Covariance absolute values spectrum sensing method based on two adaptive thresholds

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ABSTRACT

Cognitive radio is a modern wireless communication methodology that deals with the issue of spectrum untapped. Cognitive users can continually perceive the licensed spectrum to hunt for unoccupied spots. The essential technology in cognitive radio (CR) for primary user detection is spectrum sensing. Due to signal to noise ratio (SNR), noise uncertainty in spectrum sensing would make the detection unreliable. In this paper, the two adaptive thresholds based on_covariance absolute values (TATCAV) are proposed to increase detection performance in the presence of noise uncertainty. According to the computer simulations using MATLAB 2021b, the value of the probability of detection is Pd=98.1% Compared with the results of two thresholds based on_covariance absolute values (TTCAV) Pd= 95.3% at SNR=-18, noise uncertainty Nu=1.761 dB, and using quadrature amplitude modulation (QAM). And the error rate for the proposed approach is Pe=12.1% under the same circumstances. The proposed approach results, according to the simulations, are considerably better than the results of the fixed two-threshold approach.

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1. INTRODUCTION

Cognitive radio (CR) is widely recognized as among the most critical promising developing technologies for accelerating the development of future wireless communications. It can help to solve the problem of increasing radio spectrum scarcity by dynamically allocating spectrum. The phrase "cognitive radio" describes the radio as aware of its surroundings and can change its transmissions based on interference it detects. CR appear to recognize the available systems around them in their most basic form and alter their frequencies, waveforms, and protocols to access those systems efficiently [1]. The initial stage in implementing a Cognitive radio system is spectrum sensing and estimation [2]. The federal communications commission (FCC) of the United States has established a spectrum licensing model that wastes the radio spectrum. Unlicensed users cannot utilize the radio frequency allotted to licensed users while it is not in use [3]. CR networks are proposed as a viable core technology for resolving this problem [4]. CR is a critical enabler technology that allows next-generation communications systems, usually called dynamic spectrum access (DSA) systems, to take advantage of the available spectrum more effectively and opportunistically without obstructing the licensed users [5]. CR can adjust their transmitter factors to different signaling systems to adapt to their surroundings; they can exchange information about their location and environment depending on the network and cooperation with other cognitive gadgets [6]. The unlicensed user (UU) in a cognitive radio system continuously detects whether a licensed user (LU) is present in the licensed frequency range when a LU is missing from a licensed spectrum; the UU can make use of these spectral gaps as soon as a LU arises, to reduce LU interference, the UU should immediately free up spectrum. Consequently, the algorithm for spectrum sensing must be both trustworthy and quick [7], [8]. Primary and secondary nodes in cognitive radio networks use interweave to share the same spectrum [9]. Interference-based, non-cooperative, and cooperative detection are the three sorts of techniques for spectrum sensing [10], [11]. Several spectrum sensing methods and solutions have been developed throughout the last decade, each with operational needs, benefits, and drawbacks [12]. The most effective of these techniques is the method of energy detection (ED). This was the most extensively utilized research technique since it still does not need any previous knowledge of the LU signal [13]. Which is regarded as a high performance because of its simplicity and convenience of installation under a low signal to noise ratio (SNR) [14]. However, correct noise power estimation is required for energy detection, and inaccurate noise power estimation leads to an SNR wall and a significant likelihood of false alarm; as a result, Noise uncertainty makes detection difficult. Energy detection is ideal for recognizing signals that are spread independently and identically, and It's not the best tool for finding associated signals, as with the vast majority of real-world applications [15]. The alternative option is to detect based on covariance absolute value (CAV); this has a benefit. There must be no prior understanding of the licensed user signal, noise, and blinded detection [16]. To improve the the previously mentioned ways. This paper proposes a new approach built on the two adaptive threshold covariance absolute value (TATCAV) of the signal received. The following is a description of how this paper is organized. Section 2 presents the system model, and section 3 describes the conventional approach. The proposed approach model is described in section 4. The numerical results and analyses are presented in section 5. Lastly, section 6 brings this paper to a conclusion.

