Performance Analysis of Cognitive Spectrum Sensing in Wireless Networks

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الملخص:

أجزاء مختلفة من الطيف الراديوي تم استخدامها من قبل تقنيات لاسلكية مختلف، والنتيجة هي أن بعض نطاقات التردد اليوم مزدحمة، في حين أن البعض الآخر نادرا ما يستخدم على الإطلاق، وهذا ما ينتج عنه ضعف في الكفاءة الطيفية. الراديو المعرفي (الادارکي) (Cognitive Radio) هو تقنية تعمل على حل مشكلة الكفاءة الطيفية باستخدام الراديو المحدد بالبرمجيات (Software Defined Radio). في SDR، يكون المرسل أو المحطة الأساسية قادرا على استشعار الأجزاء المستخدمة من الطيف سواء كانت أقل أو أكثر استخداما، ثم يعيد توزيع الإرسال لضمان استخدام الطيف بشكل أكثر كفاءة. تقنيات استشعار الطيف هي مبدأ الشبكات الراديوية الإدراكية؛ تهدف إلى الكشف عن قنوات الطيف غير المستخدمة من أجل استخدام الطيف الراديوي بشكل أكثر كفاءة. في هذه الورقة، تم تحليل ومحاكاة تقنيتين لاستشعار الطيف وهما الكشف عن الطاقة (Energy Detection)وتقنيات الكشف عن المرشحات المتطابقة (Matched Filter Detection) لتقييم أداء المستخدم الرئيسي (المرخص) والمستخدم الثانوي. تتميز هذه التقنيات بعتبة الاستشعار (Sensing Threshold) لتقييم استشعار الأداء. تستخدم معظم التقنيات الحالية حدًا ثابتًا، بالمقابل في هذه الورقة، يتم استخدام عتبة ديناميكية (Dynamic Threshold) لأن الضوضاء تعتبر عشوائية وبالتالي. وبناءً على النتائج، يمكن لتقنية الكشف عن الطاقة تحقيق أفضل أداء للكشف في حالة معرفة ضوضاء التباين، في حين يصعب تقدير هذا في الغالب، مما قد ينتج عنه عدم يقين من الضوضاء. في هذه الحالة، قد يتدهور اكتشاف الطاقة بشكل كبير مما يؤدي إلى عدم اكتشاف الخطأ أو فترة الإنذار الخاطئ. لحل هذه المشكلة، يتم استخدام تقنية التصفية المتطابقة بما في ذلك كل من مرشح متوسط ومرشح IR. من خلال استخدام الفلتر المطابق، يتحسن أداء النظام الكلي مقارنة بتقنيات الكشف عن الطاقة، خاصة عند استخدام مرشح متوسط نظرًا لقدرته على تقليل الضوضاء العشوائية والاحتفاظ

باستجابة الخطوة الحادة. يتم تحقيق النتائج من خلال تقييم احتمالية الكشف والإنذار الخاطئ كدالة لإخراج SNR لكل حالة، مما نتج عن ذلك تحسن كبير في اكتشاف المرشح المطابق فوق 5 ديسيبل من SNR. يتم تنفيذ جميع النتائج باستخدام MATLAB®.

الكلمات المفتاحية: الراديو المعرفي، استشعار الطيف، كشف الطاقة وكشف المرشح المطابق

Abstract:

Different parts for radio spectrum of wireless networks have traditionally been defined for use by different wireless technologies; this currently causes crowding in some frequency bands, while others are hardly used, resulting in spectral inefficiency. Cognitive radio is a technology that resolves the effect of spectral inefficiency with software defined radio (SDR). In SDR the sender or base station is able to sense the under or over utilized parts of spectrum, then redistributes the transmission to ensure that the spectrum is more efficiently used. In this paper, two spectrum-sensing techniques of energy detection and matched filter detection are analyzed to evaluate the performance of the licensed user (primary user) and the cognitive user (secondary user). This is characterized by a sensing threshold to evaluate the sensing performance. Both static and dynamic thresholds are considered. Based on the results, energy detection technique can attain better performance detection in case of the noise of the variance is known, whereas this is mostly estimated, which may produce noise uncertainty. In this case, energy detection may significantly degrade resulting in either miss-detection or false alarm period. In order to mitigate this issue, matched filter technique is used including both averaging filter and IR rational filter. By deploying matched filter, the overall system performance improves comparing to energy detection techniques, particularly when averaging filter is used due to its ability to reduce the random noise and retain the sharp step response. The results are achieved by evaluating probability of detection, and false alarm as a function of output SNR for each case, which shows a considerable improvement for matched filter detection above 5 dB of SNR. All results are carried out using MATLAB®.

Keywords: cognitive radio, spectrum sensing, energy detection and matched filter detection

I. INTRODUCTION

The demand for new services of wireless networks experiences a rapid increase, which in turn causes a shortening or unavailability of spectrum. Traditionally, the allocation of spectrum is achieved by assigning the band totally to a licensed user where the system has to operate in the particular frequency band. This results in inefficient performance of spectrum because the spectrum remains underutilized (Sun, H et al, 2013).

The underutilization of spectrum becomes a considerable issue and attention should be shifted to look for better spectrum management policies because the enhancement in of wireless networks throughput considerably depends on the channel utilization. Therefore, The cognitive radio is considered as an alternative candidate to resolve this issue. It supports the function of spectrum sensing, which is based on sense and identify the frequency band in which user can be able to transmit (Ranjan, A, and Balwinder S, 2016).

However, the realization of cognitive radio concerns about potential interference comes from secondary users (SUs) communications at the time that primary users (PUs) exist. Such noise can degrade the quality of service (QoS) and functions of PUs. Therefore, secondary users must have efficient mechanisms to keep PUs' communicated in detecting the idle band through spectrum sensing (Captain, Kamal M., and Manjunath V. Joshi,2022). In addition, the lack of spectrum sharing for PUs due to inability to open up their spectrum resources to cognitive users even if SUs can control interference with PUs' transmission, since no comprehensible incentive exists to share their spectrum. Thereby, there is a need for providing an efficient mechanism (Sun, H et al, 2013).

