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Energy Detector based Spectrum Sensing towards Efficient Detection of Primary User

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Spectrum sensing is the key factor of cognitive radio for efficient utilization of the spectrum resources by identifying and making use of spectrum holes i.e., unused licensed frequency band. The performance of available spectrum sensing techniques may degrade substantially in low signal to noise ratio, multipath fading & shadowing environments. An attempt has been made to implement a transmitter and receiver section for efficient spectrum sensing in cognitive radio environment. A primary user detection algorithm using energy detector-based spectrum sensing technique is designed to analyze the effect of message length on the identification of primary user. Input message of variable length have been modulated using binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) before transmission. Additive white Gaussian noise (AWGN) is added as it possesses wide range of frequency over the channel. The energy of the received signal has been determined by applying Welch Periodogram based power spectral density approach. The performance of the developed algorithm has been evaluated by comparing selected threshold with the computed energy level of the received signal. The results reveal that that power spectral density (PSD) amplitude (received energy) obtained for QPSK modulated messages is found to be less as compared to using binary phase shift keying for similar message lengths. The primary users are identified along with unused spectrum frequencies (spectrum holes) to be utilized by secondary users. This may lead to development of applications to determine spectrum utilization and subsequently the spectrum holes in cognitive environment for varying signal loads.

Keywords: Cognitive Radio, Energy Detector, Spectrum Sensing, Primary User, Secondary User, Spectrum Utilization, Signal Load

1. Introduction

Today's advancement in technology, growth in population and subsequent wireless applications are the primary reasons for increased demand of spectrum. The survey report by Federal Communications Commission indicates that some of the frequency bands of radio frequency spectrum are not utilized or partially utilized leading to spectrum scarcity. The reason cited for this is the use of conventional access. To overcome above issues, a new spectrum access technology called Dynamic Spectrum Access (DSA) also known as Cognitive Radio (CR) was introduced. The two categories of cognitive radio are full cognitive radio and spectrum sensing CR. In the full cognitive radio, wireless network will consider every single possible parameter (operating frequency, type of waveform, protocols, sensing time, delay time etc.). Whereas spectrum sensing cognitive radio usually considers only radio frequency spectrum. Cognitive radio has main two parameters. One is their cognitive capabilities, which define the capability to observe the environment to subsequently create, plan and orient itself. The other is re-configurability property, which defines capability of cognitive radio to be programmed with dynamism for each range of the radio environment. Four fundamental functions of cognitive radio include spectrum sensing, at this stage, cognitive radio continuously monitors the radio environment and geographically detects possible free frequency band. This is followed by spectrum decision, i.e., when to start its operations. For this cognitive radio, might use data from authorized policies and databases to improve the operations. The next is spectrum sharing, it can be performed by two methods, underlay and overlay. In underlay method of spectrum sharing, level of noise

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and interference is below the threshold values. In the overlay method, the unlicensed users share the frequency band which is already engaged by the licensed user. The last is spectrum mobility; in this case cognitive radio vacates the channel if the primary/licensed user is detected. Spectrum sensing techniques are classified into three main categories viz, transmitter detection, wideband spectrum sensing and null space-based cognitive radio. Transmitter detection techniques are further grouped in to matched- filter detection, blind detection/energy detection and cyclostationary detection technique. Energy/blind detection technique provides the information of absence or presence of signal just by measuring the value of energy level in the received signal. In cyclostationary technique, different signal modulation techniques like binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), amplitude modulation (AM) and orthogonal frequency division multiplexing (OFDM were introduced because of their cyclostationary feature. For large spectral bandwidths in MHz or GHz range wideband spectrum sensing techniques are introduced. Cooperative/Transmitter detection and interference-based detection are two main classifications of wideband spectrum technique. In null based technique, multiple antennas are used to find out the null space to transmit the signal with minimum effect of interference. Numerous spectrum sensing techniques and their implementations details have been explored. Many of the researchers discussed about the need of spectrum sensing and various methods to enhance the spectrum sensing so that utilization of available spectrum can be improved [30,33,38]. Multiple wireless services need to share radio spectrum. Careful planning and management could maximize the well-organized use of radio spectrum environment. The National regulatory agency has issued the radio spectrum to the individual users. For commercial or public interest, frequency bands are already licensed. Demand of wireless communication services are continuously increasing. This further increases the requirement of radio spectrum. To solve the problem of underutilization of the allocated spectrum and spectrum allocation congestion, cognitive radio approach has been proposed [1,34].In radio frequency environment cognitive radio is fully re-configurable and cognitively adapts itself to the communication environment. Cognitive radio does opportunistic spectrum access. The purpose of cognitive radio is to effectively use the radio spectrum with less interference with the licensed user [2,35]. While determination of primary receiver many issues has been faced i.e. Interference, hidden node detection problem, spectrum sharing at vertical and horizontal sections. Basic three on-line tasks of cognitive radio have been introduced. The first one is related to radio scene analysis which consists of finding the available spectrum holes and in radio environment calculating the interference temperature (availability of RF power at receiving antenna to amount of power delivered to a receiver). This is followed by channel identification, which provides the idea about the capacity of available channel at transmitter.The final task is dynamic control of power transmission and management of spectrum [3,36]. Different aspects are considered within the field to obtain an optimal system. It includes spectrum holes identification, spectrum management, sharing and mobility of spectrum. During spectrum sensing process, cognitive radio detects the unutilized frequency band by the licensed/primary users [27,37]. After sensing, spectrum management and other functions are introduced. Spectrum sensing techniques are classified as cooperative, non-cooperative and interference-based sensing. By using numerous cognitive sensors, the cooperative sensing can raise the strength of the network [4]. Feasible implementation can be achieved by using radio – frequency front–end and Analog/Digital converter [5]. Detection of primary user and radio sensitivity can be improved by using digital signal processing-based spectrum estimation techniques. Due to fading and shadowing, reliable detection of licensed users is difficult in case of individual sensing. Probability of interference for high priority users can be minimized by cooperative decision making. In wireless channel, phase and amplitude of signal may change with the effect of fading. Different fading models like Rayleigh, Nakagami-n, Rice and lognormal have been introduced for analyzing the behavior of spectrum sensing techniques. In case of lognormal fading, energy detector provided better performance for different ranges of signal to noise ratio [6]. Coordination in sensing is very important factor for accurate sensing, however in the absence of time synchronization, coordination would become a very difficult factor to be achieved at the MAC (Medium access control) layer [7]. Exchange of information from several CR users may be integrated, therefore sensing information dissemination is also very important in the sensing. At MAC layer by using efficient power control techniques, adaptive modulation and maintaining trade–off between actual transmission time & allocated time, more efficient sensing could be achieved while maintaining quality of service requirement to prevent performance degradation.