Puttupu [17] was proposed double-threshold based on ED and analyses of Pd, Pf and Pm, and their results show that this proposed system can make a lower crash probability between the PU and the SU, despite increasing the frequency spectrum unavailability. Deep and Singh [18] proposed a new adaptive sensing algorithm considering noise uncertainty. Simulation results show a constant detection probability has been achieved under noise uncertainty. P_d is 96% for N=1000 Samples at Pf=0.1 and SNR=-11 dB. Verma and Singh [19] proposed a double threshold in which each CR sends local decision or observed energy to the fusion center (FC) depending on the region in which the observed energy lies. FC makes a final decision. There is almost a 10% improvement in the cooperative probability of detection at -8 dB.

2. METHOD

2.1. System model

Two hypotheses for the received signal are considered: hypothesis Ho when LU is absent and hypothesis H1 when UU is present in [20], [21]:

$$H_0 : X(N) = n(N) \tag{1}$$

$$H_1 : X(N) = S(N) + n(N) \tag{2}$$

X(t) represents the sample of the received signal by UU [22], S(t) is the sample of the transmitted signal by LUs [23], and $n(t)$ is additive white gaussian noise (AWGN), N is the samples number [24]. Where Hi = (0,1) denotes the binary possibilities of a LU's presence or absence [25], The probability of detection (P_d) can be given:

$$P_d = Q\left(\frac{\gamma - N(\sigma_x^2 + \sigma_\omega^2)}{\sqrt{2N(\sigma_x^2 + \sigma_\omega^2)^2}}\right) \tag{3}$$

the probability of false alarm (Pf):

$$P_f = Q\left(\frac{\gamma - N\sigma_\omega^2}{\sqrt{2N(\sigma_\omega)^4}}\right) \tag{4}$$

and (P_m) the probability of missing detection [26].

$$P_m = 1 - P_d \tag{5}$$

The Q-function for Gaussian tail probability is Q(.) given in (6) [19]:

$$Q(z) = \int_z^\infty \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx \quad (6)$$

σ_x^2 is the signal variance, and σ_ω^2 Variation in noise, , and γ is the threshold decision, N number of samples [27].

2.2. Covariance absolute values spectrum sensing method based on two thresholds (TTCAV)

The following is the signal's sample covariance matrix received at UU [22].

$$R_x(N) = \begin{bmatrix} f(0) & f(1) & \cdots & f(L-1) \\ f(1) & f(0) & \cdots & \cdot \\ \vdots & \vdots & \ddots & \vdots \\ f(L-1) & \cdot & \cdots & f(0) \end{bmatrix} \quad (7)$$

Where,

$$f(i) = \frac{1}{N}\sum_{m=0}^{N-1} X(m)X(m-i)^* \quad (8)$$

i = 0,1,2, ⋯, L-1.
L: Smoothing factor.
(*): complex conjugate.

$$T_{c1}(N) = \frac{1}{L}\sum_{n=1}^{L}\sum_{m=1}^{L} |r_{nm}(N)| \quad (9)$$

$$T_{c2}(N) = \frac{1}{L}\sum_{n=1}^{L} |r_{nn}(N)| \quad (10)$$

From (9) and (10), we have (11).

$$T_{CAV}(N) = \frac{T_{c1}(N)}{T_{c2}(N)} \quad (11)$$

Where $T_{CAV}(N)$ is the test statistic, T_{c1}(N) is the sum of all sample covariance matrix components' absolute values,T_{c2}(N) is the sum of all of the sample covariance matrix diagonal elements' absolute value. The two thresholds (γ_1 and γ_2) are determined with the help of random matrix theory and consider the two false alarm probabilities (P_{f1} and P_{f2}). The two characteristics that define cognitive radio ability are the P_d , and Pf. As a result, γ_1 is accounted at a low value of Pf, ensuring that the unlicensed user has a high throughput. The information is:

$$P_{f1} < P_{f2}$$

$$\gamma_1 = \frac{1+(L-1)\sqrt{\frac{2}{N\pi}}}{1-Q^{-1}(P_{f1})\sqrt{\frac{2}{N}}} \quad (12)$$

$$\gamma_2 = \frac{1+(L-1)\sqrt{\frac{2}{N\pi}}}{1-Q^{-1}(P_{f2})\sqrt{\frac{2}{N}}} \quad (13)$$