Many Studies were conducted on this field and demonstrated that some frequency bands are almost occupied; others are partially used, while some are rarely used. This will result in one-day non-availability of bands, which is expected to cause a major issue in spectrum. For this reason, cognitive radio become the desired candidate to resolve this problem. However, the main challenge is to evaluate the CR in terms of sensing, allocation and mobility of spectrum.

Cognitive radio aims at improving spectrum use by allowing the SUs to coexist with PUs as long as the interference may be caused by SUs is controlled and regulated. The main concentration of this paper is on the problem of inefficient spectrum sharing, studying and analyzing the spectrum sensing of CR using techniques of energy, and matched filter detections over a noisy channel. For each technique, the system performance is evaluated in terms of probability of detection, miss-detection and false alarm.

The rest of paper is organized as follows: cognitive radio network is briefly introduced in section (II). In section (III) system model and analysis of energy detection and matched filter are discussed. Simulation results and conclusions are illustrated in sections (IV) and (V) respectively.

II. COGNITIVE RADIO NETWORKS

A cognitive radio is a wireless communication system where a transceiver is intelligently being distinguishable of the channels for communication, which are being or not being used, and move into ideal channels while keeping a strategic distance from used ones. This improves the use of available radio frequency while interference is minimized to other users. Cognitive radio networks can be classified into two types, which are as follows:

1- Full Cognitive Radio: A wireless system network is conscious of each possible observable parameter (Abdulsattar, Mahmood A., and Zahir A. Hussein,2012)

2- Spectrum Sensing: to develop the mechanism of the detection probability, many techniques of signal detection are used in spectrum sensing.

There are also some characteristics to support using of cognitive radio networks, such as

1- Cognitive ability: is to characterize the capacity to catch or sense the data from its radio surroundings of the radio technology.

2- Reconfigurability: it is the capability of changing the functions, dynamically empowers the system to be programmed in terms of frequency reconfiguration, transmission power, modulation scheme, communication protocol reconfiguration.

Therefore, to measure the performance of cognitive radio and its ability to reduce the congestion of applications over the bandwidth, cognitive radio provides four major mechanism such as spectrum sensing, spectrum management, system allocation and sharing and spectrum mobility as shown in figure 1.

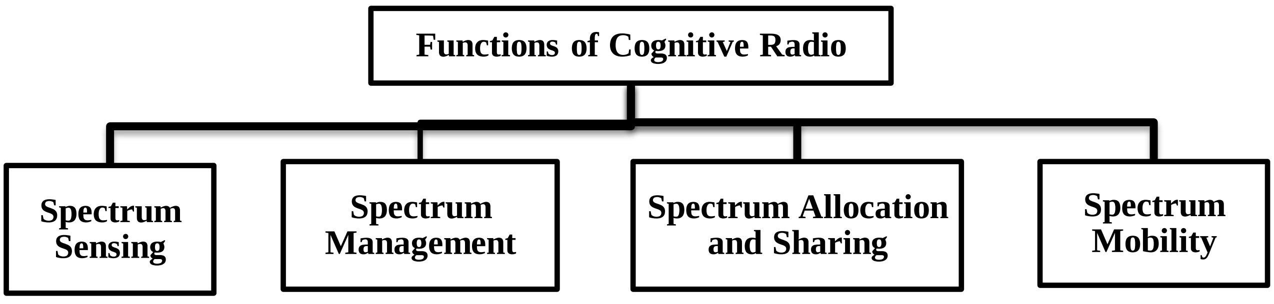

Figure 1: functions of cognitive radio networks

The principle property of cognitive radio is the spectrum sensing, which intends to sense and identify the vacant period of spectrum, and provides information about the parameters regarding to channel characteristics to temporarily identify spectrum holes without causing interference to the licensed user activities. Once the band is available, spectrum sharing and allocation functionalities are in place to use the spectrum bands (Atapattu, Saman, Chintha Tellambura, and Hai Jiang, 2011, Abdulsattar, Mahmood A., and Zahir A. Hussein,2012).

On the other hand, some challengeable terms may be faced associated with spectrum sensing technique such as, high sampling rate, high resolution of analog to digital converters and high-speed signal processors are required for sensing process (Sun, H et al, 2013). Hidden PU issue is also experienced, which is similar to the hidden node in carrier sense multiple access (CSMA). This is due to severe multipath fading or shadowing effects at the time of scanning for PU transmissions.

Sensing time duration is also essential, as primary users can claim their licensed bands during the transmission of CR users. Cognitive radio users should be able to perceive the presence of PUs as fast as possible to avoid interference to and from license holders, and to vacate the band immediately. Therefore, sensing should be processed within a particular duration to identify the existence of primary users.

Other function of spectrum management, spectrum allocation and sharing provide the scheduling technique of reasonable spectrum among coexisting users. The vacant space or channel is fast selected by cognitive radio once found. In addition, An efficient spectrum sensing along with spectrum sharing and allocation are necessary. The sensing process delivers information to the SUs about the channel status even though the channel status may change quickly based on the PUs behavior. Therefore, to obtain better performance, the SUs should select the channel and how to get admission to the channel. The PU system should be protected from the harmful interference caused by the SUs (Abdulsattar, Mahmood A., and Zahir A. Hussein,2012)

For spectrum mobility, the primary users have ability to claim their own channels while secondary users carry on sending. If this happens, secondary users require cease transmission, and look for other alternative channels to maintain transmitting; this is known as spectrum handoff. Every time, a CR user alters its spectrum; the network protocols may need modifications to the parameters of operation. The key of spectrum mobility management is to ensure smooth as well as quick spectrum handoff resulting in minimizing performance degradation (Abdulsattar, Mahmood A., and Zahir A. Hussein,2012).