It has been witnessed that on the basis of signal detection, spectrum sensing techniques are classified as transmitter detection/signal detection sensing techniques. In these techniques, position of the licensed user is not known and no communication exists between the different secondary users. Matched filtering, energy detector and cyclo-stationary detection are the subcategories of transmitter detection technique [26,28]. Co-operative sensing techniques are those in which the communication between the different secondary users takes place to give the decisions. Multipath fading effects, shadowing and penetrations due to buildings are the reasons that affect primary signal detection [29]. Interference based sensing technique are used to specify and manage interference at the receiver interference temperature model. Spectrum sensing concepts could be re-evaluated by considering the different dimensions like frequency, time; code, angle and geographical space [25]. The summary of energy detection-based spectrum sensing techniques to identify primary user are provided in Table 1.

Table 1: Energy Detector based Spectrum Sensing Techniques

Spectrum sensing Techniques	Features	Remarks
For finite time interval [FTT] the value of energy can be calculated by using Shannon sampling theorem [8].	For Additive white Gaussian noise (AWGN), unknown deterministic signal could be found out and detector consists of square law device and time integrator.	This technique is beneficial for large time bandwidth.
Arbitrary positive power operation was implemented instead of squaring operation [9].	Power operation performance depends upon different parameters i.e., probability of false alarm (P_{fa}), sample size, signal to noise ratio (SNR), probability of detection (P_d).	Performance of energy detector could be improved by the best selection of optimum power operation.
Windowing technique was studied for setting the threshold value and new non-orthogonal transform technique also has been incorporated for setting the threshold value [10].	Gaussian distribution considered as the input.	Noise statistics were utilized for setting up of the threshold value.
Quadrature phase shift keying modulation (QPSK) and Rayleigh fading were incorporated [11].	Energy detection and correlation matrices are used in linear form toto be evaluated via optimal hybrid metrics.	Applicable for low signal to noise ratio (SNR) and larger sample sizes.
Selection of dynamic threshold [12].	Sensitivity improved while incorporating dynamic threshold detection.	Better performance was achieved.
Periodogram approach was incorporated for power spectrum estimation [13-15].	Squared magnitude operation of the FFT has been implemented. Two-bit quantization, soft decision method, hard decision, non-quantized combined with additive white Gaussian noise, Less complexity.	In the frequency domain power spectrum-based analysis, better performance is achieved.

Modified Energy detection technique using modified periodogram & Welch methods by incorporating various type of windowing function [16].	Used narrow-band FM-signals	Better performance achieved as compared to conventional method.
Power spectral density estimation performed by simplified discrete Fourier transform (DFT) matrices [17].	In conversion of time to frequency domain no requirement of multiplication.	Complexity is less as compared to simple DFT technique.
Analyzed the performance of energy detector spectrum sensing technique under additive white gaussian noise (AWGN) & fading channels using sampling theory-based approach [18,19].	Performance under AWGN and fading channels	Detection capability improved by employing Square law combining (SLC) and square law detection (SLD) diversity schemes.
Detection of primary user by using equal gain combining (EGC) techniques for Nakagami-m fading channels [20].	Performance under number of diversity branches and time bandwidth was evaluated.	Energy threshold values were selected to obtain a specified probability of false alarm rate.
Double threshold detection [21].	Low value of probability of misdetection as increases the distance between PU (primary user) and CU (cognitive user)	By selecting maximum SNR channel, cognitive radio received the signals and improved the performance of detection
For Rayleigh and Nakagami-m channels, average missed detection (AMD) probability was determined [22].	For AWGN channel, optimal value of detection threshold was determined	Low SNR has been witnessed
For Rayleigh fading channel used Welch's periodogram approach [23].	Cooperative and single node scenarios were considered.	Improvement in sensing performance by cooperation between the different cognitive nodes is witnessed.
Multipath fading & shadowing effect was considered over the channel [24].	Two fusion techniques i.e., data and decision fusion were considered	Performance of detection probability considered due to use of more cognitive relays has been analyzed.

