A Modified Energy Detection Based Spectrum Sensing Algorithm for Green Cognitive Radio Communication

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ABSTRACT

Spectrum Sensing is the first and fundamental function of Cognitive Cycle which plays a vital role in the success of CRs (Cognitive Radios). Spectrum Sensing indicate the presence and absence of PUs (Primary Users) in RF (Radio Frequency) spectrum occupancy measurements. In order to correctly determine the presence and absence of Primary Users, the algorithms in practice include complex mathematics which increases the computational complexity of the algorithm, thus shifted the CRs to operate as "green" communication systems. In this paper, an energy efficient and computationally less complex, energy detection based Spectrum Sensing algorithm have been proposed. The design goals of the proposed algorithm are to save the processing and sensing energies. At first, by using less MAC (Multiply and Accumulate) operation, it saves the processing energy needed to determine the presence and absence of PUs. Secondly, it saves the sensing energy by providing a way to find lowest possible sensing time at which spectrum is to be sensed. Two scenarios have been defined for testing the proposed algorithm i.e. simulate detection capability of Primary Users in ideal and noisy scenarios. Detection of PUs in both of these scenarios have been compared to obtain the probability of detection. Energy Efficiency of the proposed algorithm has been proved by making performance comparison between the proposed (less complex) algorithm and the legacy energy detection algorithm. With reduced complexity, the proposed spectrum sensing algorithm can be considered under the paradigm of Green Cognitive Radio Communication.

Key Words: Spectrum Sensing, Cognitive Radios, Green Communication, Energy Detection.

1. INTRODUCTION

Green communication is termed as the telecommunication systems that have design concerns about environment and aim to save energy especially in societies where consumer is greedier of resources which are limited and valuable. Green communication promotes the initiative where the engineers, industry and the users all on one hand compete for the resources while on the other hand are well aware of the issues related with environment, availability of resources and their impact on society [1].

In the context of green communication, radio spectrum is not unlimited and CR aims to solve increasing consumer demands by utilizing spectrum efficiently. In this way CR is also green [2]. CR tries to give an intelligent flexible design in order to solve issues in sharing and accessing

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the resource that causes interference [3]. CR is green not only because it is about management of scarce resources in the consumer society but also because it faces problems having impact on the environment, such as; energy efficiency, energy saving, and electromagnetic radiations [4]. Conventionally, in CR wireless networks, the Secondary Users need to continuously sense the wireless spectrum for the presence of Primary Users in order to opportunistically access the spectrum when the Primary Users are inactive [5]. Sensing the spectrum continuous can completely catch the spectrum opportunities for the Secondary Users and Secondary User transceivers are required to be in active state always. When the transceiver works in the active state, it consumes almost the same amount of power as is used during the transmit state, hence becomes the major energy consumption part in the battery-driven mobile device. Thus, the continuous sensing scheme is not energy efficient, especially when the Primary Users occupy the spectrum for a long time. One of the major issues in wireless CR network is the inefficient energy usage in sensing the spectrum [6]. The main reason for this is the existing continuous/fixed schedule spectrum sensing schemes in the CR networks which consume a lot of sensing energy but do not provide much spectrum opportunities [7].

Energy efficient algorithms are the most recent need of to-days telecommunication system in order to fulfill the paradigm of green communication. The algorithms on which the telecommunication system devices work make the processing more complex to achieve good performance [8]. The same happens in case of CR [9]. The fundamental performance of CRs lies in spectrum sensing [10]. In CRs, transceiver first sense the spectrum for white spaces. This sensing results in good performance of CRs only if it correctly detects the Primary Users and provide no opportunity for Secondary Users to access those spectrum on which Primary Users are present [11]. Hence, correct detection of the PUs is necessary in order to achieve good performance of CRs.

Sensing time and threshold value are the two factors that play an important role in energy detection based spectrum sensing algorithm to work efficiently [12]. Complex mathematics is usually involved in the setting of these two parameter. However, to overcome the above mentioned energy inefficiency problem in energy detection based spectrum sensing, in this paper , we have proposed an energy efficient spectrum sensing algorithm which include simple and less Modified Energy Detection Based Spectrum Sensing 3 complex technique for detecting PUs and also proposes a simple and less complex dynamic threshold setting for correct detection of PUs. The paper also proposes a simple methodology to save the sensing energy.