An essentiality of mobility management protocols is to have information about the period of a spectrum handoff. When a secondary user modifies its frequency, its transmission process hangs up, thus latency increases. Therefore, a mechanism of good spectrum handoff is involved to guarantee imperceptible and fast transition with minimum performance degradation. To enhance the performance or minimize latency, reservation of a particular number of spectrum bands is required for spectrum handoff. Figure 2 illustrates the spectrum holes (Abdulsattar, Mahmood A., and Zahir A. Hussein,2012)

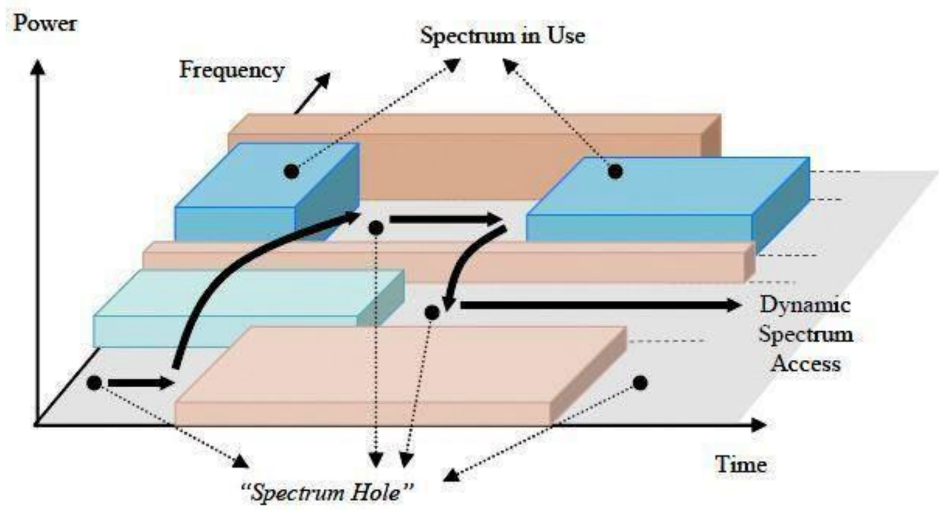

Figure 2: Illustration of the Spectrum Hole concept (Abdulsattar, Mahmood A., and Zahir A. Hussein,2012)

III. SYSTEM MODEL

There are three common transmission techniques for detecting and identifying the occurrence of primary users: energy detection, matched filter detection and Cyclostationary detection (Abdulsattar, Mahmood A., and Zahir A. Hussein,2012). In this section, the investigation of detection techniques will only limited to consider the analysis of both energy and matched filter techniques. The primary transmitter detection scenario presents analysis of the received signal at the secondary user. The key point is to determine primary transmitters working at a particular time by using local measurements and observations. In this case, the secondary user examines the strength of the signal produced by the PU to exploit the vacant period in the channel.

Figure 3 illustrates the hypothesis of system and their conditional probabilities.

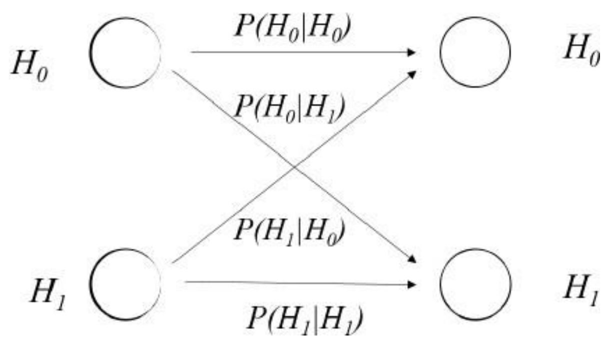

Figure 3: Hypothesis of transition states (Usman, Mustefa ,et al ,2022).

The Spectrum Sensing consists of making a decision on the presence of PU in the bandwidth of interest. The problem formulation on the presence/absence of the PU can be presented in a classic Bayesian detection problem: Under H_0, the PU is absent, whereas under H_1 PU exists (Verma, Pradeep Kumar, Sachin Taluja, and R. Lal Dua,2012)

$$y(n) = \begin{cases} w(n) & for\ \mathrm{H}_0 \\ h * s(n) + w(n) & for\ \mathrm{H}_1 \end{cases} \quad (1)$$

Where, $y(n)$ represents the output at sampled interval n, h defined as the channel gain, $s(n)$ represents the transmitted signal and $w(n) = w_r(n) + jw_i(n)$ is noise in its narrowband form with zero mean of variance σ^2 in the channel. The H_0 is the null hypothesis; meaning primary user is absent . H_1 denotes the existence of a licensed user signal (Usman, Mustefa ,et al ,2022).

1. Having H_0 when H_0 is sent (H_0/H_0);
2. having H_1 when H_1 is sent (H_1/H_1);
3. having H_0 when H_1 is sent (H_0/H_1);
4. Having H_1 when H_0 is sent (H_1/H_0).

Hypotheses 1 and 2 are considered a correct detection, whereas hypotheses 3 and 4 are called a missed detection and false alarm respectively. Missed detection probability can determine how will the system is functioning as it indicates interfering with the primary user. The false alarm probability should be as low as possible, to allow the system exploit possible transmission opportunities (Verma, Pradeep Kumar, Sachin Taluja, and R. Lal Dua,2012). The performance of the spectrum sensing technique is influenced by the probability of false alarm, PFA = P(H_1/H_0), an important metric for spectrum sensing. Equation (1) shows that a reliable method to differentiate a signal form noise is required.

Energy detection method is based on the energy of a signal to be detected is always higher than the energy of the noise. Two assumptions are required to analyze the system model:

1) The noise power is treated as a random.

2) The statistics are modeled as independent and identically distributed (IID) Gaussian random variables (RVs).

$$\mathrm{E}[{w_r}^2(n)] = \mathrm{E}[{w_i}^2(n)] = \mathrm{E}[w^2(n)] = {\sigma_w}^2 \quad (2)$$

It can be assumed that $s(n)$ is normalized. In this case, the signal to noise ratio (SNR), γ, is defined as follows:

$$\gamma = \frac{|h|^2}{{\sigma_w}^2} \quad (3)$$

For this case, a prior knowledge is not required for primary user signal; so that energy detection (ED) can work. Figure 4 shows the block diagram of ED technique. In this method, signal is passed through band pass filter of the bandwidth w and is integrated over time interval, the output of the block of an integrator is then compared to a predefined threshold.

$$\mathrm{H}(f) = \begin{cases} \frac{2}{\sqrt{\mathrm{N_0}}} & |f - f_0| \le w \\ 0 & otherwise \end{cases} \quad (4)$$

Where N_0 is the one-sided noise power spectral density.