γ_1 the upper threshold, γ_2 the lower threshold [28]. As illustrated in Figure 1, the thresholds are calculated, and then the signal is received so that the thresholds value is fixed for all received signals.

2.3. Proposed two adaptive thresholds based on covariance absolute values (TATCAV)

In the previous approach, the thresholds are fixed and do not change according to the received signal. In this proposed approach, the thresholds are variable according to the received signal, called adaptive thresholds. The optimal decision threshold used [29].

$$\gamma = \frac{a}{A}\left[-1 + \sqrt{(1 + \frac{Ab}{a})}\right] \quad (14)$$

Where:

$$a = \left[(L-1)\sqrt{\frac{2}{N\pi}} - V\right] \quad (15)$$

$$V = \frac{\gamma_l \, SNR}{(SNR+1)} \quad (16)$$

$$\gamma_l = \frac{T_{c1}(N) - T_{c2}(N)}{SNR \, \sigma_\omega^2} \quad (17)$$

$$SNR = \frac{\sigma_x^2}{\sigma_\omega^2} \quad (18)$$

$$b = \left[(L-1)\sqrt{\frac{2}{N\pi}} - V + 2\right] \quad (19)$$

$$A = \ln\left[\frac{1-P_f}{P_f} \, \frac{1+(L-1)\sqrt{\frac{2}{N\pi}}}{1+V}\right]\frac{4}{N} \quad (20)$$

The upper threshold γ_1 is chosen based on the largest noise variance, while the lower threshold γ_2 is determined based on the least noise variance in the proposed two adaptive –thresholds [30].

$$\gamma_{l1} = \frac{T_{c1}(N) - T_{c2}(N)}{SNR \, \sigma_\omega^2 \, N_u} \quad (21)$$

Where N_u is the noise uncertainty in the wireless environment.

$$V_1 = \frac{\gamma_{l1} \, SNR}{(SNR+1)} \quad (22)$$

$$a_1 = [(L-1)\sqrt{(2/N\pi)} - V_1] \quad (23)$$

$$b_1 = \left[(L-1)\sqrt{\frac{2}{N\pi}} - V_1 + 2\right] \quad (24)$$

$$A_1 = \ln\left[\frac{1-P_f}{P_f} \, \frac{1+(L-1)\sqrt{\frac{2}{N\pi}}}{1+V_1}\right]\frac{4}{N} \quad (25)$$

$$\gamma_1 = \frac{a_1}{A_1}\left[-1 + \sqrt{(1 + \frac{A_1 b_1}{a_1})}\right] \quad (26)$$

And the lower threshold,

$$\gamma_{l1} = \frac{T_{c1}(N) - T_{c2}(N)}{SNR/\sigma_\omega^2 \, N_u} \quad (27)$$

and, calculate it as in the upper threshold and get,

$$\gamma_2 = \frac{a_2}{A_2}\left[-1 + \sqrt{(1 + \frac{A_2 b_2}{a_2})}\right] \quad (28)$$

the steps for the proposed detection system are as shown in:
Step 1: Select the required values for (L), (N), and (P_f).
Step 2: The covariance matrix R x(N) is calculated using auto-correlation for the noisy signal received at the receiver (UU).
Step 3: Find $T_{c1}(N), T_{c2}(N)$ from (9) and (10).