The rest of paper is drafted as follows: Section 2 highlights the literature review. System model of the proposed energy efficient algorithm and its simulation setup are described in Section 3. Results are illustrated and concluded in Section 4 and 5, respectively.

2. RELATED WORK

Energy efficient spectrum sensing algorithms have been proposed by many researchers [8,10-12] as discussed in Section 1. In [13], Hang, and Xi, have proposed that sensing energy can be saved by adaptively changing the sensing periods in available spectrum usage time by taking the advantage of PUs activity pattern. They also proposed a novel two threshold based sequential sensing policy for reducing false alarm probability and limiting missed detection. Although, the technique Hang and Xi have proposed on one hand guaranteed the detection of PUs with minimum sensing time while on the other hand, it requires a lot of processing power. Furthermore, they also have proposed another complex scheme for reducing false alarm and limiting missed detection. Hence it can be said that more the complex algorithm is, more energy would it consume but more accurate it would be. In this paper the prime objective on one hand is to save the sensing energy along with processing or computational energies while on the other hand detection of Primary Users must be guaranteed in order to make efficient utilization of CRs in green communication paradigm.

3. PROPOSED ENERGY EFFICIENCY ALGORITHM

Proposed energy efficient spectrum sensing algorithm is based on two key scenarios. First, the signal detection in ideal (without noise) and noisy scenarios. Second, dynamic threshold setting. Signal detection in ideal (without noise) and noisy scenarios are used to determine the probability of detection of the PUs signal on different SNRs (Signal-to-Noise Ratios). Dynamic threshold setting avoid noise to cross the threshold and guarantee the presence of actual PUs Signal. The justification of the above mentioned scenarios is given in the performance evaluation section (Section 4).

3.1 System Models

There are a lot of techniques through which spectrum can be sensed [14]. The algorithm proposed in this paper is based on Energy Detection spectrum sensing technique. Below are the system models for PUs detection through energy detection in ideal (without noise) and noisy scenario.

There are three main parts of the system models presented in Figs. 1-2. First, the PU signal generation. Second, transmission of the signal in ideal (without noise) channel and last is spectrum sensing part. The only difference between both (Figs. 1-2) the models is addition of noise. In the system model presented in Fig. 2, AWGN (Additive White Guassian Noise) channel is assumed. Therefore, signal generated in first part will added with noise in the channel. The methodology of the systems models (Figs. 1-2) is as follows: At first the signal is generated in the PU signal generation section, secondly it is transmitted in the ideal (without noise) and noisy channel, after that it is acquired by the transceiver and finally the spectrum sensing process will start. After acquiring the signal, first it will transform into frequency domain through FFT (Fast Fourier Transform), secondly squaring of the complex valued data is performed, in the end FFT bins are converted into usable frequency by the method called averaging. Once this is completed, the Squared values will be plotted against Averaging values and threshold will be Modified Energy Detection Based Spectrum Sensing 5 placed in the plot in order to find correct PU's signal. Finally, Decision