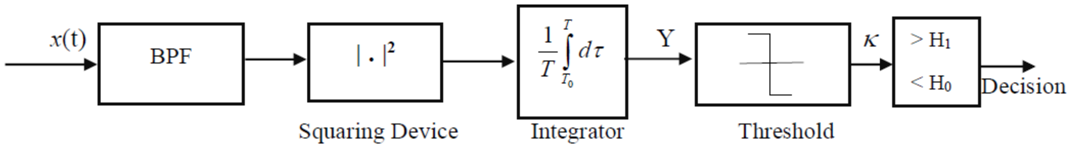

Figure 4: Energy Detection technique (Usman, Mustefa ,et al ,2022).

A wrong decision about the channel status can affect either the PU transmission or the efficient use of the channel. In fact, a missed detection can cause a harmful interference, which is caused by the transmission of the SU in the same band of the PU. A false alarm, however, decreases the profit of the channel. Therefore, the probability of detection (P_d) should be increased as much as possible, by keeping the probability of false alarm (P_{fa}) low (Abdulsattar, Mahmood A., and Zahir A. Hussein,2012 , Hong, Xuemin, et al., 2009 and Usman, Mustefa ,et al ,2022). The probabilities of False Alarm and Detection of ED for a large N can be calculated as follows:

$$P_{fa} = Q\left[\frac{\delta - {\sigma_w}^2}{\frac{1}{\sqrt{N}}{\sigma_w}^2}\right] \tag{5}$$

$$P_d = Q\left[\frac{\delta - ({\sigma_w}^2 + {\sigma_s}^2)}{\frac{1}{\sqrt{N}}({\sigma_w}^2 + {\sigma_s}^2)}\right] \tag{6}$$

Where $({\sigma_s}^2)$ is the squared mean value of the received signal, and $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{+\infty} \exp\left(\frac{-t^2}{2}\right) dt,$ the sensing threshold depends on the noise power (Usman, Mustefa ,et al ,2022). It is expressed for a target P_{fa} as:

$$\delta = Q^{-1}(P_{fa})\sqrt{2N} + N)\, {\sigma_w}^2 \tag{7}$$

The ED method calculate the input signal energy and compares it with a threshold energy value ,if the signal energy exceeds these threshold value the signal is presented in this particular frequency otherwise the frequency is empty, but is more susceptible to noise (Arjoune, Youness, et al., 2018). As seen from the analysis ED does not depend on the information about the PU signal, which makes it easy to design and has a short sensing period (S. Jo, 2015). It involves searching for the frequency band of interest and performing tests to compare the received energy with a predefined threshold to determine whether the PU is active or not. Inappropriately, at low SNRs, the ED technique is not robust in sensing spectrum holes properly.

Unlike energy detection, a matched filter (MF) is a linear filter designed to maximize the output signal-to-noise ratio for a given input signal. With this scheme, secondary users (SU) require complete knowledge of the PU transmitted signal. These information includes modulation format, carrier frequency,…etc (Kapoor, Shipra, S. V.

R. K. Rao, and Ghanshyam Singh, 2011). Typically, an MF is implemented digitally, and its realization is illustrated in Figure 5.

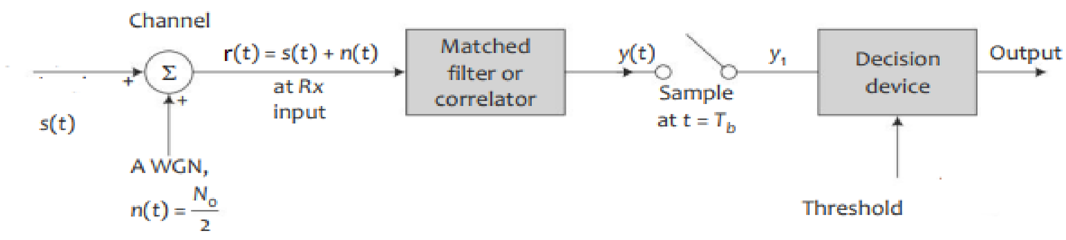

Figure 5 Realization of a Matched filter detector (Singal, T., 2012)

The main target of matched filter is to provide the maximum output SNR for a given transmitted signal, and select the response of the filter for meeting this condition. Therefore, an advantage of the MF is that it requires less time to achieve detection; however, false detection occurs when incorrect information concerning the transmitted signal is available at the SU end. A significant drawback of this technique is that an SU would require dedicated receivers for every primary user class. Therefore, it is important to analysis the digitally modulated signal received over AWGN channel. Consider the block diagram in figure 5 and that a known signal s(t) is modulated and transmitted over noisy channel that has power spectral density (PSD) constant over au frequencies with $N_o/2$, where N_o (is the power spectral density measured in watts per hertz (W/Hz)) (Singal, T., 2012).

$$r(t) = s(t) + n(t) \tag{8}$$

Then the filter output is expressed as:

$$y(t) = r(t) * h(t) \tag{9}$$

$$y(t) = \int_0^t r(\tau)\, h(t-\tau)\, d\tau \tag{10}$$

At $t = T$

$$y_K(T) = \int_0^t r(\tau) * h(T-\tau)\, d\tau \tag{11}$$

From (10)

$$y(t) = \int_0^t [s(\tau) + n(\tau)]\, h(t-\tau)\, d\tau \tag{12}$$

$$y(t) = \int_0^t s(\tau)h(t-\tau)d\tau + \int_0^t n(\tau)h(t-\tau)\, d\tau \tag{13}$$