Step 4: $T_{CAV}(N)$ can be found in (11).
Step 5: the thresholds (γ_1) and (γ_2) are calculated using (26) and (28).
Step 6: The way for selecting the sensor is as follows:

$$\text{compute} = \begin{cases} \text{compute} = 0 \text{ if } (\gamma_2) > T_{CAV}(N). \\ \text{go to the second step } (\gamma_1) > T_{CAV}(N) > \gamma_2. \\ \text{compute} = 1 \text{ if } (\gamma_1) < T_{CAV}(N). \end{cases}$$

The received signal is merely noise when compute=0, and the unlicensed user can use the free spectrum. When compute=1, the licensed user is presented; the spectrum has been occupied. As shown in the Figure 2, First, received the signal and then the thresholds are calculated and find the value of the test statistics according to the previous equations to compare both of them and make the sensing decision therefore the value of the thresholds depends on the received signal, unlike other traditional approaches.

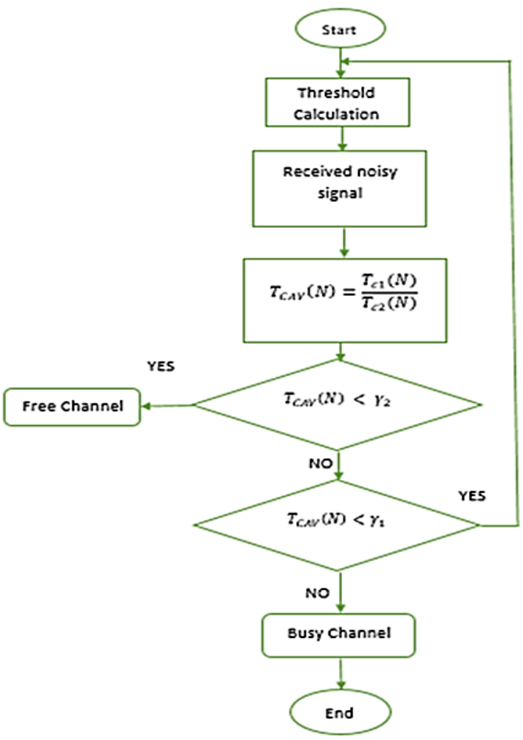

Figure 1. Flowchart for the (TTCAV) approach

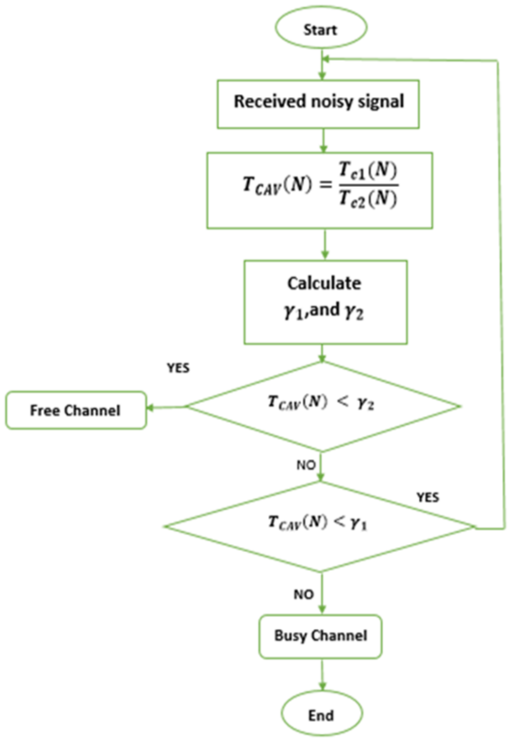

Figure 2. Flowchart for the proposed approach

3. RESULTS AND DISCUSSION

The simulation results in this section show how well the two adaptive thresholds covariance based detection (TATCAV) approach performs. In the computer simulation, the value of L is set to 5; the SNR ranges from -20 to 0 dB. the number of samples (N) is kept at 10000, Pf = 0.1, noise uncertainty is equal to (1.761 dB), and quadrature amplitude modulation (QAM). Figure 3 compares the proposed approach's performance against the performance of the previous approach. 1000 Monte-Carlo simulations were done independently to determine the P_d. Table 1 shows the improvement after using the proposed approach by the amount of P_d values of the two approaches at different SNRs.