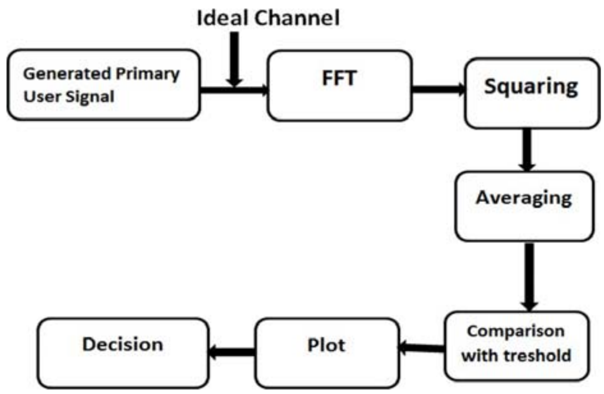


FIG. 1. IDEAL SCENARIO

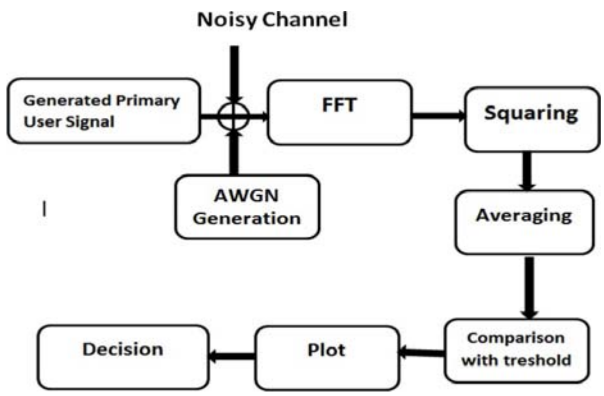


FIG. 2. NOISY SCENARIO

will be taken whether the PU is present or not. Since the proposed algorithm is based on energy detection, therefore, the decision on the presence or absence of PU depends upon whether the signal level is above or below the threshold. The signal level on the desired frequency above the threshold indicate the presence of Primary Users otherwise absence of PU is shown.

3.2 Threshold Setting

Focus of this paper is to utilize CRs in green communication paradigm, therefore, a technique have been adapted for obtaining threshold setting such that the threshold setting should not be computationally complex.

Threshold is set on the basis to keep it at least 3dB above the noise floor in all noise uncertainties. In order to get rid of noise uncertainties, it is recommended to set threshold at 3dB or just above it, therefore keeping the said recommendation in mind, threshold is set 9dB above the noise floor in order to ensure the detection is noise free. A simple technique has been adopted to set the threshold rather than going for computational complexities. The technique is based on the utilization of Polyfit command of the Simulation software MATLAB. This command results slope as well as a Curve fitted value as given below:

$$Y = m * x + C \tag{1}$$

Keeping in observation the second parameter C, it is found that the value of this parameter always changes as the impact of noise changes and it always lies at or just above noise floor in all noise uncertainties. Keeping advantage of this parameter, we efficiently utilize the Polyfit command in the code to detect the curve fitted value of the signal and with the addition of 9dB in its value resulted in the dynamic threshold value that was desired to detect the Primary Signals without any noise ambiguities.

3.3 Complexity Calculation of Algorithm

Greenness of cognitive radio depends on complexity of algorithm. But CR requires some calculation of complexity to show how complex an algorithm is. If we consider number of adders and multipliers required in process of periodogram as complexity of that process we can _nd an expression showing the MAC operations in periodogram. Periodogram consist of following steps.

(1) ***Fourier Transforms:*** In Fourier transform quality or accuracy of signal in frequency domain depends on N points or bins at which Fourier transform is applied. Actually N represent real data values in time domain that are transformed into N complex frequency domain values hence calculations or processing depends on N points. In the proposed algorithm complexity is calculated in terms of N.

(2) ***Squaring:*** squaring is performed to find absolute of FT. For absolute we need conjugate and then multiplication of original vector with conjugate as shown as x.*(real(x)-j*img(x))

(3) ***Averaging:*** Averaging is required to cancel out or average the temporal changes in frequency that are caused with respect to time.

DFT

$$Multiplier = 4*N^2 + 5*N + 1 \tag{2}$$

$$Adder = 4*N^2 - 2*N \tag{3}$$

FFT Radix-2

$$Multiplier = 2*N*log(N) + 5 * N + 1 \tag{4}$$

$$Adder = 4*N*log(N) + 2 * N \tag{5}$$

FFT Radix-4

$$Multiplier = 3:5*N*log(N) + 5 * N + 1 \tag{6}$$

$$Adder = 4*N*log(N) + 2 * N \tag{7}$$

3.4 Less Complex and Complex (Legacy) Algorithm

Less complex algorithm is basically an algorithm which has fewer computational complexities. Less complex algorithm provide same or small difference in performance when compared to complex (legacy) algorithm. A complex (legacy) algorithm is the algorithm which involves time-consuming computations in order to obtain correct results. In this paper, less complex algorithm is proposed which is free from additional (computational) complexities for obtaining good results like window, filter etc. The complex version of the proposed algorithm includes the filtering or windowing complexities. The idea of representing the concept of these two (complex and less complex) algorithms is to prove energy efficiency of the proposed algorithm (less complex) and is discussed in Section 4.4.