The first part of equation (13) represents the signal part, and the second part represents the noise, therefore the output signal to noise ratio can be calculated as follows,

$$\mathrm{SNR}_o = \frac{\mathrm{P}_s}{\mathrm{P}_n} = \frac{y_s^2(\mathrm{T})}{\mathrm{E}\,[y_n^2(\mathrm{T})]} \tag{14}$$

$$\text{Where } y_s^2(\mathrm{T}) = \left[\int_o^{\mathrm{T}} s(\tau)h(\mathrm{T}-\tau)d\tau\right]^2$$

$$\mathrm{E}\,[y_n^2(\mathrm{T})] = \mathrm{E}\left[\int_{\tau_1=o}^{\mathrm{T}} n(\tau_1)h(\mathrm{T}-\tau_1)d\tau_1 . \int_{\tau_2=o}^{\mathrm{T}} n(\tau_2)h(\mathrm{T}-\tau_2)d\tau_2\right] \tag{15}$$

$$\mathrm{E}\,[y_n^2(\mathrm{T})] = \int_{\tau_1=o}^{\mathrm{T}} \mathrm{E}[n(\tau_1)n(\tau_2)]\, h(\mathrm{T}-\tau_1)h(\mathrm{T}-\tau_2)\, d\tau_1 d\tau_2 \tag{16}$$

Assuming that $n(t)$ is stationary process, means the statistical characteristics of the sampled function do not change with time.

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$$\mathrm{E}[n(\tau_1)n(\tau_2)] = \mathrm{R}_{nn}(\tau_2-\tau_1) = \mathrm{R}_{nn}(\Delta\tau) \tag{17}$$

Where R_{nn} is an auto-correlation is function or second order process. In this case, it is considered as stationary process that depends only on the difference between the observation timesτ_2 *and* τ_1. Use Einstein-Wiener-Khintchine relations stating that;

$$\mathrm{R}_{nn}(\Delta\tau) = \int_{f=-\infty}^{+\infty} \mathrm{G(f)}\, e^{j2\pi f\Delta\tau} df \tag{18}$$

Where G(f) is the power spectral density of the process, in this case $\mathrm{G(f)} = \frac{\mathrm{N_0}}{2}\ \forall$ f.

$$\mathrm{R}_{nn}(\Delta\tau) = \int_{f=-\infty}^{+\infty} \frac{\mathrm{N_0}}{2}\, e^{j2\pi f\Delta\tau} df = \frac{\mathrm{N_0}}{2}\delta(\Delta\tau) = \frac{\mathrm{N_0}}{2}\delta(\tau_2-\tau_1) \tag{19}$$

Substituting (19) into (16) to get,

$$\mathrm{E}\,[y_n^2(\mathrm{T})] = \int_{\tau=o}^{\mathrm{T}} \frac{\mathrm{N_0}}{2}\delta(\tau_2-\tau_1)\, h(\mathrm{T}-\tau_1)h(\mathrm{T}-\tau_2)\, d\tau_1 d\tau_2 \tag{20}$$

For $\tau_2 = \tau_1$

$$\mathrm{E}\,[y_n^2(\mathrm{T})] = \int_{\tau=o}^{\mathrm{T}} \frac{\mathrm{N_o}}{2}\, h^2(\mathrm{T}-\tau)d\tau \qquad (21)$$

Recall equation (14),to get

$$\mathrm{SNR}_o = \frac{\left[\int_o^{\mathrm{T}} s(\tau)h(\mathrm{T}-\tau)d\tau\right]^2}{\frac{\mathrm{N_o}}{2}\int_{\tau=o}^{\mathrm{T}} h^2(\mathrm{T}-\tau)d\tau} \qquad (22)$$

Using caudy –Schwartz inequality

$$|< g_1(t).\, g_2(t) >| \leq \left|\int g_1(t).\, g_2(t)dt\right|^2 \leq |g_1(t)|^2|g_2(t)|^2$$

Thus,

$$\mathrm{SNR}_o = \frac{\int_o^{\mathrm{T}} s(\tau)^2 d\tau \int_{\tau=o}^{\mathrm{T}} h^2(\mathrm{T}-\tau)d\tau}{\frac{\mathrm{N_o}}{2}\int_{\tau=o}^{\mathrm{T}} h^2(\mathrm{T}-\tau)d\tau} \qquad (23)$$

Where $\int_o^{\mathrm{T}} s(\tau)^2 d\tau = \mathrm{E}_g$(energy of transmitted signal)

$$\mathrm{SNR}_o = \frac{2\mathrm{E}_g}{\mathrm{N_o}} \qquad (24)$$

This value is hold only if the impulse response of the filter gives maximum outputSNR_o. Therefore, it is important to select the impulse response $h(\mathrm{T}-\tau)$ that gives maximum SNR_o at the filter output to be matched. After sampling at $t = iT$ the result is pass through a discussion device to determine whether the observed value is shows that the PU exists or not based on static threshold. Although, most of the existing techniques used a static threshold, the noise is random, and, thus the threshold should be dynamic to update the system performance and gives the secondary user notification that primary or licensed user will use the band (Jin, Zilong, et al., 2018). In matched filter, probabilities of detection and false alarm detection techniques are expressed as:

$$\mathrm{P}_{fa} = \mathrm{Q}\left[\frac{\delta}{\sqrt{\sigma_w{}^2}}\right] \qquad (25)$$

$$\mathrm{P}_d = \mathrm{Q}\left[\frac{\delta - \mathrm{E}_g}{\sqrt{\sigma_w{}^2}}\right] \qquad (26)$$

Where E_g is the PU signal energy. Sensing threshold is given as a function of PU signal energy and noise variance.

$$\delta = Q^{-1}(P_{fa})\sqrt{\sigma_w{}^2} \qquad (27)$$

An estimated dynamic threshold λ' can be expressed as

$$\lambda' = k * \lambda \qquad (28)$$

Where λ is the predictable threshold based on every sensing method algorithm and k is a positive factor. For dynamic threshold the system is periodically updates the status of detection process, this gives an advantage for dynamic over static threshold, which will be noticed in the simulation results.

