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Cluster Based Triple Threshold Energy Detection for Spectrum Sensing in Vehicular Ad-Hoc Networks

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Abstract*: Realization of better transport experience has become a global concern with the growth in the number of vehicles on roads. Various technologies using Intelligent Transportation System (ITS) have been fronted as the solution. Vehicular Ad Hoc Networks (VANET) is an ITS technology that can be used to effectively support many vehicular applications for effective traffic control as well as information sharing between vehicles on the same route. With the advancement in wireless technologies, many applications related to vehicular communication are bound to be advanced. These applications will ease the exchange of information from one vehicle to another with the help of modern wireless technologies. The use of cognitive radio system provides additional radio resources in the already crowded licensed spectrum for vehicular communication. Spectrum sensing capability and effectiveness of the nodes is paramount in the vehicular environment. Establishing a reliable threshold level for energy detection has been shown to be essential for efficient spectrum sensing with double energy detection threshold being fronted in the recent past. Small scale primary users too like WIFI span over short range meaning they are not reliable. In this paper, a triple threshold energy detection method is proposed. This method improves the spectrum sensing efficiency as well as addressing the small scale primary users which are unreliable for use in cognitive radio systems.

Index Terms*: Energy Detection, Cognitive Radios, Spectrum Sensing, VANET.

I. INTRODUCTION

As the number of vehicle on major roads, especially in urban centers increases, related challenges such as traffic management, accidents, insecurity, and traffic snarl-ups are bound to increase too. There is need for effective traffic control using technology as well as information sharing between vehicles on the same route [1]. In an attempt to address these challenges, researches as well as car manufactures have adopted the use of communication technology with various applications and services for vehicular environments are being researched and developed. This is achieved by use of Intelligent Transportation System (ITS) which employs the use of wireless communication systems [1]–[3].

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Wireless access in vehicular environments (WAVE) is therefore an essential part of ITS. Vehicular Ad Hoc Network (VANET) is a type of WAVE that can effectively support many vehicular applications. Moving on the road in a spontaneous and unconstrained manner, vehicles forms an ad hoc network. These vehicles in VANET act as mobile nodes in a mobile ad hoc network (MANET) thus creating a high mobility network with free vehicle movements and the capability to organize and group themselves arbitrary, whilst exchanging information between themselves [2], [4], [5]. Various VANET applications span from the highly sensitive road safety to various optimization of the vehiclar traffic like routes and link optimization, and congestion/traffic jam control to applications like free space parking reporting, internet access, and file sharing and that are generally commercial [5]–[7]. A VANET can comprise of Vehicular to Vehicular (V2V), V2P (Vehicular to Person), or Vehicular to Infrastructure (V2I) Communication [2], [5], [8], [9]. V2V is cheaper in terms of setting up and managing the infrastructure thus, it has the potential as the future to effective vehicle management and communication. There are various wireless technologies that can be used by vehicles to communicate with each other or with other communication devices. The most dominant technology is Dedicated Short-Range Communication (DSRC). DSRC with 75 MHz band between 5.850 and 5.925GHz based on IEEE 802.11p standard is a communication technology set aside to support various applications that are based on vehicular communications [2], [10]. Supporting vehicular communications up to vehicular speeds of 200 km/h, IEEE 802.11p standard uses a reserved frequency band of 5.9 GHz [8]. With the increase in wireless enabled vehicles, Cognitive Radio (CR) technology, over the last few years, has been fronted as the ultimate solution to looming spectral scarcity disaster [1][11], [12]. CR is a wireless communication system that is intelligent with capability of adaptively modifying in real-time its fundamental operating parameters for efficient and optimized radio spectrum utilization. It has environmental awareness and learning capability that are crucial in provision of reliable communication. CRs have the capability to detect the unused spectrum bands (spectrum holes also called white spaces), and can subsequently access these holes when vacant opportunistically [11], [13]. Primary users (PU) who are the license holders and secondary users (SU) who are the unlicensed users seeking to opportunistically use the spectrum are essential members of a CR system as seen in Figure 1. SU can only temporarily occupy unused licensed spectrums when the PUs are not using and vacate as soon as the PUs start to use them.