The research paper is organized in five subsections. Section-II of this research paper summarizes materials & methods to identify the primary user and different techniques utilizing energy detector spectrum sensing technique.

Result and subsequent detailed analysis are discussed in section-III. Comprehensive discussion of the results is discussed in section IV followed by a conclusion and future scope in section V

2. Materials and Methods

A system has been implemented for determination of primary user for efficient spectrum sensing. Figure 1 shows the block diagram of a system to detect primary user using energy detector-based spectrum sensing technique. The system implementation consists of three main stages namely transmitter section, channel and receiver section while incorporating spectrum sensing for detection of primary user and spectrum holes.

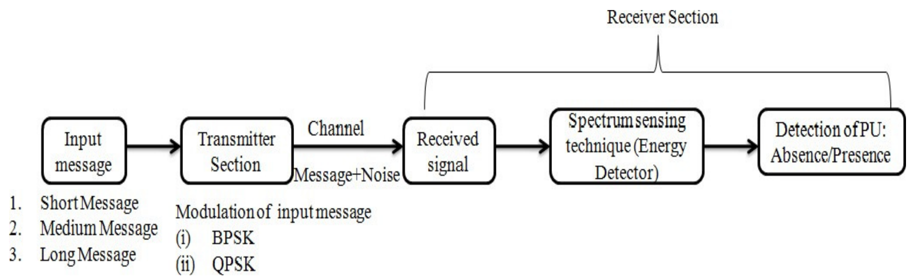


Figure 1 : Block diagram to detect primary user using spectrum sensing

2.1 Transmitter Section

Transmitter section includes selection of signals/messages to be transmitted with appropriate signal modulation block. The input messages of variable length (short, medium and long) have been considered to analyze the effect of packet length and number of packets on spectrum utilization. The operating frequency, sampling frequency, number of samples per symbol period for input message has been selected. At first, input messages are filtered using raised cosine band pass filter with appropriate roll off factor. It helps in minimizing the inter-symbol interferences. This is followed by modulation of input message using two digital modulation techniques i.e., binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) before message transmission. Binary phase shift keying separates two phases of input message by 180 degree and encodes message as one bit per symbol (binary bit1 for in-phase and bit 0 for 180degree out of phase) as given in equation (1). On the other hand, in QPSK the input message is encoded as 2bits/symbol (00, 01, 10 and 11) as clear from equation (2) and is best suited for high data rate applications. Once modulated, the messages are transmitted over selected channels where noise (Additive white Gaussian noise AWGN is considered in this research) gets added to the transmitted message.

$$\mathbf{S_n}\ (t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f t + \pi(1-n)), \quad n = 0, 1 \tag{1}$$

$$\mathbf{S_n}\ (t) = \sqrt{\frac{2E_s}{T_s}}\cos(2\pi f_c t + (2n-1)\tfrac{\pi}{4}, \quad n = 1, 2, 3, 4 \tag{2}$$

Here, Eb represents energy/bit, Tb denotes bit duration, f is the frequency of the base -band, fc is the frequency of carrier band and Es = nEb (Energy /symbol with n bits).

2.2 Receiver section

At the receiver section, modulated message embedded with noise is received. The energy of the received signal is calculated using Welch's periodogram approach. This is a non-parametric technique to calculate the power spectral density of the received signal. Let r (n) represents the received message which is assumed to be sampled for specific bandwidth and time period. The received message is constituted of transmitted message with added AWGN noise as represented by equation (3).

$$r(n) = m(n) + w(n) \tag{3}$$

where m(n) is the input message, w(n) is additive white Gaussian noise (AWGN). Decision of presence or absence of primary user depends upon the energy of the received message (ER) obtained by equation (4) and set threshold value (λ) represented in equation (5).

$$E_R = \frac{1}{Ns}\sum_{n=1}^{Ns}(r[n])^2 \quad (4)$$

Here, received input message is represented by r(n), Ns denotes the total number of samples, ER is the energy of the received message. When the large number of samples are available and received message is independent in nature then in this case received message ER followed the normal distribution. In normal distribution, noise variance and signal variance are the factors responsible for presence or absence of primary users.

2.3 Spectrum Sensing

This includes the detection of presence or absence of primary user signal in the given frequency band. To detect this energy detector-based spectrum sensing technique has been used here. Figure 2 shows block diagram of spectrum sensing technique using energy detector.

