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Efficient Multi Stage Spectrum Sensing Technique For Cognitive Radio Networks Under Noisy Condition

Gajendra Singh Rathore[1]
M.Tech (Communication Engineering), SENSE
VIT University, Chennai Campus
Chennai, India.

[1]ORCID: 0000-0002-9051-6291

Sitadevi Bharatula[2]
Assistant Professor (Sr), SENSE
VIT University, Chennai Campus
Chennai, India.

[2]ORCID : 0000-0001-7022-1026

Abstract
Cognitive radio has potential to efficiently use the frequency band allotted to the licensed user (primary user) in order to minimize the problem of inefficient spectrum usage. In this paper, proposed work is the combination of the two well-known detection methods: energy detection (ED) and combination of maximum- minimum eigenvalue detection (CMME). First stage consist of energy detector to identify the existence of the primary user by comparing the received signal to the fixed threshold. When primary user is active in spectrum the signal will always greater than threshold to indicate the presence of primary user and vice versa. In second stage combination of maximum-minimum eigenvalue used to detect the primary user and using random matrix theory threshold for second stage is determined. Proposed work can be used to minimize the probability of false alarm, improved sensing time and better probability of detection.

Keywords: Energy detection; probability of detection; CMME; licensed user (primary user); cognitive user (secondary user);

INTRODUCTION

Cognitive radio (CR) concept was first suggested by Joseph Mitola III in a seminar at KTH (The Royal Institute of Technology in Stockholm) in 1998 & published in an article by Mitola & Gerald Q. Maguire, Jr in 1999. CR was counted as a goal towards which a SDR should develop a fully reconfigurable wireless transceiver which spontaneously adjust according to network & user necessaries. It is commonly believed that problem of bandwidth scarcity occurs due to inefficient usage of the spectrum by primary user (licensed user). CR gives the freedom to the secondary users (cognitive user) to use the licensed spectrum when the PU is absent in particular time/ frequency and as soon as PU returns to use the spectrum SU have to leave the spectrum and switch to another white space (space/slot which is not used by PU).

Cognitive radio networks consist of four stages: Spectrum sensing (SS), Spectrum management (SM), Spectrum sharing, and Spectrum mobility. SS is first and most important stage to establish a network without interfering with the PU, it detects the white space for the communication while PU is not present so that SU can use the spectrum. For spectrum sensing, SU can use one of the traditional methods like MF detection, Energy Detection (ED) and Feature detection technique. Spectrum management is the second stage which define the duration of available white space for SU to use. Spectrum sharing is used to fairly allocate the white spaces between the SUs in the network having in mind usage costs. Spectrum mobility is used to sustain the uninterrupted transmission while switching to the available white space, when PU returns to use the spectrum. Holes are classified into three types in terms of power spectrum of radio frequency: black space, grey space and white space. Black spaces are dominated by high-power interference, Grey spaces are partially dominated by low power interference and white space are suitable for the cognitive radios in which RF interference is not present.

RELATED WORK

Following techniques can be used to identify white spaces: Matched Filter Detection (MFD), Cyclostationary Feature Detection (CFD) and Energy Detection (ED). These are the standard techniques to create CR network but each technique has its own limitation. The main drawback of MFD is it needs the prior information of PU to sense the spectrum and if the information is inaccurate then performance of MFD degrades. CSD uses the periodicity property of the signal to sense the spectrum, it can sense the signal in low SNR regime but it's computationally complicated and require higher sensing time. Energy detection is the optimal solution for SS as it doesn't require the prior information of the PU and the sensing time is less than MFD & CSD, but at low SNR value the performance of ED degrades where it is unable to differentiate between desired signals and noise.

To overcome the limitations of the standard techniques several methods have been proposed in the literature. In [8], CSS technique is suggested which focuses on the signal detection under noise uncertainty but it was affected by minimal noise uncertainty problem. Each detector used two-threshold detector for local detection. In [5], two stage SS is proposed in which first stage is ED and in second stage CSD is used to improve the performance and mean detection but sensing time doesn't always smaller than the mean detection time of CSD. In [3], CSS with two stage is proposed in which Multiple Energy Detector (MED) with the fixed threshold is the first stage and in second stage adaptive double threshold (ADT) is used which minimize the multipath and shadowing effects but sensing time is high. In [1], modified eigenvalue detection CSS is proposed to utilize the correlation of PU signal to detect PU. It performed better in low SNR value scenario but signal should be highly correlated. In [4], CMME is proposed to detect the PU, a robust algorithm is used based on the eigenvalue of covariance matrix of the received signal and decision threshold is set according to the MME. It outperforms maximum eigenvalue detection, ED, especially at low SNR value but to avoid interference with PU probability of detection should be high. In [7], dynamic detection of white space using spectrum sampling and variance estimation is proposed. It can be used in military communication scenarios, unmanned vehicle operating in enemy region but when signal fades significantly it is difficult to set the optimal threshold.