This must be done effectively without causing interference to the PUs [1], [2]. In this paper, PU has been categorized as reliable and unreliable PUs. Reliable PUs are those users whose network span over a large geographical area. Examples are licensed television broadcast frequencies. Unreliable PUs are the short range frequency users like Wi-Fi, Bluetooth, etc., and they pose a new challenge of detection. Many papers have been published on various methods performing spectrum sensing for effective cooperation and occupation of spectrum. Most researchers have concentrated on methods of improving the spectrum sensing as a whole without factoring in the effect of unreliable small scale users that span over short distances. In this paper, a triple energy detection scheme is proposed that provides effective spectrum sensing as well as eliminating the unreliable PUs.

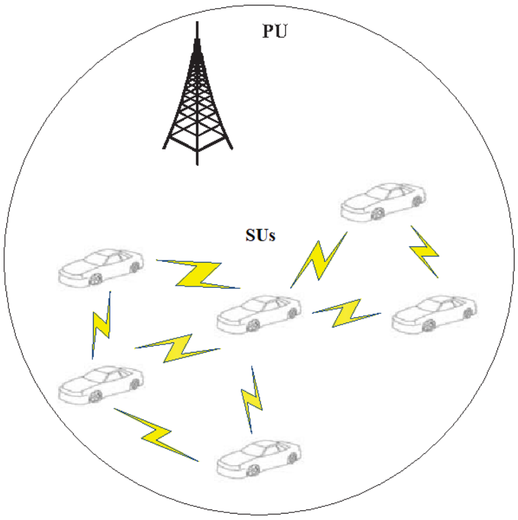

Figure 1: Illustration of a VANET with PU and SUs [2]

II. SPECTRUM SENSING

Observe, Analyze, Reason, and Act are the four main phases of the CR cognition cycle [13]. Here, the spectrum should be detected effectively and occupied by adjusting the node's operational parameters. Also, this identified spectrum can be shared with other users by coordinating with them. The goal is to utilize these spectrum but vacate the band immediately the PU appears. Therefore, there are four cognitive radio networks functionalities that are important. These are the spectrum sensing, sharing, management, and spectrum mobility or spectrum handoff. In this work, the process of spectrum sensing is investigated. Spectrum sensing is the detection of the PUs process undertaken by sensing the radio frequency (RF) environment. The objectives of spectrum sensing are [1], [2], [13].

i. No harmful interference should be caused to Pus. The SUs can reduce interference caused to PUs to an acceptable level or vacate the band to switch to another available band.
ii. Efficient and effective identification and exploitation of the spectrum holes for the required quality-of service (QoS) and throughput.

In CR, each SU must determine the frequency bands to use by sensing the spectral environment of its surroundings and learning about the presence of interferers or incumbents [14]. SUs with limited sensing capabilities in CR ad hoc networks strive to acquire information from other SUs about the available spectrum bands and share with them without impairing the PU transmission. The design objectives for sensing strategy includes reliable system performance under high node mobility, high throughput, non-SU competition, and distributed implementation. All these are further complicated by the high mobility nature of nodes in VANETs [15].

There are three fundamental requirements for spectrum sensing [1], [2], [16].

i. Continuous spectrum sensing to monitor the absence or presence of the PU.
ii. Precautions to avoid interference to potential PUs.
iii. Independent detection of the presence of PUs without their help.

Such spectrum sensing can therefore be conducted non-cooperatively (individually), in which each SU conducts radio detection and makes decisions by itself. Spectrum sensing can be done by using either energy detection, cyclostationary based detection, matched filter detection, and Eigen value based detection methods [13], [17]. For faster and easy spectrum sensing which is ideal for VANETs without prior PU information, energy detection method has been chosen.