IV. SIMULATIONS

In this section, simulations are performed alongside description of scenarios involved with applying the energy detection and matched filter schemes. The figure 6 shows the flow chart of cognitive radio using energy sensing technique. The generated signal is modulated using BPSK modulation scheme, and then noise is added to the modulated signal. The noise is additive white Gaussian noise (AWGN) channel with zero mean and variance ($\boldsymbol{\sigma^2}$). At the receiver side, the received power is calculated and then the distributed energy is calculated accordingly. If the energy to noise ratio is greater than threshold, the primary user exists; otherwise secondary user can use the vacant period.

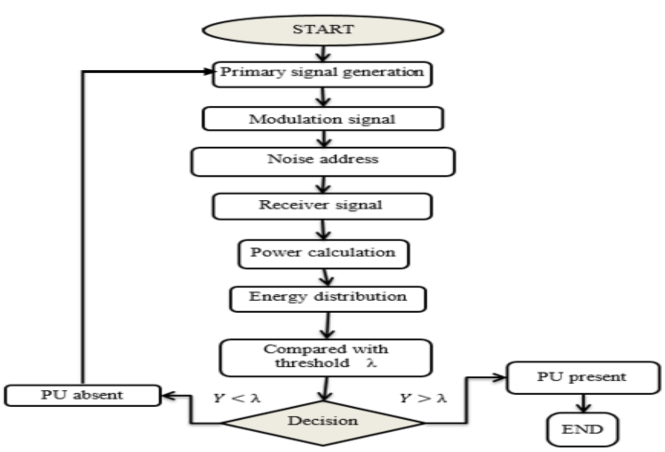

Figure 6: Process flow diagram of energy detection

Figure 7 shows the processing steps of matched filter detection technique, where the modulated signal is sent over fading channel with addition to AWGN. The received signal is then passed through a front-end filter to pass the desired signal and then convolved with the filter response, impulse response of this filter is selected properly to provide maximum SNR at filter output, and then passed through a decision device to compare the result with the threshold. If the result is greater than the threshold this implies that PU exists, otherwise the SU can occupy the band

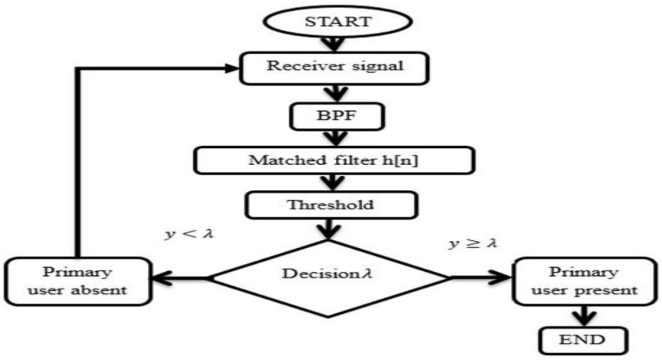

Figure 7 : Process flow diagram of Matched filter Detection.

V.RESULTS

In this section, the simulation is compiled based on the schemes illustrated in previous section. Figure 8 shows the complementary ROC curve for energy detection over a non- fading (AWGN) channel (a case where the form of interference is only noise).

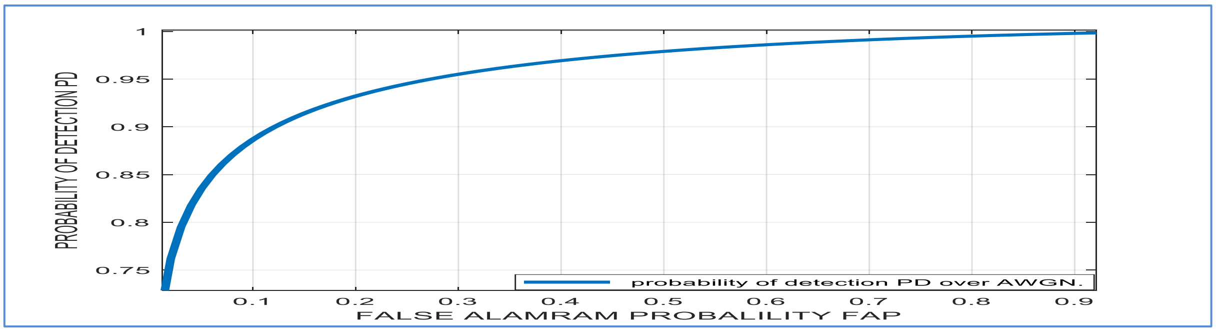

Figure (8): The complementary ROC curve for energy detection over a AWGN channel.

The probability of miss-detection is a compliment of detection probability expressed as

$$P_{md} = 1 - P_d \quad (29)$$

Form the plot, the probability of miss-detection improves rapidly with increasing the signal to noise ratio (γ), roughly a gain of one order of magnitude is achieved when γ increases when a node experiences no channel fading effects.

Figure 9 shows the relationship between the probability of miss-detection and false alarm probability, considering an average SNR form 0 to 15 dB with an increment by 5 dB and time bandwidth product (d) of 4 and sample size (N) is equal to 1000 respectively. Recall equation (6), to derive the relationship between the probability of miss-detection and SNR,

$$P_{md} = 1 - P_d = 1 - Q\left[\frac{\delta - ({\sigma_w}^2 + {\sigma_s}^2)}{\frac{1}{\sqrt{N}}({\sigma_w}^2 + {\sigma_s}^2)}\right] \qquad (30)$$

$$P_{md} = 1 - Q\left[\frac{\delta - (1 + \frac{{\sigma_s}^2}{{\sigma_w}^2})}{\frac{1}{\sqrt{N}}(1 + \frac{{\sigma_s}^2}{{\sigma_w}^2})}\right] \qquad (31)$$

$$P_{md} = 1 - Q\left[\frac{\delta - (1 + SNR)}{\frac{1}{\sqrt{N}}(1 + SNR)}\right] \qquad (32)$$

From equation (32), it is noticed that increasing in SNR improves the probability of miss-detection. Figure 8 shows the probability of false alarm versus the probability of miss-detection as a function of SNR, for example in case of setting $P_f = 10^{-2}$, when SNR = 5 dB, the probability of miss-detection $P_{md} \approx 8x10^{-2}$, and for SNR= 10 dB, $P_{md} \approx 8x10^{-3}$, form this result it is observed that an increase in SNR results in reduction in probability of miss-detection, this will increase the opportunity for making true decision. Similarly, an increase in SNR reduces the effect of false alarm probability; therefore, the system performance improves.