Figure 4 shows the value of the probability of detection increases as the number of samples N increases, using the value of L set to 5. Table 2 present the results of using the two adaptive thresholds covariance absolute values spectrum sensing technique (TATCAV) at different value of a number of samples.

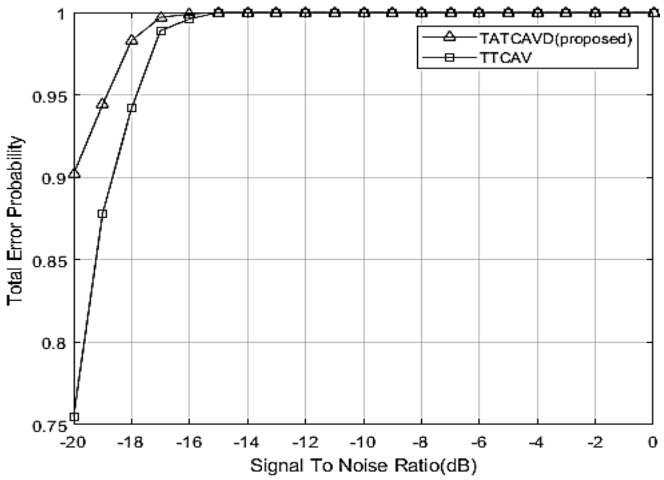

Figure 3. Comparison between P_d for (TATCAV) and (TATCAV)

Table 1. The relation between P_d and various SNR (dB) values for the two approaches

Methods type	P_d at (-20dB)	P_d at (-18dB)	$P_d$at (-16dB)
TATCAV (proposed)	90.2%	98.3%	99.9%
TTCAV	75.5%	94.2%	99.6%

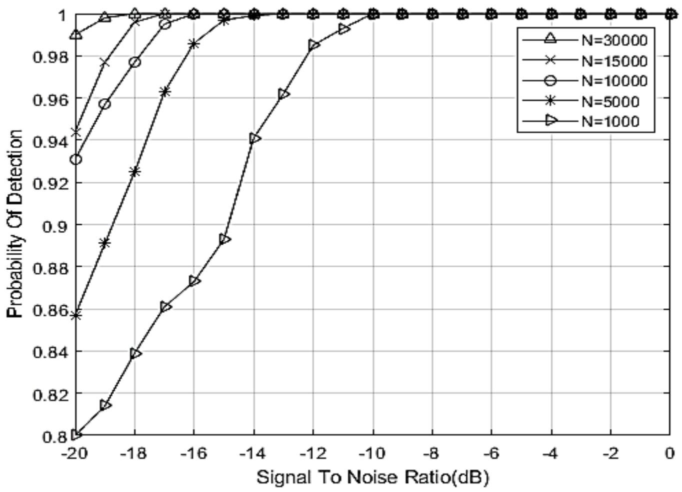

Figure 4. Probability of detection (P_d) with different samples' numbers (N)

Table 2. Shows the relation between P_d and various N, whereas the SNR is (-19dB)

Ns	1000	5000	10000	15000	30000
$\boldsymbol{P_d}$	81.5%	88%	94.1%	97.1%	100%

Figure 5 shows the change in the value of probability detection depending on the value of the probability of a false alarm. Figure 6 illustrates the effect of the value noise uncertainty N_u on changing the value of the probability of detection. Figure 7 indicates that the proposed approach has the lowest error rate compared to the previous approach. And the probability of error rate can calculate by using (29) [30].