As shown in [18]–[20], local signal sensing using primary signal detection can be expressed as;

$$x(n) = \begin{cases} w(n) & , H_0 \\ s(n) + w(n), & H_1 \end{cases} \quad (1)$$

where, *x(n)* is the signal received at the cognitive radio terminal, *w(n)* is the Additive White-Gaussian Noise (AWGN), *s(n)* - The primary user signal, *Ho* represents absence of licensed PU, and H_1 represents the presence of licensed PU

The Signal to Noise Ratio (SNR), can be given as;

$$\gamma = \frac{\sigma_s^2}{\sigma_w^2} \quad (2)$$

where, γ is the SNR, σ_s^2 is the variance of the signal, and σ_w^2 is the variance of the noise.

The following performance metrics are used for the hypothesis:

- **Probability of detection (P_d)**: This is when the vacant frequency channel is declared vacant. This can lead to utilization of the spectrum band.
- **Probability of false alarm (P_f):** This is when the vacant frequency channel is declared occupied. In this case, the SUs fails to utilize the free band.
- **Probability of miss detection (P_m)**: This is where the occupied channel is declared vacant. This can cause interference to the PU.

Higher P_d with a low P_f is the goal of the sensing schemes. But there is always a trade-off between these two probabilities. A high P_m (low P_d) results in missing the presence of PU, meaning there is high probability of causing interferes to the PU. With a high P_f, the SU observes PU while it does not exists, which turns out to be less spectrum utilization.

A band-pass filter in CR system is applied to the received signal for power measurement in a particular frequency region in the time domain. The power of received signal samples is then measured. The received power can be estimated as;

$$E = \sum_{i=1}^{N} |x_i|^2 \quad (3)$$

where, E is the received signal, x_i is the ith sample of the received signal, and $N = 2TW$ is the time bandwidth.

Detection probability, missing probability, and false alarm probability can be given as [13], [18]–[20];

$$P_d = P\{E > \lambda | H_1\} = Q(\sqrt{2\gamma}, \sqrt{\lambda}) \quad (4)$$

$$P_m = P\{E \le \lambda | H_1\} = 1 - P_d \quad (5)$$

$$P_f = P\{E > \lambda | H_0\} = \frac{\Gamma(n, \lambda/2)}{\Gamma(n)} \quad (6)$$

where, λ is the threshold value, Q(a, b) is generalized Marcum function, Γ(a) is complete gamma function, and Γ(a, b) represents incomplete gamma function.

III. TRIPLE THRESHOLD ENERGY DETECTION

In [13], [18]–[20], a cooperative spectrum sensing with a double threshold detection method was proposed to reduce the PU interference since single threshold detection has high interference problems. The double threshold therefore, avoids the unwanted interference by introducing a fuzzy region (uncertainty region). [13], [21]–[24] proposes the elimination of unreliable small scale users as it spans over a short distance which can lead to constant reallocation of spectrum space to SU. In this work, a triple threshold energy detection is proposed that seeks to provide reliable and effective spectrum sensing.

The Figure 1 below shows one threshold conventional detection, double threshold, and triple threshold methods.

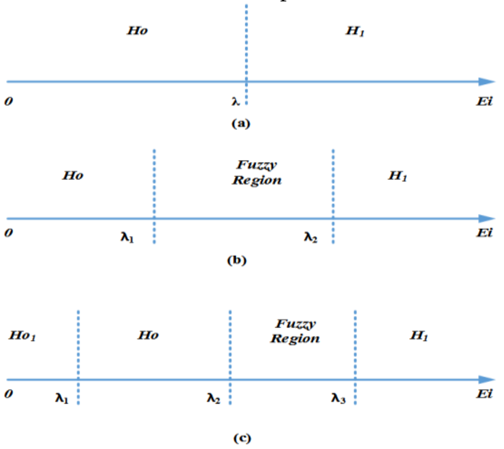

Figure 2: Energy Detection Methods. (a) Conventional single threshold, (b) Double threshold, and (c) Triple threshold

In Figure 2 (a), Decision H_0 and H_1 is made when there is a greater or lesser E_i than the threshold value λ, respectively as shown in Eq. 1. In Figure 2 (b), the user reports H_1 if the energy value exceeds λ_2. If E_i is less than λ_1, the decision H_0 will be made. Otherwise, if E_i is between λ_1 and λ_2, then the SU reports its observational energy value E_i for further decision making at the fusion center.