3.5 Probability of Detection, False Alarm and Energy Efficiency Calculation

Suppose N is the number of Averaged frequency bins above the threshold in noisy scenario at any SNR and Ni is the number of averaged frequency bins above the threshold at same SNR in ideal (without noise) scenario. According to the proposed algorithm, the PD (Probability of Detection) calculated in terms of percentage is given as follows:

$$P.D = \frac{N}{Ni} * 100 \tag{8}$$

PF (Probability of False) alarm will remain zero at the true threshold. However, it will increase as the threshold set at the low level and in that case, number of crossings of averaged frequency bins in noisy scenario would become greater than number of crossings of averaged frequency bins in ideal scenario. Therefore, PF alarm in terms of percentage can be obtained simply by:

$$P.F = \frac{N - Ni}{Ni} * 100 \tag{9}$$

Energy Efficiency according to the proposed algorithm is:

$$E.E = \frac{P.DoftheLessComplexA\lg orithm}{P.D.oftheComplexA\lg orithm}[13] \tag{10}$$

According to Equation (3), energy efficiency is the ratio of performance of less complex and complex algorithms. As there is no compromise upon the performance in order to increase energy efficiency. Therefore, the performance of an algorithm having fewer computational complexities in terms of calculation is little bit less as compared to that of the complex algorithm and hence, can be considered as energy efficient.

4. PERFORMANCE EVALUATION

First the performance of the proposed algorithm is evaluated with respect to SNR. SNR has been taken from -10dB to 10dB. Unlike [13], No complex computation have been used to reduce the False Alarm. Threshold and the detection method are perfect and will not give any False Alarm in detection of the PU's and is shown in Fig. 3.

4.1 SNR vs Probability of Detection and False Alarm

From Fig. 3, shows that Probability of Detection is increasing as the SNR is increasing and 100 percent detection of the Primary Users occurred when the SNR is 10dB. In order to prove that the detection is noise free, probability of False Alarm is also shown on the same graph and it can be seen that Probability of False Alarm is zero at the set or true threshold as discussed in Section 3.2. This result has been obtained by taking FFT size of 2048 when the sensing time was 50sec. Although the FFT size and the sensing time is much higher but in order to reduce missed detection, it is important to choose the optimum FFT size. For the proposed algorithm FFT size is chosen as 2048 but the sensing time can be reduced more in order to save sensing energy and it is shown in Section 4.5.

4.2 Justification of Detection

In Fig. 3, Probability of Detection and False Alarm are shown with respect to the SNR. In order to justify the result, we are representing the detection plot of the PU's signals.

Graphs of Figs. 4-5 prove that signals above threshold on low and high values of the SNR scale are able to cross the threshold only. Hence it makes sense that for other values of the SNR scale, detection would also be noise free.