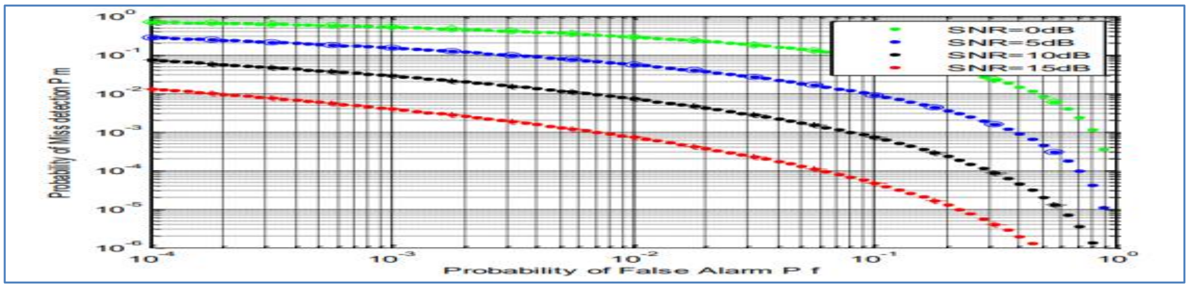

Figure 9: Probability of false alarm versus miss-detection as a function of SNR.

Figure 10 represents the comparison between static and dynamic miss-detection probability versus the SNR. It shows that static case has linear decrease in miss-detection as SNR increases, for SNR greater than 0 dB, where the power of signal is greater than power of noise, the miss-detection probability is zero, whereas in case of dynamic threshold the result has the same trend but has miss-detection problem less than that for static case as it reaches zero before static one i.e at SNR= 5dB. However, when the power of signal to noise ratio gets more than 5 dB the miss-detection for both cases is zero

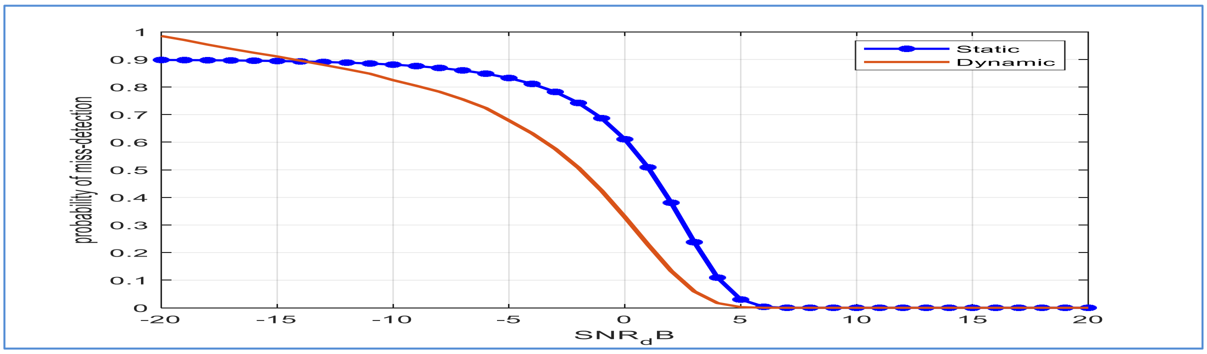

Figure 10 : Static versus dynamic miss-detection probability as a function of SNR .

For evaluating probability of detection, it has to be the complement of miss-detection probability, meaning it increases as SNR increases, as shown in figure 11, where the dynamic threshold still exhibits better performance. However, in figure 12 the probability of false reduces considerably as increasing the SNR. In this case, the system expects the period is idle and can be used by SU, while PU exists, these results in collision and degrades the system

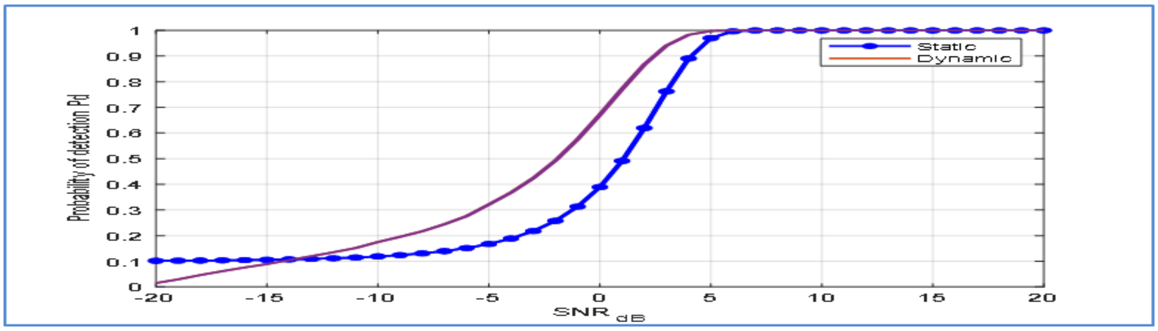

Figure 11 : Static versus dynamic detection probability as a function of SNR

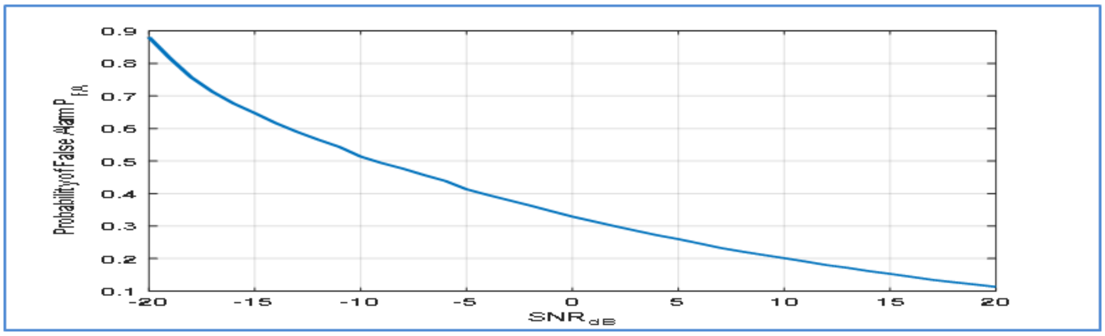

Figure 12: False alarm probability versus SNR

By deploying matched filter detection techniques, it becomes possible to consider the bit error rate as a parameter of evaluation. As expected by increasing SNR, the overall error will decease dramatically by using both averaging and rational IR filter, where averaging filter shows slightly better BER than the other one as shown in figure 13. In figures, 14 and 15 averaging filter has better performance of probability of detection and therefore miss-detection than that for rational IR filter. Averaging filter has a function of reducing the random noise while retaining the sharp step response, while rational IR filter has a problem of non- linearity. For that reason, the following results shows performance of averaging filter is better than that for rational IR filter for both probabilities of detection and miss-detection.

