The "hiddenterminal problem" must be overcome to ensure that primaryusers of a band are protected from interference. The solution to this hidden terminal problem is cooperativespectrum sensing technique.

Cognitive radio cooperative spectrum sensing occurs when network of cognitive radios shares the sense information they obtain with each other. The operation of this technique can be performed as follows:

Step 1: Every cognitive radio performs local spectrum measurements independently and then makes a decision.

Step 2: All the cognitive radios forward their decisions to a common receiver which is a Fusion Centre.

Step 3: The common receiver combines those decisions and makes a final decision to infer the absenceor presence of the primary user in the observed band.

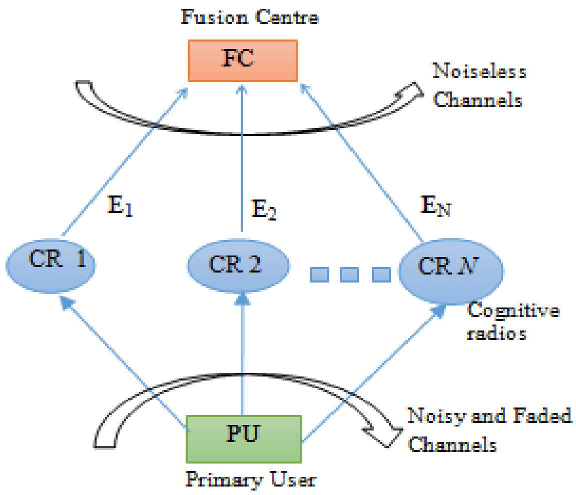

Figure 3 Cooperative Spectrum Sensing

B. Energy detection

Each CR senses the PU individually using energy detector which is shown in Fig. 1 and send its sensing information/data in the form of energy values to the FC. Next, the FC gathers these sensing data (energy values) which are coming from individual CR, and employs any one of the softdata combining techniques such as Equal Gain Combining (EGC), Maximal Ratio Combining (MRC), etc. to make the global decision about the presence or the absence of the PU.

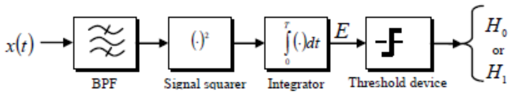

Figure 4 Block diagram of energy detector

The R-channels are considered as ideal (noiseless) channels. The received signal *x(t)* at *k*-th CR can be represented as:

$$x_k(t) = \begin{cases} n_k(t)H_0 \\ h_k s(t) + n_k(t)H_1 \end{cases}$$

where, *s(t)* is the PU signal with energy E_s and *n(t)* is the noise waveform. The noise *n(t)* is modelled as a zero-mean white Gaussian random process. The S-channel fading coefficient for the *k*-th CR is denoted as h_k.$H_1$and $H_0$are the two hypotheses associated with presence and absence of a PU, respectively. When the PU is absent i.e., under hypotheses H_0, each CR receives only the noise signal at the input of the ED and the noise energy at *k*-th CR can be approximated over the time interval (0, *T*), as

$$\int_0^T n_k^2(t)dt = \frac{1}{2W}\sum_{i=1}^{2u} n_{k_i}^2,$$

where u is the time-bandwidth product, W is the one-sided bandwidth and

$$n_{k_i} \sim N(0, N_{01}W), \qquad \forall\, i$$

Where $N_{01}$is the one-sided noise power spectral density, and $N(\mu, \sigma^2)$ is a Gaussian variate with mean μ and variance σ^2. The received signal energy under hypotheses H_0 at *k*-th CR, denoted as E_k, can be written as:

$$E_k = \sum_{i=1}^{2u} n_{k_i}^{\prime 2}\ ;\ n_{k_i}^{\prime} = \frac{n_{k_i}}{\sqrt{N_{01}W}}$$

The same approach is followed to evaluate the received signal energy under hypotheses H_1at the *k*-th CR when the primary signal is present with the replacement of each $n_{k_i}$by $n_{k_i} + s_i$where $S_i = S(\frac{i}{2W})$. In non-fading environment (AWGN case, i.e.,h_k=1), the detection and false alarm probabilities for the *k*-th CR can be expressed as follows:

$P_{d,k} = P(E_{k1} > \lambda | H_1) = Q_u(\sqrt{2\gamma_k}\ , \sqrt{\lambda})$

$P_{f,k} = P(E_{k0} > \lambda | H_0) = \Gamma(u, \lambda/2) / \Gamma(u)$

$P_{m,k} = 1 - P_{d,k}$

where $\gamma_k$is instantaneous *k*-th S-channel SNR, Γ (.,.) is theincomplete gamma function, and Q_u(.,.) is the generalizedMarcum *Q*-function. The expression for $P_{f,k}$ for the *k*-th CR remains the same when fading is considered inthe S-channel due to independence of $P_{f,k}$ from SNR. Thedetection threshold λ can be set for a chosen $P_{f,k}$.

C. Equal gain combining

In the case of soft data fusion, each CR forwards the entire sensing information (energy value) i.e., E_k to the FC without performing any local decision. The FC employs any one of the soft data combining rules (EGC, SLC and MRC) and makes a global decision about the presence or the absenceof the PU. Soft data fusion rules provide better performancethan hard decision fusion rules, but it requires a largerbandwidth for the control channel.

In equal gain combining we first co-phase the signals on individual branches and then combine them with equal magnitude.

In the soft combination, different CR users in the same cluster apply Multiple Resolution Spectrum Sensing and the observed values are summed with weights, the weighted summation is given by,

$$X_i = \sum_{j=1}^{N} w_{i,j} X_{i,j}$$

$$Issue\ to; \quad \sum_{j=1}^{N} w_{i,j}^2 = 1 \qquad 0 < w_{i,j} < 1$$

where $w_{i,j}$ weight coefficient to the j[th] CR user in i[th] cluster, $X_{i,j}$ the test statistic and is the number of CR users in cluster. Similar to multiple receive antennas systems, the equal gain combination (EGC) is given by,

$$w_{EGC_{i,j}} = 1/\sqrt{N} \qquad 1 \leq j \leq N$$

Suppose $X_{i,j}$ and $w_{i,j}$ are individual values for different CR users, then $X_{i,j}$ follows a Gaussian distribution,

$$X_i = \begin{cases} N\left(\sqrt{N}, \frac{2}{M}\right) & , H0 \\ N\left(\sum_{j=1}^{N} \frac{1}{\sqrt{N}}(1+\gamma), \frac{2}{MN}\sum_{j=1}^{N}(1+\gamma)^2\right) & , H1 \end{cases}$$

where H1 and H0 represent that primary signal as present or absent, γ the SNR of the CR user, and M the number of samples of the CR user.

IV. LITERATURE SURVEY

A. Md. Zulfikar Alom, Dr. Tapan Kumar Godder, Mohammad Nayeem Morshed, Asmaa Maali, "Enhanced Spectrum Sensing Based on Energy Detection in Cognitive Radio Network using Adaptive Threshold", IEEE 2017

There's a huge demand for spectrum, but in conventional system radio spectrum is inefficiently used. To overcome this problem and increase array use of spectrum, cognitive radio (CR) technology concept was proposed.CR is the greatest mechanism for use spectrum efficiently. The main objective of CR is to use scarce and limited natural resources efficiently without any interference to the primary users (PUs). Among most challenging problems in cognitive radio systems is spectrum sensing concepts. Energy detection, Matched filter detection and Cyclostationary detections are most common strategies for spectrum sensing. This study has been performed based on Energy detection spectrum method. The reason for choosing Energy detection technique, it doesn't need any earlier information from the PU transmission. Also, the particular result of energy detection method degrades with lower sign to noises ratio (SNR) level signal location. General detection performance of Energy detection is highly dependent upon noise, especially while the SNR is very low for PU. Considering this issue, this paper presents an adaptive threshold model for efficient Energy detection technique to enhance the detection performance at low SNR level. Simulation outcomes show, the detection performance using offered system model is more preferable than fixed threshold at low SNR signal locations. This paper proposed adaptive threshold detection model of energy detection based spectrum sensing. Through maximized the probability of detection with respect to a false alarm rate constraint in order to find the detector thresholds for each stage. Derivation and simulation outcomes show that our offered system can effectively enhanced the detecting probability and the utilization of spectrum holes at low SNR region. [1]