Local sensing using primary signal detection for double threshold method can be expressed as;

$$x(n) = \begin{cases} 0, & E_i > \lambda_1 \\ No\ Decision, & \lambda_1 \le E_i \le \lambda_2 \\ 1, & E_i > \lambda_2 \end{cases} \quad (7)$$

By adding two parameters $\Delta_{0,i}$ and $\Delta_{1,I}$ to represent the probability of $\lambda_1 \le E_i \le \lambda_2$ for the ith secondary user under hypothesis H_0 and H_1 respectively, we have;

$$\Delta_{1,i} = P\{\lambda_1 \le E_i \le \lambda_2 | H_1\} \quad (8)$$

$$\Delta_{0,i} = P\{\lambda_1 \le E_i \le \lambda_2 | H_0\} \quad (9)$$

So it can be derived that:

$$P_{d1} = P\{E > \lambda_2 | H_1\} = Q(\sqrt{2\gamma}, \sqrt{\lambda_2}) \quad (10)$$

$$P_m = P\{E \le \lambda_1 | H_1\} = 1 - \Delta_{1,i} - P_{d1} \quad (11)$$

$$P_f = P\{E > \lambda_2 | H_0\} = \frac{\Gamma(n, \lambda_2/2)}{\Gamma(n)} \quad (12)$$

In this proposed work, the three threshold levels are used as shown in Figure 2 (c). The first threshold λ_1 undresses the unreliable small scale users by creating a minimum threshold. While thresholds λ_2 and λ_3 applies the same concept as double threshold detection mentioned above. In this model, two kinds of information: observational values of the SU i.e. local energy values and local decisions are received at the fusion center.

$$x(n) = \begin{cases} Unreliable, & E_i \le \lambda_1 \\ 0, & \lambda_1 < E_i < \lambda_2 \\ No\ Decision, & \lambda_2 \le E_i \le \lambda_3 \\ 1, & E_i > \lambda_3 \end{cases} \quad (13)$$

By adding two parameters $\Delta_{0,i}$ and $\Delta_{1,I}$ to represent the probability of $\lambda_2 \le E_i \le \lambda_3$ for the ith secondary user under hypothesis H_0 and H_1 respectively, we have;

$$\Delta_{1,i} = P\{\lambda_2 \le E_i \le \lambda_3 | H_1\} = Q(\sqrt{2\gamma}, \sqrt{\lambda_2}) - Q(\sqrt{2\gamma}, \sqrt{\lambda_3}) \quad (14)$$

$$\Delta_{0,i} = P\{\lambda_2 \le E_i \le \lambda_3 | H_0\} = \frac{\Gamma(n, \lambda_2/2)}{\Gamma(n)} - \frac{\Gamma(n, \lambda_3/2)}{\Gamma(n)} \quad (15)$$

$$P_{d1} = P\{E > \lambda_3 | H_1\} = Q(\sqrt{2\gamma}, \sqrt{\lambda_3}) \quad (16)$$

$$P_{d0} = P\{\lambda_1 < E_i < \lambda_2\} = \frac{\Gamma\left(n, \lambda_1/2\right)}{\Gamma(n)} - \frac{\Gamma\left(n, \lambda_2/2\right)}{\Gamma(n)} \quad (17)$$

$$P_{d0u} = P\{E_i \le \lambda_1\} = 1 - \frac{\Gamma\left(n, \lambda_1/2\right)}{\Gamma(n)} \quad (18)$$

$$P_m = P\{E < \lambda_2 | H_1\} = Q\left(\sqrt{2\gamma}, \sqrt{\lambda_1}\right) - Q\left(\sqrt{2\gamma}, \sqrt{\lambda_2}\right) \quad (19)$$

$$P_f = P\{E > \lambda_3 | H_0\} = \frac{\Gamma\left(n, \lambda_3/2\right)}{\Gamma(n)} \quad (20)$$