PROPOSED WORK

Traditional cognitive radio spectrum sensing techniques has its own demerits in certain scenarios like matched filter detection technique required the prior information of PU, this is one reason why it is also known as non-blind technique. In CFD, it uses feature detection (like cyclic prefix, hoping sequence, sine wave carrier pulse train, repeating spreading etc.) which results in periodicity to detect the signal and it can perform better than the matched filter technique but it is complex and takes more time to sense the spectrum, it is also known as semi-blind technique. In ED, it does not require any prior information of PU but as signal to noise ratio (SNR) decreases the performance of ED degrades but it is simpler than CFD and matched filter detection techniques[2][3][5]. Therefore, to overcome the demerits of the existing techniques and optimize the sensing mechanism, a combination of existing techniques / hybrid technique is introduced to get improved results.

Proposed technique is combination of energy detection (ED) and CMME. In first stage ED is used to identify whether the PU is accessing the spectrum or not, if PU present it will leave that spectrum and sense other existing spectrum to utilize the unused spectrum band but if PU is absent it will initiate the second stage. In second stage CMME technique is used as it is complex than ED and it will give more accurate results by which probability of missed detection and interference with PU can be minimized. The block diagram of proposed technique is shown in Fig. 1.

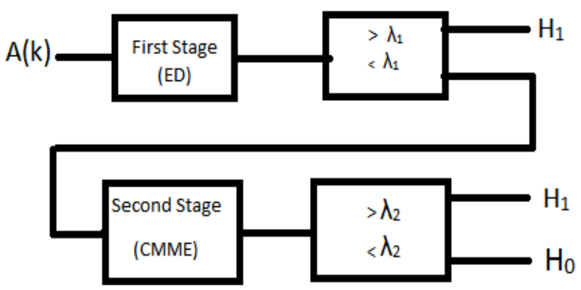

Figure 1. Hybrid Technique

A. First Stage / Coarse Sensing

In first stage / coarse sensing, ED is used due to less sensing time and it does not need any prior information of PU. The basic hypothesis for sensing the spectrum in cognitive radio [2] [5] is given below:

$$A\ (l) = \begin{cases} n(l) & ; \quad H_0 \\ B(l) + n(l) & ; \quad H_1 \end{cases} \qquad (1)$$

Where, A (*l*) is received signal by SU, B (*l*) is transmitted signal by PU, n (*l*) is additive white Gaussian noise (AWGN). When the PU is present, it is denoted by H_1 and when the PU is absent, it is denoted by H_0. ED gathers the energy signal in opportunistic spectrum and calculate the power spectral density of the collected signals. If the energy of the signal is greater than the threshold λ_1 then the spectrum is declared occupied by PU else the received signal is analysed by the second stage.

The average energy of the received signal is

$$y\ (l) = \frac{1}{N}\sum_{k=1}^{N} A(l)^2 \qquad (2)$$

Where, y (*l*) is test statistic and N is the sample interval. The probability of false alarm (P_f) and probability of detection (P_d) are given by

$$P_f = P\ [y\ (l) \geq \lambda_1\ |H_0\ ] \qquad (3)$$

$$P_d = P\ [y\ (l) < \lambda_1\ |H_1\ ] \qquad (4)$$

B. Second Stage / Fine Sensing

If the energy of the received signal is less than the threshold λ_1 then the received signal analyzed again using CMME technique. CMME works better in low SNR with correlated signal without any prior information of PU [6]. Assume that there are $l \geq 1$ SU, then the received signal at the ith secondary user is denoted by A_i (*l*) (i =1, 2, 3,.... *l*). Then the statistical matrix can be defined as:

$$A(l) = [A_1\ (l),\ A_2\ (l),\ A_3\ (l)\ ,..,\ A_k(l)]^T \qquad (5)$$

$$B(l) = [B_1\ (l),\ B_2\ (l),\ B_3\ (l)\ ,\ldots,\ B_k(l)]^T \qquad (6)$$

$$n(l) = [n_1(l),\ n_2(l),\ n_3(l),\ldots,\ n_k(l)]^T \qquad (7)$$

Where A (*l*) is the received signal, (*l* = 1, 2, 3..., N) where N is samples in CMME technique, B (*l*) is the transmitted signal forwarded through a wireless channel and n (*l*) is the AWGN noise with zero mean and variance σ_n^2.