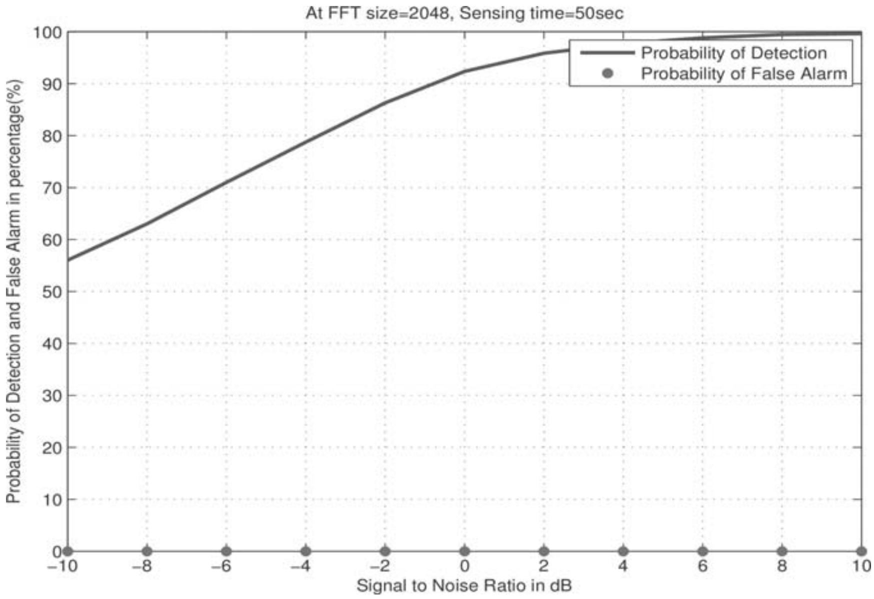
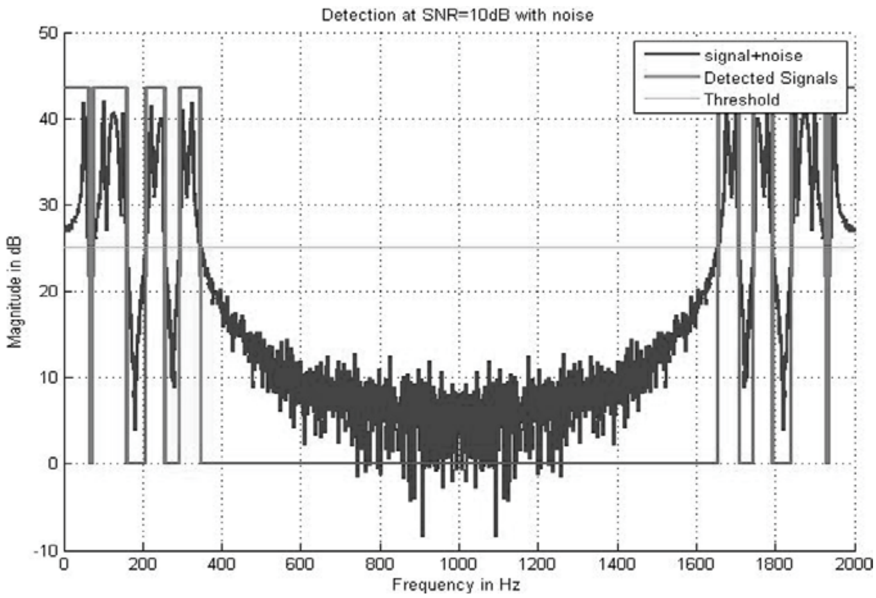


FIG. 3. SNR VS PROBABILITY OF DETECTION AND FALSE ALARMFIG



4. DETECTION OF PUS ON DESIRED FREQUENCIES AT SNR=10DB

4.3 Windowing Impact

The use of window increases the performance of detection but as we said our algorithm would not make a big difference in performance when use with window. The comparison of the performance of the algorithm with and without window is given below.

It can be seen from Fig. 6 that use of window is not creating a large difference in performance when compared with the performance of the algorithm without window (Fig. 3). Although, detection has increased slightly and for this little increment in performance, it would be better to ignore its complexities in order to make system energy efficient.