IV. RESULTS AND DISCUSSION

In the simulations, the main emphasis was to show that triple threshold energy detection method at the local node stage produces better results in comparison with the single and double threshold methods. The time bandwidth factor was chosen as 1000 with the sample points given as N= =2TW where TW is the time bandwidth factor. A range of -15dB to 5dB is taken as signal to noise ratio in this work while the probability of false alarm ranges from 0.01 to 1. QPSK modulation was also used here with the modulation index of 4. The minimum threshold λ_1 was set at 3W to eliminate any unreliable small scale PUs since most of these unreliable PUs have powers of less than 1W. The simulation results can be seen as follows;

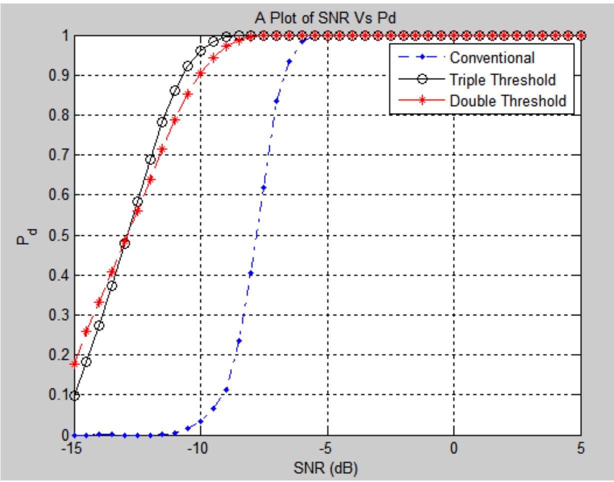

Figure 3: A Plot of SNR vs Pd

From Figure 3, it can be seen that the conventional single threshold method has low probability of detection as low SNR. This can be attributed to the fuzzy region which is not clearly defined.

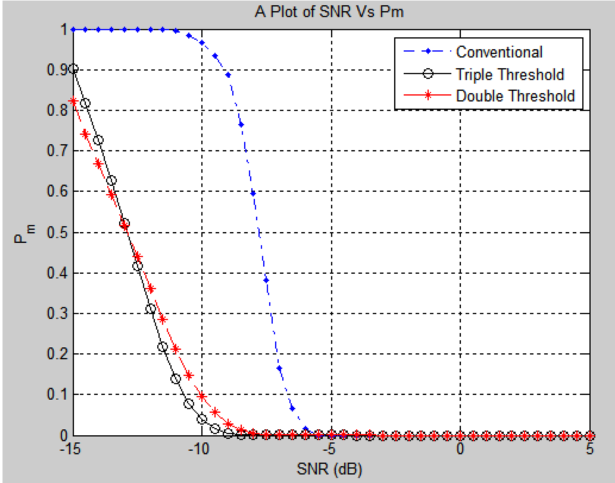

Figure 4: A Plot of SNR vs Pm

Double and triple energy detection methods performed relatively better than single threshold method. The double threshold performed better than triple threshold for very low SNR but the triple threshold performed better from around -13dB SNR and reached maximum P_d ahead of the double threshold method.

Similarly to Figure 3, Figure 4 shows the triple threshold method had lower probability of missed alarm as compared to the other two methods.

V. CONCLUSION

The use of cognitive radios has been show in various researches as the solution for the scarcity in spectrum. Spectrum sensing is an essential component in CR of which its inefficiencies will lead to interference to the licensed primary user. In this paper, a proposed triple threshold has been shown to be able to provide better spectrum sensing efficiency than the double threshold and single threshold energy detection methods. Further research to this work is to show that cooperation of SUs by fusing the sensing results can provide results for effective allocation and occupation of spectrum homes when PU is absent and vacating the same when the PUs resumes using the spectrum.

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