Corresponding the above explanation, (1) can be written as,

$$A = B + n \qquad (8)$$

Seeing the statistical covariance of the received signal, transmitted signal and noise signal as,

$$R_A = E\ (AA^T)$$
$$R_B = E\ (BB^T) \qquad (9)$$
$$R_n = E\ (nn^T)$$

$\Upsilon_{max}\gamma_{max}$ & γ_{min} is the maximum eigenvalue and Υ_{min} minimum eigenvalue of the received statistical covariance matrix.

Decision rule for second stage / fine sensing is

$$D^f = \begin{cases} \gamma_{max} \geq \lambda_2 * \gamma_{min}\ ; & H_1 \\ \gamma_{max} < \lambda_2 * \gamma_{min}\ ; & H_0 \end{cases} \qquad (10)$$

RESULT & DISCUSSION

Cognitive radio techniques aimed at using IEEE 802.22 WRAN standard which allow sharing of geographically unused spectrum on non-interfering basis [9]. First, Energy detection and CMME are individually simulated and the acquired results of both the methods are analysed to figure out the merits and demerits of each technique.

In the simulation, the total number of sample (N) are 1000, SNR range diverges from 0 dB to -30 dB, probability of false alarm P_f = 0.1, length of received signal L = 4. To analyze the proposed technique and for comparative analysis the energy detection technique and CMME detection technique are simulated individually.

Receiver operating characteristics (ROC) of energy detection technique for the SNR value 0 dB and -10 dB are shown in Fig. 2 ROC curve shows that energy detector performs well when SNR = 0 dB but when the receiver encounters the SNR = -10 dB the energy detectors performance degrades from 1 to 0.88 approximately. Fig. 3 shows the ROC curve of ED for the SNR value of -20 dB and -30 dB to analyze the behavior of the energy detector in the low SNR regime and energy detectors performance degrade. Fig. 3 Shows that the probability of detection falls in between the range of 0.2 to 0.3 for SNR = -20 dB and the performance for SNR = -30 dB is lower than 0.2 which shows that for low SNR values the performance of ED degrade and may cause interference to the primary user and increase the probability of false alarm (P_f).

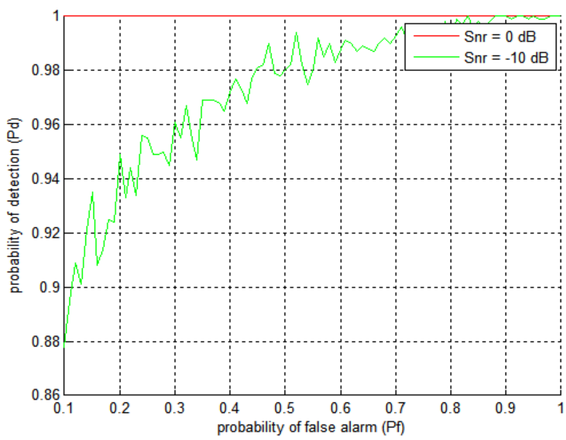

Figure 2. ROC curve of ED for SNR (0 dB & -10 dB)

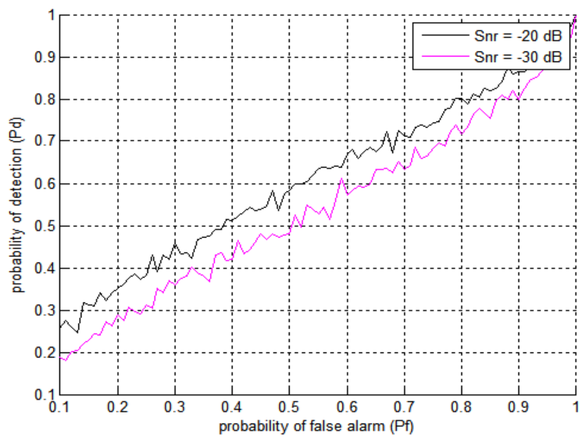

Figure 3. ROC curve of ED for SNR (-20 dB & -30 dB)

Fig. 4 & Fig. 5 shows the ROC curve of CMME detection for the SNR values ranging from 0 dB to -30 dB. ROC curve of CMME detection shows that it performs better than the energy detector under the low SNR regime and it can provide the better probability of detection (P_d) than energy detector, CMME detection is the complex computational technique due to the matrix multiplication operation using the concept of random matrix theory. This complex computation leads to slightly higher sensing time than energy detection which is one drawback of the CMME detection technique.