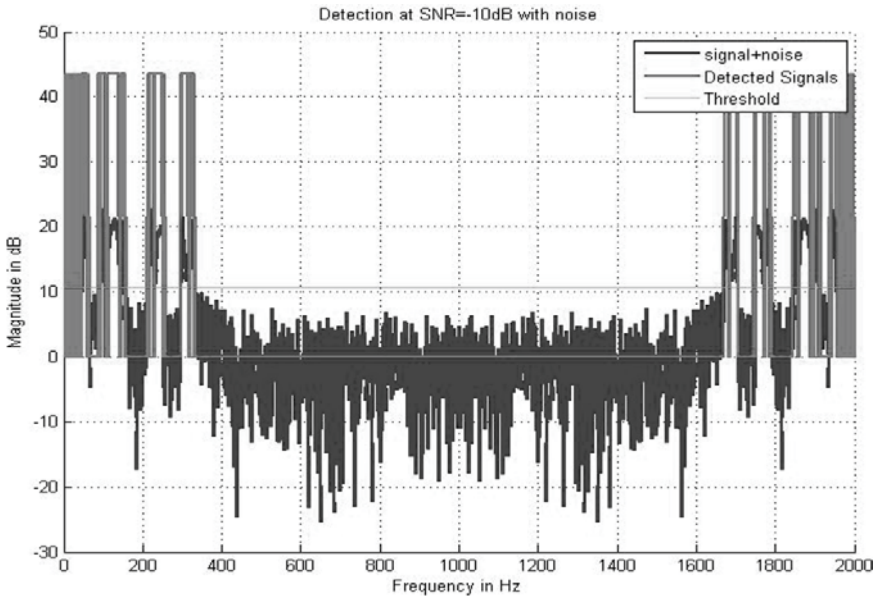


FIG. 5. DETECTION OF PUS ON DESIRED FREQUENCIES AT SNR= -10DB

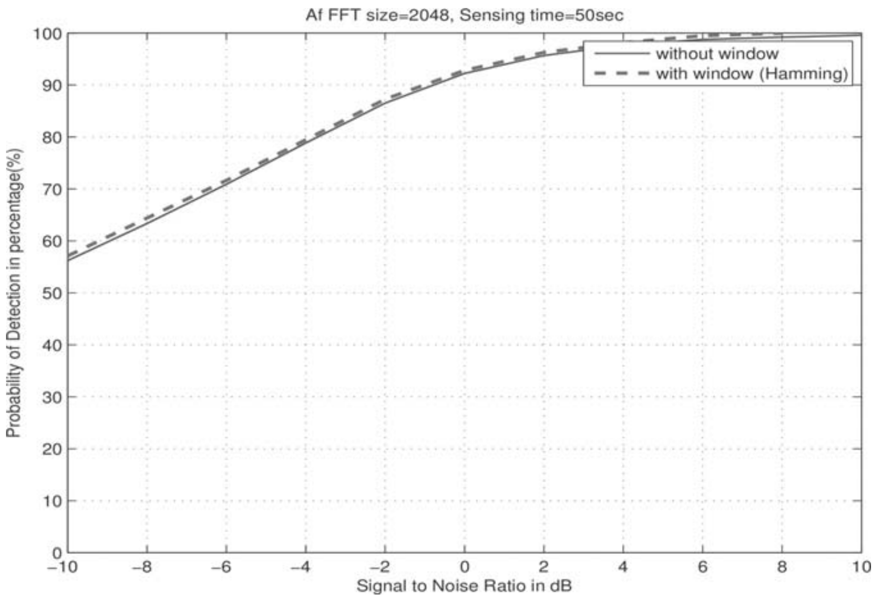


FIG. 6. SNR VS PROBABILITY OF DETECTION(WITH AND WITHOUT WINDOW)

4.4 Proof of Energy Efficiency through Complexity and Performance Analysis of Less Complex and Complex Algorithm

Complexity Analysis gives the number of adders and multipliers for the used FFT size [15]. As our proposed algorithm uses FFT for the transformation of continuous time signal into digital one, it is necessary to determine the complexity for the FFT size. It is calculated for both the versions of the proposed algorithm (complex and less complex) and is given in Tables 1-2**.**

From Tables 1-2, it is clear that complexity is directly related with the FFT size and the performance which is Probability of Detection. It is clear that complexities of the complex version of the proposed algorithm is much higher as compared to that of the proposed less complex algorithm. Although the performance difference between both of them is very small and negligible. Proposed algorithm (less complex) gives almost same result of detection as complex version of the proposed algorithm hence, we can save the addition of these complexities in algorithm which would obviously save computational energy. This is also proved in energy efficiency formula and the energy efficiency of the proposed algorithm has proved through this complexity analysis.

TABLE 1. PD VS N VS COMPLEXITY(WITHOUT WINDOW)

Probability of Detection	No: of Samples	Number of Adders	Number of Multipliers
100	2048	55297	55297
95	2048	94208	55297
90	2048	94208	55297
50	1024	43008	25601
25	512	19456	11777

TABLE 2. PD N NUMBER OF ADDERS NUMBER OF MULTIPLIERS

Probability of Detection	No: of Samples	Number of Adders	Number of Multipliers
100	2048	94208	59393
95	2048	94208	59393
90	2048	94208	59393
80	1024	43008	27649
70	512	19456	12801
50	512	19456	12801

4.5 Sensing Time Impact

Sensing time also plays a very important role in making system energy efficient. Large Sensing time reduces the chances of missed detection by providing more opportunity to SUs to access the spectrum. However, it is not always necessary to have large sensing time for better performance. It is desired to have some low (optimum) sensing time for transceivers at which same performance can be achieved. Results shown in Fig.3 are achieved when the sensing time was 50 seconds. The performance is also been observed by reducing the sensing time and we have achieved an optimum time (2 seconds) on which same performance is observed as was achieved when the sensing time was 50 seconds. Below is the performance result when the sensing time was 2 seconds.