$$P_{e=P_f} + (1 - P_d) \quad (29)$$

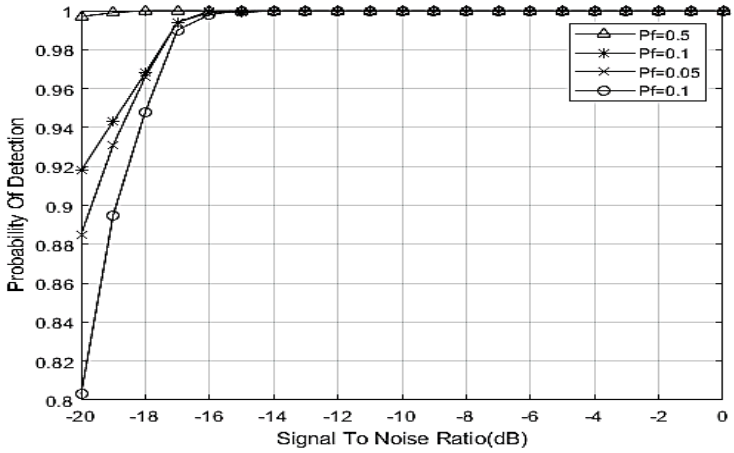

Figure 5. The relation between $P_d$and Pf

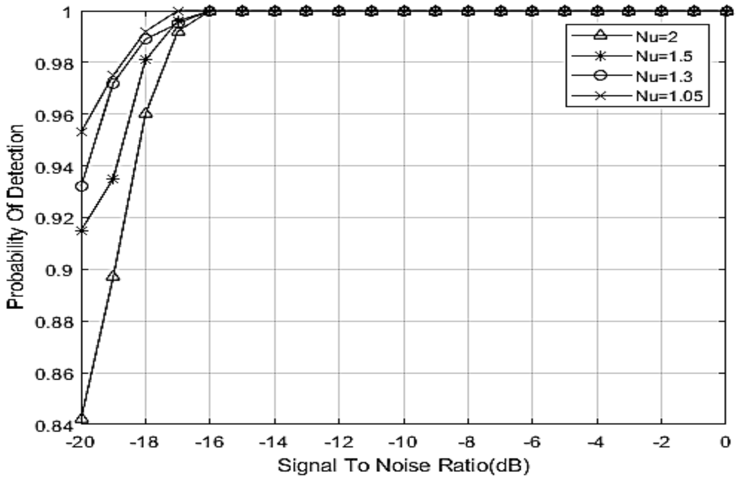

Figure 6.The relation between the Probability of detection P_d with various Nu

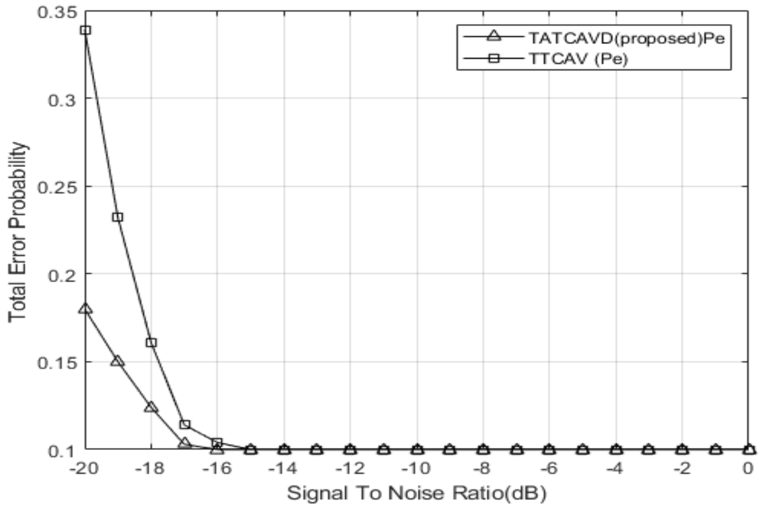

Figure 7. Comparison between Pe for (TATCAV) and (TATCAV)

4. CONCLUSION

In this paper, the proposed approach, the two adaptive threshold based on_covariance absolute value (TATCAV), was identified to increase detecting performance and provide better results. This method reduced the error rate and increased the accuracy in calculating the detection probability because the thresholds change with the change of the received signal. According to our results, the proposed approach outperforms the prior approaches in terms of spectrum detection.

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