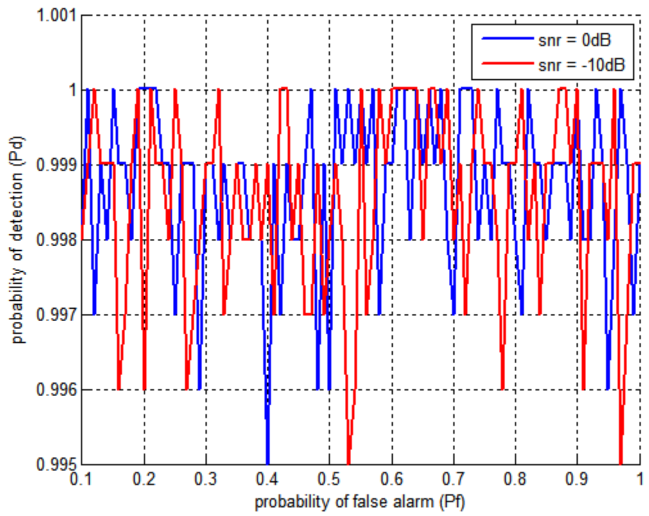

Figure 4. CMME detection for SNR (0 dB & -10 dB)

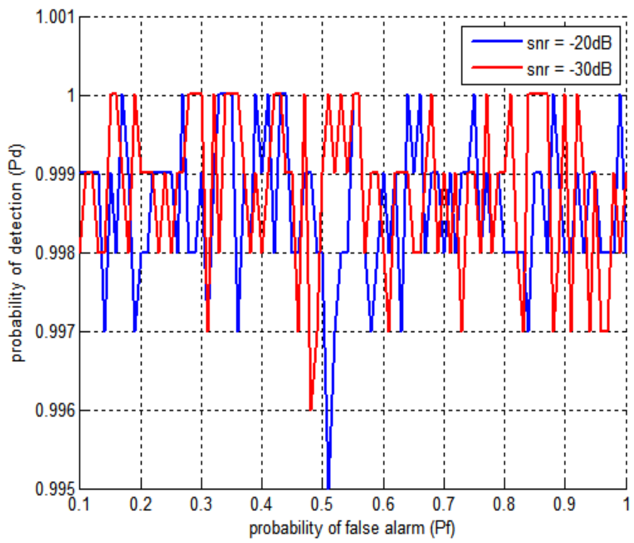

Figure 5. CMME detection for SNR (-20 dB & -30 dB)

Fig. 6 shows the ROC curve of the hybrid detection for the SNR = 0 dB which shows that for high SNR value the hybrid technique gives the result in the first stage as energy detection technique. Fig. 7 – Fig. 9 shows the ROC curve of the multi stage scheme where the receiver encounter the low SNR scenario and output shows that the multi stage detection technique acquire the advantages of energy detection and CMME detection, and the output of the multi stage detection technique shows better results than the individual either of these detection techniques, and maximize the probability of detection (P_f) without causing interference to PU and reduces the probability of false alarm (P_f).