The Graph of Fig. 7 shows the SNR vs Probability of Detection at two different sensing times. From Fig. 7, it is clear that performance is almost the same when the sensing time was 2 seconds, when compared with the performance when the sensing time was 50 seconds (Fig. 3). The decrement from 2 seconds sensing time will reduce the performance which can be seen in Fig. 6. The performance has reduced for sensing time=1 second (Fig. 7). Hence, it is not always required to have large sensing time, same performance can be achieved with low sensing time which can save sensing energy without introducing any complex computational scheme in the energy detection based spectrum sensing algorithms.

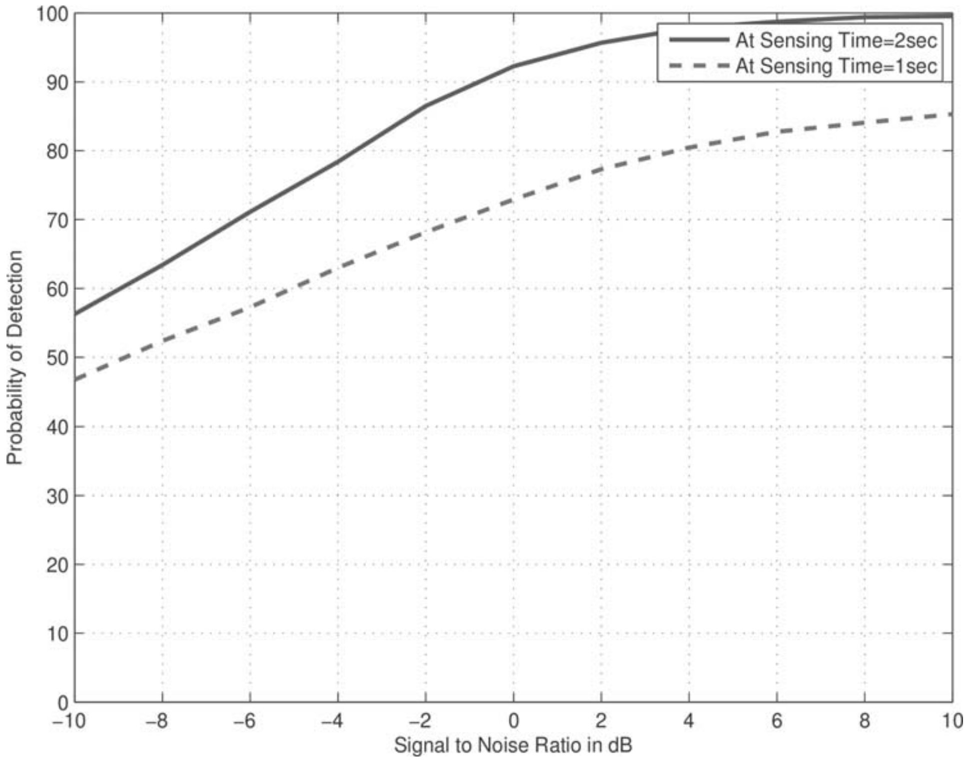


FIG. 7. SNR VS PROBABILITY OF DETECTION AT TWO DI_ERENT SENSING TIMES

5. CONCLUSIONS

In this paper an energy efficient spectrum sensing algorithm based on energy detection is proposed. In the proposed algorithm, the presence of PUs is observed in two scenarios Ideal (without noise) and noisy in order to find proper probability of detection. This technique is simple and effective to find the presence of PUs rather than using legacy complex energy detection techniques. The paper also present the method to set optimum sensing time in order to save sensing energy. With the help of the mathematical proof and simulations it is verified that the proposed algorithm works better than the legacy algorithms.

Also the comparison between the performance of the proposed algorithm (less complex and complex version) is evaluated. As is seen in Section 4.4, complex version of the proposed algorithm has more complexities as compared to that of the proposed (less complex) algorithm. These comparisons clearly shows the similarities in the results of proposed (less complex and complex) versions and hence it is proved that the proposed algorithm (less complex) is sufficient to determine presence of PUs with less computational complexities and with optimum sensing time. From the results obtained in Section 4, it is concluded that the proposed algorithm is suitable for CRs to be used in green communication paradigm.

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