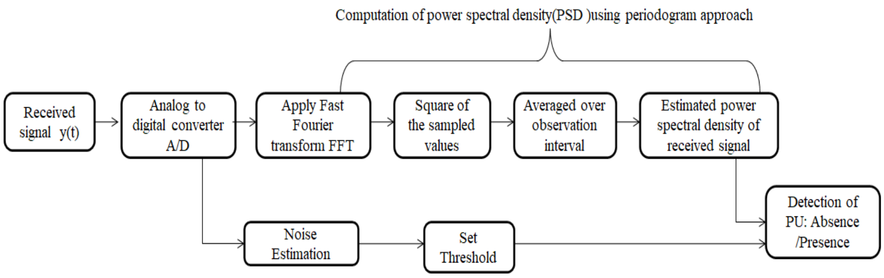


Figure 2: Energy Detector based Spectrum Sensing

In this spectrum sensing technique, no prior information of the primary user signal is required. The energy of received signal is calculated first by sampling it using analog to digital converter followed by the application of fast Fourier transform. This calculated value is compared with the set threshold (λ) which is obtained using the relation as given in equation (5).

$$\lambda = \sigma_w{}^2\,(Q^{-1}(P_{fa})\sqrt{2N_s} + N_s) \quad (5)$$

where σw= Standard deviation of the noise

Ns= Number of samples

Pfa = Probability of false alarm (defined as rate of false detection of primary user over the total number of attempted trials.

Q^{-1} = inverse Q-function i.e. $\frac{1}{2\pi}\int_X^{\infty} \exp(\frac{-u2}{2})$du (This special function represents the complement of (SNDF) standard normal distribution function and also gives the information of the Gaussian distribution).

In this work, additive white Gaussian noise (AWGN) is considered which is a random noise having wide range of frequency over the channel. The absence or presence of primary user is identified by comparing the value of both the set threshold & calculated threshold/received energy. Accurate setting of threshold depends upon the level of noise. The absence of primary user is denoted by $H0$, or presence of primary user is denoted by $H1$ and is as explained below:

Case I: If set threshold, λ > calculated threshold or PSD of received message: (Primary user absent)

Case II: If set threshold, λ < calculated threshold or PSD of received message: (Primary user present)

The algorithm to determine the absence or presence of primary user is detailed as follows:
Step1: First, select the input signal /message and apply selected modulation technique before transmission of message.
Step 2: Calculate energy of the received message (transmitted message+ noise) using Welch's periodogram approach at receiver section.
Step 3: Select threshold level using the equation (5).
Step 4: Compare the set threshold as obtained in step 3 with energy level of received signal as determined in step 2.
Step 5: If received signal energy > set threshold: Primary user is present else primary user is absent.

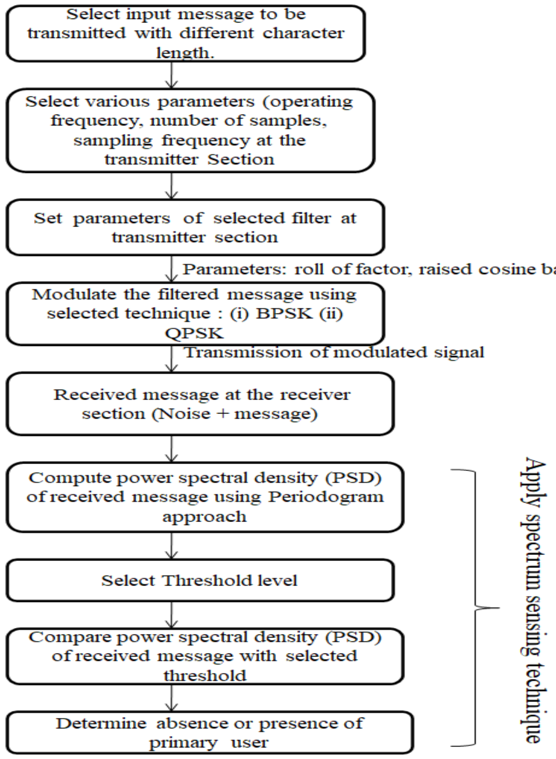


Figure 3: Framework to detect presence/absence of primary user

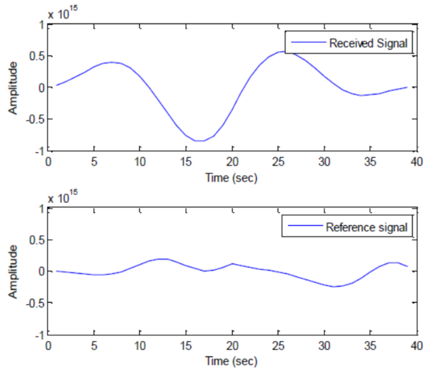
The detailed framework is depicted in flowchart as shown in figure 4. The proposed methodology firstly included the implementation of transmitter section. After that implementation of efficient energy detection technique takes place. An efficient energy detection technique is implemented to detect the primary users which subsequently determines the unused (spectrum holes) and used frequency bands for efficient spectrum utilization.

3 .Results and analysis

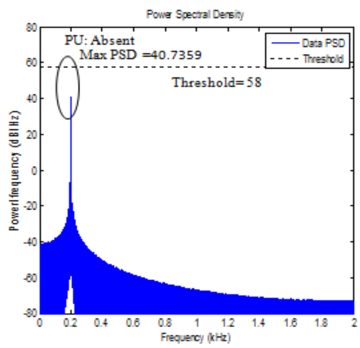
This section presents the results obtained after implementation of designed algorithm for detection of primary user using energy detector-based spectrum sensing technique. Input messages of different character length have been selected for transmission and corresponding results in terms of power spectral density are analysed. The selected input message is modulated using binary phase shift keying first & the performance is compared by modulating input messages later using quadrature phase shift keying. Threshold selection is made to evaluate the effect of character length on detection of primary user in energy detector spectrum sensing technique. The operating frequency ($f0$) for input message has been selected as 200Hz, sampling frequency as 4000Hz (fs=20*$f0$), number of samples per symbol period are set as L=100 and roll off factor for the raised cosine filter is set as alpha=0.5. The square root cosine filter of length N+1 has been designed where (N=8*L). The detection (absence/presence) of primary user with subsequent results and analysis is elaborated.