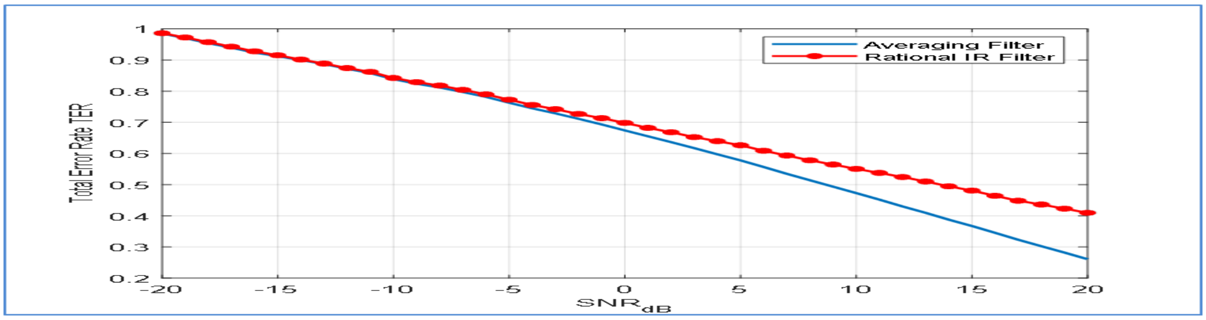

Figure 13: Total error rate versus SNR

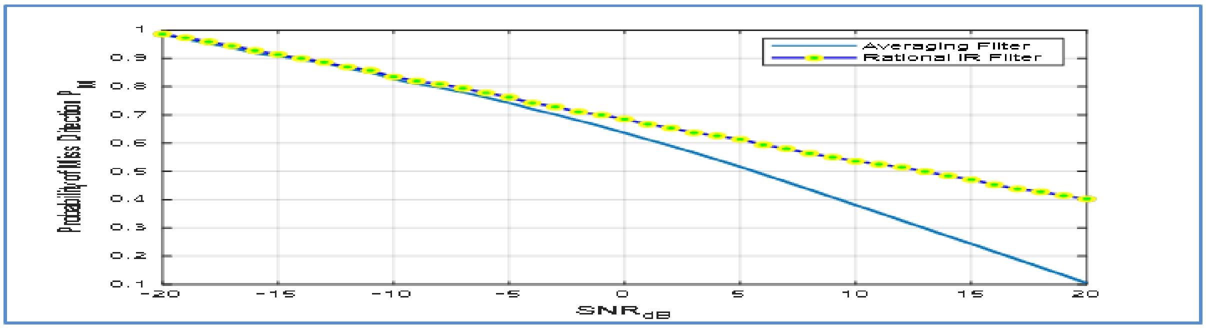

Figure 14: Probability of miss-detection versus SNR using averaging and rational IR filters

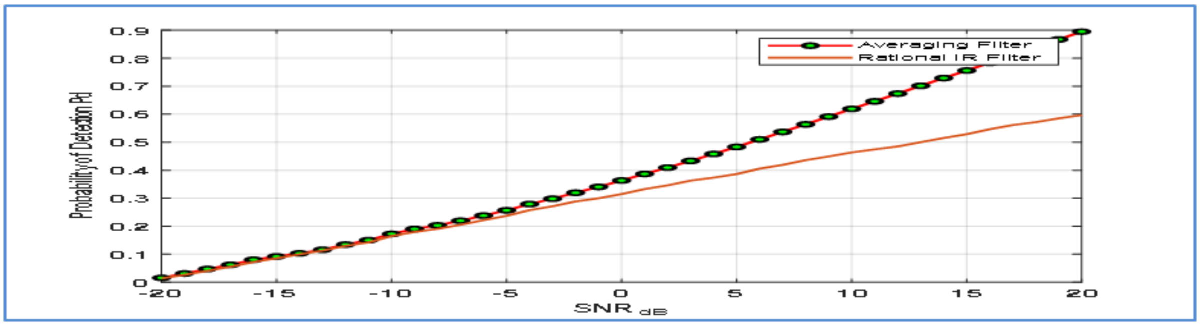

Figure 15: Probability of detection versus SNR using averaging and rational IR filters

VI.CONCLUSION

To sum up, in this paper, two techniques of sensing spectrum are discussed. An analytical expression for the false alarm and mis-detection probabilities for each method is derived and simulated. . Based on the results, it can be concluded that each method has its strengths and weaknesses. Energy detection is easy to implement and does not require any information about PU signal; however, it does not have the capability of distinguishing between signal and interference, and it experiences a high false alarm too. Although, Matched filter techniques requires a perfect knowledge of PU signal, which is inefficient in practice, it has a good performance under low SNR. Therefore, choosing one of these two sensing techniques depends on the SNR level, the uncertainty of interference for the transmission channel, and availability of information about the PU signal. However, by using a dynamic threshold, better sensing performance is achieved as it updates periodically the status of primary user, compared with a static threshold. In addition to its ability to work at low SNR, matched filter detection with averaging filter has provided better performance of probability of detection and miss-detection than that for rational IR filter. That is because averaging filter has a mechanism of controlling non-linearity issue, which is not possible if rational IR filter is deployed.

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