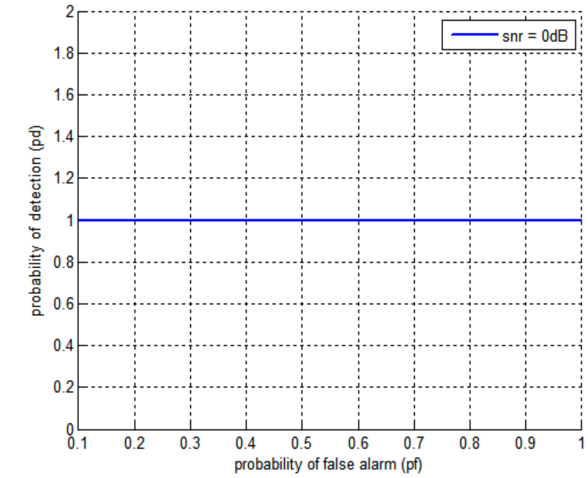

Figure 6. Hybrid detection for SNR = 0 dB

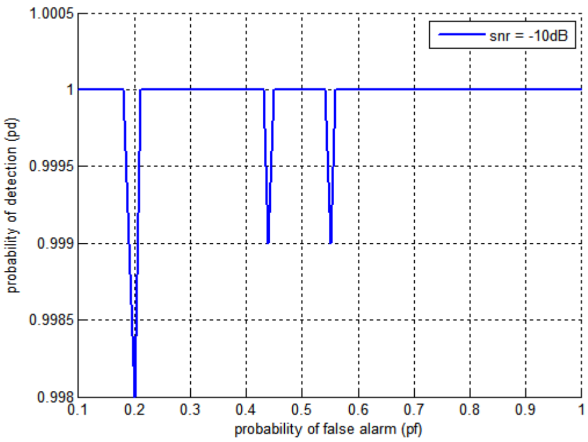

Figure 7. Hybrid detection for SNR = -10 dB

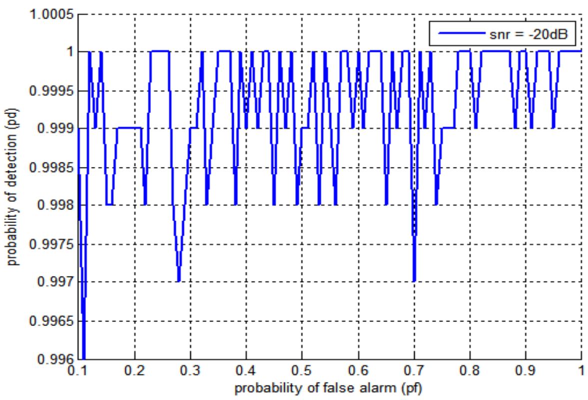

Figure 8. Hybrid detection for SNR = -20 dB

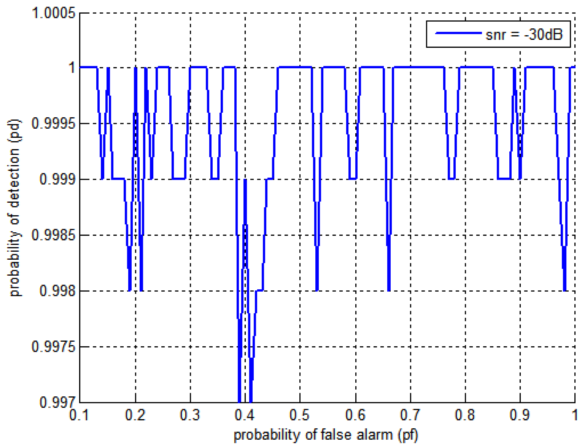

Figure 9. Hybrid detection for SNR = -30 dB

CONCLUSION

In this paper, the proposed multi stage spectrum sensing method which uses energy detection in first stage and CMME detection in second stage, reduces the probability of false alarm and retain the advantage of energy detection technique and CMME detection technique. The acquired results of hybrid technique works better than the ED and CMME in terms of the sensing a spectrum in low SNR regime also minimize the probability of causing interference to the PU.

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ABBREVIATIONS

ADT	–	Adaptive double threshold
AWGN	–	Additive white Gaussian noise
CMME	–	Combination of maximum and minimum eigenvalue
CFD	–	Cyclostationary feature detection
CSS	–	Cooperative spectrum sensing
CR	–	Cognitive radio
ED	–	Energy detection
MFD	–	Matched filter detection
MED	–	Multiple energy detector
PU	–	Primary user
ROC	–	Receiver operating characteristics
SNR	–	Signal to noise ratio
SU	–	Secondary user
SS	–	Spectrum sensing
SM	–	Spectrum management
WRAN	–	Wireless regional area network

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BIOGRAPHICAL SKETCH

Gajendra Singh Rathore, pursuing M.Tech in Communication Engineering from School of Electronics (SENSE) in VIT University, Chennai Campus. He has one year work experience as technical assistant from ITM Universe, Gwalior and his area of interest is wireless communication and cognitive radios.

Sitadevi Bharatula, is Assistant Professor in School of Electronics (SENSE) in VIT University, Chennai Campus. She has twelve years of teaching experience and three year of industry experience and her area of interest is cognitive radio networks.