3.1 Primary user detection with BPSK modulation technique for variable character length

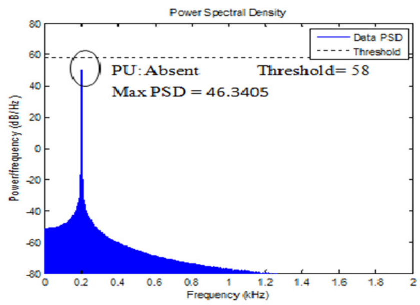
The initial length of input message is selected as 10,40 and 120 text characters. The transmitted and received messages are plotted in figure4a. The energy of received message is computed using Welch's periodogram approach. The power spectral density (PSD in db/KHz) of received message for character length 10-short, 40-medium, and 120-long is obtained & plotted as shown in figure4b, 4c and 4d, respectively. The maximum PSD value of short message is found to be 40.7359db/KHz, medium message is found to be 46.7405db/KHz and that of long message is found to be 49.7216 db/KHz as observed from figure 4a, 4b and 4c, respectively. For all messages (short, medium and long), the received energy in terms of PSD is found to be less as compared to the set threshold (58 db/KHz), therefore, primary user is absent for all available frequency slots (0-2 KHz). This indicates that entire range of frequency slots is available to be utilized by secondary users (SU) or cognitive users. These are also known as spectrum holes.



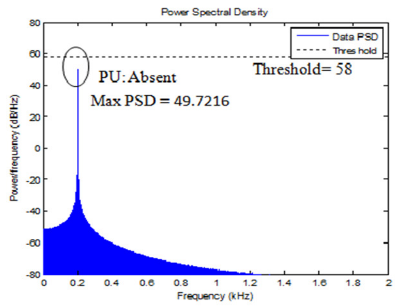
a. Reference & received signal



b. PSD of short message (db/KHz)



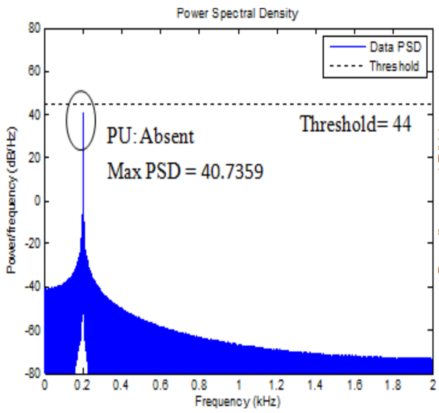
c. PSD of medium message (db/KHz)



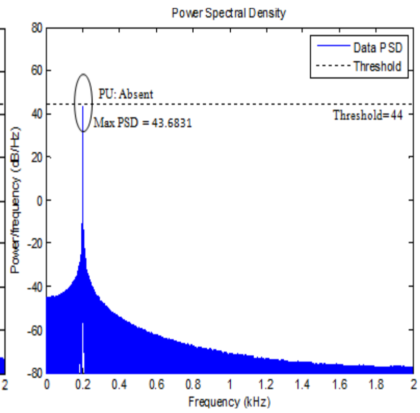
d. PSD of long message (db/KHz)

Figure 4: Reference/received signal and PSD plots for short, medium and long messages with set threshold = 58db/KHz

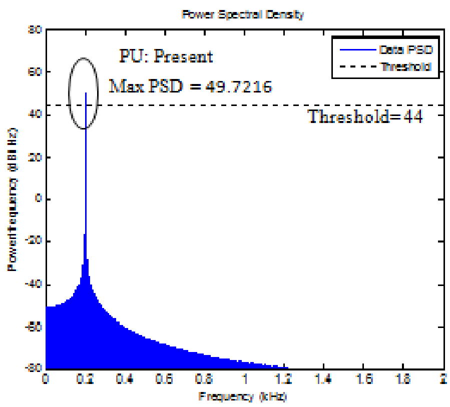
In figure 5a and 5b, maximum PSD of received message is observed as 40.7359db/KHz and 43.6831db/KHz for short and medium length message, respectively. These PSD amplitudes are found to be lower than the value of set threshold (44 db/KHz) and this shows that primary user is absent as depicted in figure 5a and 5b. However, high peak as visible in figure 5c indicates the presence of primary user as peak PSD amplitude of received message is 49.7216 db/KHz which is higher than the set value of threshold (44 db/KHz). Results reveal that frequency slot at 0.2 KHz is occupied by the user, which means this frequency is in use and rest of the frequency slots are available for secondary user.



a. PSD of short message (db/KHz)



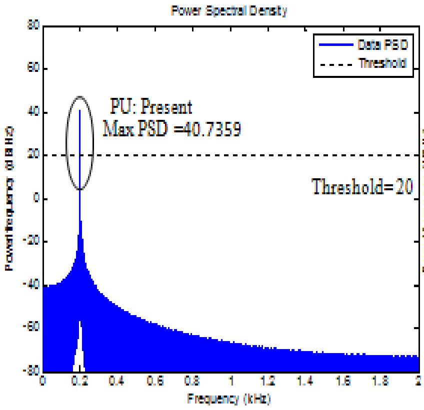
b. PSD of medium message (db/KHz)