B. Kirubakaran.S, Nagarajan.V, "Performance analysis of MRC and EGC based Cooperative Diversity System using Incremental Relaying", IEEE 2016

Cooperative diversity decreases the fading in communication system. It comprises of a source, a destination and a relay to do the error analyses. Analysis is done using Equal Gain Combining (EGC) and Maximal Ratio Combining (MRC) technique with Incremental Relaying. For a cooperative diversity system employing incremental relaying, it is assumed feedback channel is present to relay from the destination. Receiver sends the feedback to the relay then Incremental relaying works. When the receiver SNR value is below the threshold, the relay forwards source signal to the destination. This achieves better performance than other relaying protocols. The Symbol Error Probability (SEP) with incremental relaying for MRC and EGC Technique is analysed in closed form.Authors proposed Equal Gain Combining and Maximal Ratio combining Schemes and analysed with DF relaying of cooperative diversity system. Feedback signal is considered in Incremental relaying and it boosted up the bandwidth efficiency. Authors derived the equation of end to end Symbol Error Probability with the Raleigh fading channel. Authors have compared the proposed technique of EGC, MRC and Non-cooperative with value functions. It has been shown that the EGC with Incremental relaying done good than the MRC and non-coop modes of communication. [2]

C. Sitadevi Bharatula, Meenakshi Murugappan, "An Intelligent Fuzzy Based Energy Detection Approach for Cooperative Spectrum Sensing", 2016

Cognitive radio systems are helpful to access the unused spectrum using the popular technique, referred to as spectrum sensing. Spectrum sensing involves the detection of primary user (PU) signal using dynamic spectrum access. Cooperative spectrum sensing takes advantage of the spatial diversity in multiple cognitive radio user networks to improve the sensing accuracy. Though the cooperative spectrum sensing schemes significantly improve the sensing accuracy, it requires the noise variance and channel state information which may lead to transmission overhead. To overcome the drawbacks in conventional cooperative spectrum sensing, this paper proposes a fuzzy system based cooperative spectrum sensing. Selection combining (SC) and maximum ratio combining (MRC) are used at fuzzy based fusion center to obtain the value of the sensing energy. These energy values are utilized in finding the presence of PU, results in improved sensing accuracy. In addition, an intelligent fuzzy fusion algorithm determines the PU presence without the channel state information based on multiple threshold values. Simulation results show that the proposed scheme outperforms the existing schemes in terms of sensing accuracy. [4]

D. Priyanka Pandya, Aslam Durvesh, Najuk Parekh, "Energy Detection based Spectrum Sensing for Cognitive Radio Network", IEEE 2015

Cognitive radio is an intelligent radio wireless communication technology in order to increase the spectrum efficiency. In this paper one of the most important cognitive radio task i.e. spectrum sensing is explained in detail. Spectrum sensing used to detect the presence of the primary users in a licensed spectrum, which is a fundamental problem for cognitive radio. Increasing efficiency of the spectrum usage is an urgent due to increasing demand for higher data rates, better quality of services and higher capacity. In this paper, Energy Detection Technique is discussed in detail.This study provides useful insight to the behaviour of the energy detection technique, as it relates to detecting signals in a band for opportunistic access. In this work, the performance of an energy detector in detecting unused (vacant) spectrum was evaluated. The study includes a theoretical background; expressions for the detection probability and false alarm probabilities for a sensing node over both a non-fading (AWGN).Simulation results indicate that depending on the threshold of a single user energy detector, performance improves over a non-fading channel (AWGN), as SNR increases, detection probability increases for a single user detector node in a channel with no fading. Fewer samples produce better performance for non-fading channels for the case of a single secondary user. To improve performance of system we apply MIMO-STBC coding to provide spatial diversity which provide efficiency and reliability to system. [6]

E. Ireyuwa E. Igbinosa, Olutayo O. Oyerinde, Viranjay M. Srivastava, Stanley H. Mneney, "Energy Detection Based Spectrum Sensing Performance Evaluations in Cooperating Cognitive Radio Networks", 2015