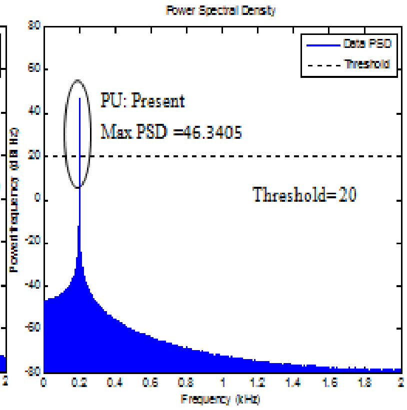


c. PSD of long message (db/KHz)

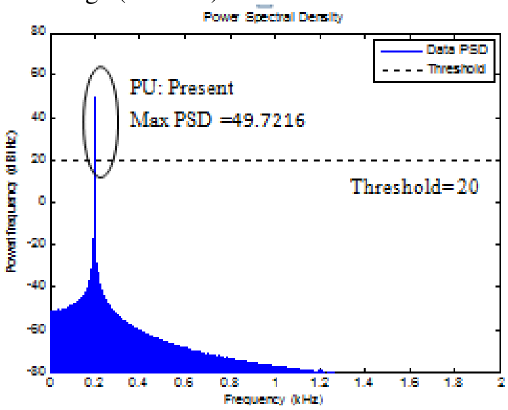
Figure 5: PSD plots for short, medium and long messages with set threshold = 44db/KHz

In the third scenario, the threshold value is set at 20 db/KHz. The received message energy amplitude in terms of maximum PSD is found to be greater than set threshold value for all the three input message lengths viz., short (40.7359db/KHz), medium (46.3405db/KHz) and long (49.7216db/KHz), respectively. This indicates the presence of primary user and the frequency slot at 0.2KHz is occupied by the primary user. However, other than 0.2KHz, all the frequency slots are found as unused bands. These spectral holes could be searched by the cognitive radio and can be allocated automatically to the secondary users.





a. PSD of short message (db/KHz) b. PSD of medium message (db/KHz)

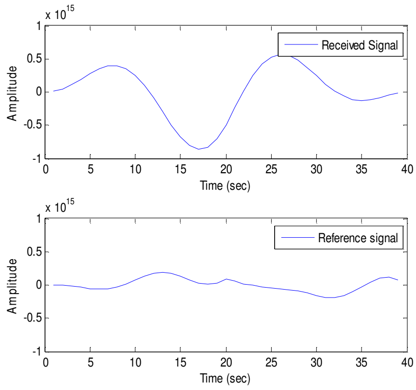


c. PSD of long message (db/KHz)

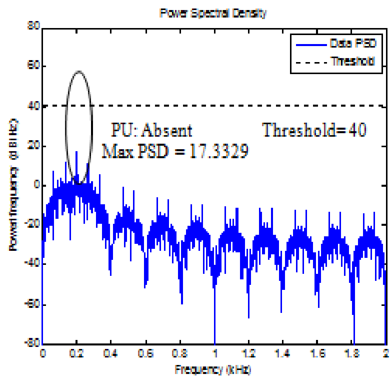
Figure 6: PSD plots for short, medium and long messages with set threshold = 20db/KHz

3.2 Primary user detection with QPSK modulation technique for variable character length

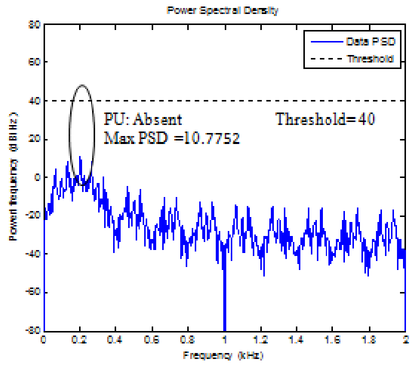
In this case, the input message of variable character length is modulated using quadrature phase shift keying technique. Here, input message is encoded as 2bits/symbol (00, 01, 10 and 11). The initial length of input message is selected as 10, 40 and 120 characters. The transmitted and received messages (transmitted message + AWGN noise) are plotted in figure 7a. The energy of received message is computed using Welch's periodogram approach. The power spectral density (PSD in db/KHz) of received message for character length 10-short,40-medium, and 120-long is obtained & plotted as shown in figure7b, 7c and 7d, respectively.



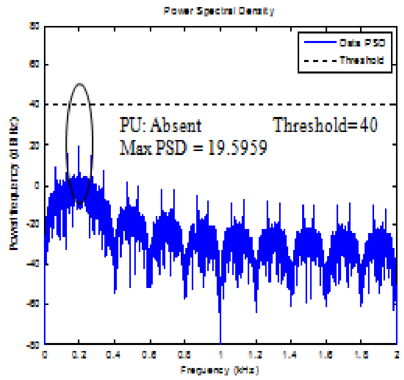
a. Reference & Received Signal



b. PSD of short message (db/KHz)



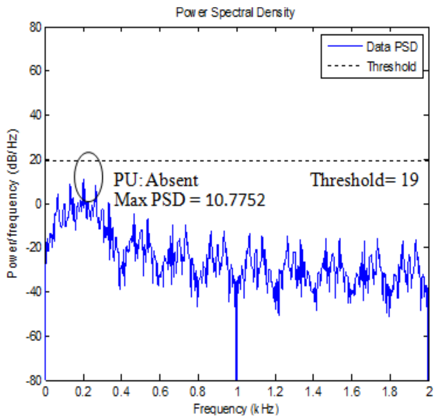
c. PSD of medium message (db/KHz)



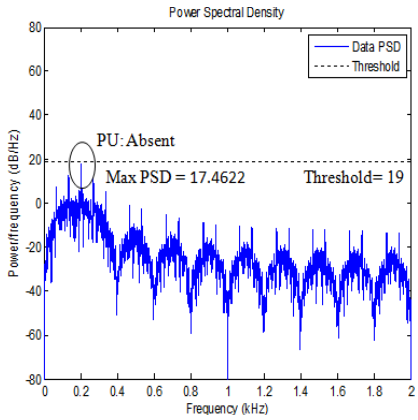
d. PSD of long message (db/KHz)

Figure7: Reference/received signal and PSD plots for short, medium and long messages with set threshold =40db/KHz

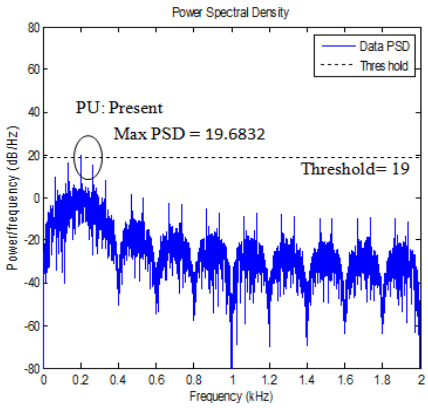
It is depicted from figure 7b that maximum PSD amplitude of received message is 10.7752db/KHz which is lower than the set value of threshold i.e. 40db/KHz. Hence, the primary user is absent for entire frequency range (0-2KHz) and empty slots are available for the secondary user. Here, it is observed that frequency slots at 1 kHz and 2 KHz are efficiently used by the SU. For medium length message, the maximum PSD amplitude of received message is 17.3329db/KHz which is also lower than that of the set threshold (40db/KHz) as shown in figure 7c. Therefore, all frequency slots are available for SU. It is also observed that frequency slots at 1KHz, 1.8 KHz and 2 KHz are efficiently utilized by secondary user (figure 7c). For long length message, the maximum PSD amplitude of received message is 19.5959db/KHz which is again lower than that of the set threshold (40db/KHz) as shown in figure 7d. Therefore, all frequency slots are available for SU. It is also observed that frequency slots at 1KHz and 2 KHz are efficiently occupied by secondary user (figure 7d).



a. PSD of short message (db/KHz)



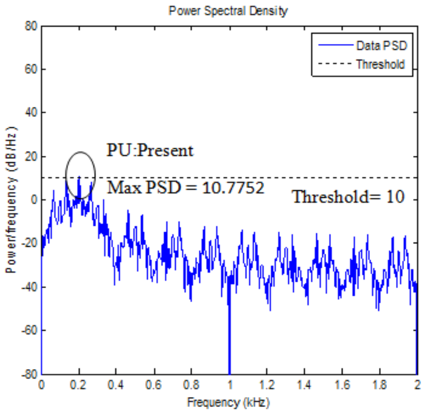
b. PSD of medium message (db/KHz)



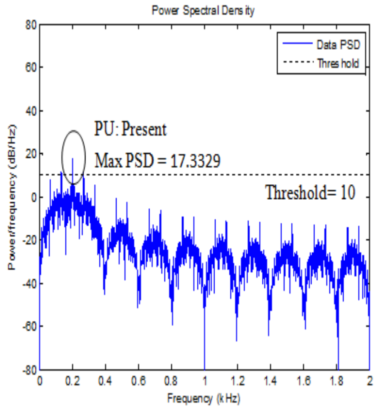
c. PSD of medium message (db/KHz)

Figure 8: Reference/received signal and PSD plots for short, medium and long messages with set threshold = 19db/KHZ

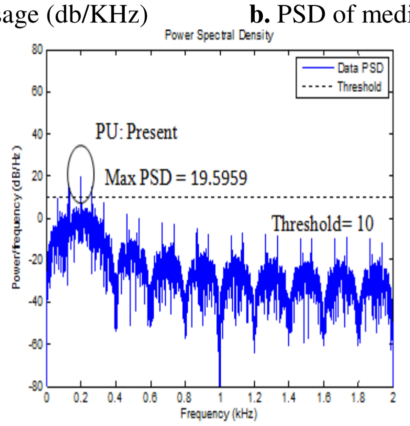
In next case, the threshold value is set at 19db/KHz. To analyse the effect of this threshold value, the power spectral density of received message with character length 10-short, 40-medium, and 120-long is obtained & plotted in figure8a, 8b and 8c, respectively. For short and medium length messages, it is found that primary user is absent in both the cases and the peak PSD amplitude of received message is 10.7752db/KHz (figure 8a) and 17.4622db/KHz (figure 8b), respectively. These values are lower than the set value of threshold (19db/KHz). It is also observed that 1KHz frequency slot and 2KHz frequency slots have been efficiently used by the secondary users. Further for long message length, maximum PSD amplitude of received message is found to be 19.6832db/KHz which is greater than the set value of threshold (19db/KHz). This indicates the presence of primary user and as observed from figure 8c, frequency slot at 0.2 KHz got occupied by the primary user whereas other left-over frequency slots are available for secondary users. It is observed that frequency slots at 1 KHz and 2 KHz have been efficiently used by the SU.