The ever-growing wireless technologies has put a lot of demand on the usage of available spectrum, thus leading to spectrum underutilization and scarcity. To address this issue and improve spectrum utilization gave rise to the concept of the cognitive radio. The cognitive radio is known to enhance the utilization of spectrum of where a secondary user can utilize the spectrum of the primary user without causing harmful interference to the incumbent primary user. In this paper, we evaluated the performance of the energy detection based spectrum sensing in a fading and non-fading environments. Also we presented results on the single user detection and cooperative detection applying the energy detector. The performance of the energy detection technique was assessed by the use of the receiver operating characteristics (ROC) curves over additive white Gaussian noise (AWGN), Rayleigh and Nakagami channels. The cooperative detection shows better performance to the single user in the fading environments.In this work, we have considered the performance analysis of energy detection based spectrum sensing in a cooperative scheme, we evaluated the performance of energy detection in detecting unused spectrum in fading and non-fading channels models. The effects of cooperating nodes using energy detection over various fading channels are assessed by using complementary ROC curves. In conclusion, simulation results show that the cooperating spectrum sensing is a viable technique in combating the inherent performance degradation of the energy detectors in a severe fading and shadowing environments. [7]

F. Doha Hamza, Sonia Aïssa, Ghassane Aniba, "Equal Gain Combining for Cooperative Spectrum Sensing in Cognitive Radio Networks", IEEE 2014

Sensing with equal gain combining (SEGC), a novel cooperative spectrum sensing technique for cognitive radio networks, is proposed. Cognitive radios simultaneously transmit their sensing results to the fusion center (FC) over multipath fading reporting channels. The cognitive radios estimate the phases of the reporting channels and use those estimates for coherent combining of the sensing results at the FC. A global decision is made at the FC by comparing the received signal with a threshold. We obtain the global detection probabilities and secondary throughput exactly through a moment generating function approach. We verify our solution via system simulation and demonstrate that the Chern off bound and central limit theory approximation are not tight. The cases of hard sensing and soft sensing are considered and we provide examples in which hard sensing is advantageous to soft sensing. We contrast the performance of SEGC with maximum ratio combining of the sensors' results and provide examples where the former is superior. Furthermore, we evaluate the performance of SEGC against existing orthogonal reporting techniques such as time division multiple access (TDMA). SEGC performance always dominates that of TDMA in terms of secondary throughput. We also study the impact of phase and synchronization errors and demonstrate the robustness of the SEGC technique against such imperfections. [10]

G. Sanjeewa P. Herath, Nandana Rajatheva, "Analysis of Equal Gain Combining in Energy Detection for Cognitive Radio over Nakagami Channels", IEEE 2008

This paper addresses the problem of energy detection of unknown deterministic signal of a primary user in a cognitive radio environment. As an extension to the previous works, we focus on equal gain combining technique when the wireless channel is modeled as Nakagami-m. We derive series form exact expressions for probability of detection and false alarm when the number of diversity branches are 1, 2, 3 and $L \geq 4$. Finally, performance variation is shown against the number of diversity branches and the time bandwidth product in decision statistic with the aid of numerical results.We consider the problem of primary user detection in cognitive radio over the Nakagami-m fading channel with the equal gain combining diversity receiver. Expressions are derived for exact probability of detection when the number of diversity branches are 1, 2, 3 and $L \geq 4$. Interestingly, all the expressions could be expressed in terms of confluent hypergeometric function of the first kind. These results could be readily used in deciding the number of diversity branches and the energy threshold value to achieve a specified false alarm rate of equal gain combiner energy detector receiver in cognitive radio. [16]

V. CONCLUSION

In this paper, we proposed Energy detection based spectrum sensing over AWGN channel. Cooperative spectrum sensing is not applicable in all the applications, but where it is applicable, considerable improvements in system performance can be gained. Energy detection is the most popular signal detection method due to its simple circuit in practical implementation. The principle of energy detector is finding the energy of the received signal and compares that with the threshold.

The EGC method does not need any channel condition information of CR users compared with other schemes, such as maximal ratio combination (MRC).

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