a. PSD of short message (db/KHz)



b. PSD of medium message (db/KHz)



c. PSD of long message (db/KHz)

Figure 9: Reference/received signal and PSD plots for short, medium and long messages with set threshold = 10db/KHz

In the last scenario (with set threshold as 20 db/KHz) the power spectral density (PSD) of received message with character length 10-short, 40-medium, and 120-long is obtained & plotted as shown in figure9a, 9b and 9crespectively. Primary user is found to be present in all the cases with respective maximum PSD amplitudes as 10.7752db/KHz,17.3329db/KHz and 19.5959db/KHz which are greater than the set value of threshold. Frequency slot at 0.2 KHz is found to be occupied by the primary user and frequency slots 1 KHz , 1.8 KHz and 2 KHz are occupied by the secondary users. Once any slot is assigned to the users, system will not allow any other user to use that slot and will free the spectral slots one by one.

Table 2: Maximum power spectral density amplitudes in energy detector spectrum sensing technique

Input message length (Number of character)	Modulation (BPSK/QPSK)	Threshold	Maximum power spectral density (db/KHz)	Determination of Primary User
10	BPSK	58	40.7359	PU absent
10	BPSK	44	40.7359	PU absent
10	BPSK	20	40.7359	PU Present
10	QPSK	40	10.7752	PU absent

10	QPSK	19	10.7752	PU absent
10	QPSK	10	10.7752	PU Present
40	BPSK	58	46.3405	PU absent
40	BPSK	44	43.6831	PU absent
40	BPSK	20	46.3405	PU Present
40	QPSK	40	17.3329	PU absent
40	QPSK	19	17.3329	PU absent
40	QPSK	10	17.3329	PU Present
120	BPSK	58	49.7216	PU absent
120	BPSK	44	49.7216	PU Present
120	BPSK	20	49.7216	PU Present
120	QPSK	40	19.5959	PU absent
120	QPSK	19	19.5959	PU Present
120	QPSK	10	19.5959	PU Present

The maximum PSD amplitude values for different length messages for distinct threshold values and modulation techniques (both BPSK and QPSK) are tabulated in table 2. Following are the key observations:

a. Received power of message > set threshold = Primary User (PU) is present. Received power of message < set threshold =Primary User (PU) is absent.
b. It is observed that maximum power spectral density (PSD) amplitudes obtained for received messages modulated using quadrature phase shift keying is found to be less as compared to using binary phase shift keying for similar message lengths. This indicates that at even low threshold levels, the presence of primary user (PU) can be detected, in case of QPSK modulation.
c. Range of frequencies at which maximum received power amplitude is below the threshold value indicates unused frequency range else frequency band is occupied.
d. BPSK modulation technique may help in covering longer distances because of high power content and QPSK modulation technique is applicable for high data rate applications thereby increasing the usage of spectrum.

In this work, primary user detection by incorporating energy detector-based spectrum sensing algorithm using Welch's periodogram approach has been implemented. The performance has been evaluated by considering short, medium and long character length messages as input and these messages are modulated using BPSK & QPSK modulation techniques. In previous researches, detection of spectral holes has been done by automatic insertion of primary user while secondary users can use the empty slots without producing any interference [31]. Others, also implemented the energy detector spectrum sensing technique by creating the primary users in Simulink model which is based upon FFT and Welch periodogram approach but performance of energy detector spectrum sensing technique degrades with increasing amount of noise. However, by using QPSK modulation technique this limitation could be minimized [32]. In future work, other strategies shall also be explored for utilizing the spectrum in more efficient manner.

4. Conclusions

This research includes implementation of energy detector-based spectrum sensing technique for variable message lengths to identify spectrum holes. This has been selected because of its robustness, less complexity and low sensing time requirement as compared to other spectrum sensing techniques. Detection of primary user in energy detector spectrum sensing has been performed by considering different modulation techniques (BPSK and

QPSK) for input messages of variable length and proper selection of threshold. Determination of primary user is solely dependent upon the received energy amplitude with respect to selected frequency band. Proper selection of modulation technique may enhance the usage of spectrum. Simulation results revealed that better detection of primary user takes place in QPSK instead of BPSK. Detection of primary user can be enhanced by introducing advanced detection schemes. Further to reduce the interference, shadowing and multipath effects cooperative sensing may also be introduced instead of individual sensing. In future significant improvements in spectrum sensing technique shall be explored by adopting other modulation techniques, dynamic threshold selection, hybrid detection methods at receiver end and incorporating machine learning algorithms for automated detection of primary user & subsequent spectrum holes.

5. **Future Scope**

In future significant improvements in spectrum sensing technique shall be explored by adopting other modulation techniques, dynamic threshold selection, hybrid detection methods at receiver end and incorporating machine learning algorithms for automated detection of primary user & subsequent spectrum holes.

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