Spectrum Monitoring Using Energy Ratio Algorithm for OFDM-Based Cognitive Radio Networks

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Abstract: In this paper we are monitoring spectrum of Orthogonal Frequency Division Multiplexing (OFDM) based cognitive radios. Cognitive radio is a novel approach for improving the utilization of the radio electromagnetic spectrum. When a frequency band has primary and secondary users, the cognitive radios of the secondary users must monitor the band and be ready to cease their transmissions if a primary user's radio begins to transmit. in which the primary user reappearance can be detected during the secondary user transmission.

Here we have provided decision threshold parameter based on Receiver Operating Characteristics (ROC) which helps in the process of spectrum monitoring algorithms for Orthogonal Frequency Division Multiplexing (OFDM) based cognitive radios by which the primary user reappearance can be detected during the secondary user transmission.

The cognitive engine makes intelligent decisions and configuring the radio and PHY parameters. Based on the information from policy engine as well as local and network spectrum sensing data, the transmission opportunities are identified by the decision unit. When the PHY layer is concerned, CR can communicate with various radio access technologies in the environment, or depending on the environmental characteristics it can improve the communication quality, by simply changing the configuration parameters of the OFDM system parameters) and the radio frequency (RF) interface.

The proposed technique reduces the frequency with which spectrum sensing must be performed and greatly decreases the elapsed time between the start of a primary transmission and its detection by the secondary network. This is done by sensing the change in signal strength over a number of reserved OFDM sub-carriers so that the reappearance of the primary user is quickly detected.

KEYWORDS**:** cognitive radio network, orthogonal frequency division multiplexing (OFDM), multiple input multiple, energy ratio algorithm, Receiver Operating Characteristics (ROC)

I. INTRODUCTION

The radio spectrum is becoming increasingly congested everyday with the increasing number of wireless devices. Also wide ranges of spectrum is rarely used where as other bands are heavily used. The unoccupied portions of the licensed spectrum can only be used by licensed users. CR system uses its gained experience to plan future actions and adapt to improve the overall communication quality and meet user's needs. Thus a CR can be defined as an intelligent wireless system that is aware of its surrounding environment through sensing and measurements. CR autonomously exploit locally unused spectrum to improve spectrum utilization. CR's ability to sense and be aware of its operational environment, and dynamically adjust its radio operating parameters accordingly can be achieved by making the physical layer (PHY) highly flexible and adaptable. One of the most widely used technologies in current wireless communications systems is a multicarrier transmission known as orthogonal frequency division multiplexing (OFDM).OFDM can overcome many problems that arise with high bit rate communications, the biggest of which is time dispersion. The symbol stream that bears data is split into several lower rate streams and these streams are transmitted on different carriers. This splitting increases the symbol duration by the number of orthogonally overlapping carriers (subcarriers), multipath echoes affect only a small portion of the neighboring symbols.

Nowadays, static spectrum access is the main policy for wireless communications. Under this policy, fixed channels are assigned to licensed users or primary users for special use while unlicensed users or secondary users (SUs) are prohibited from accessing those channels even when they are unoccupied. The idea of a cognitive radio was developed in order to achieve more efficient utilization of the RF spectrum. One of the main approaches utilized by cognitive networks is the interweave network model in which secondary users seek to opportunistically use the spectrum when the primary users are idle. Primary and secondary users are not allowed to operate simultaneously. In this method, secondary users must sense the spectrum to identify whether it is available or not prior to communication. If the PU is idle, the SU can then use the spectrum, but it must be able to detect very weak signals from the primary user by monitoring the shared band in order to quickly vacate the occupied spectrum. During this process, the CR system may spend a long time, known as the sensing interval, during which the secondary transmitters are dumb while the frequency band is sensed. Since the CR users do not utilize the spectrum during the detection time, these periods are also called quiet periods (QPs). In the IEEE 802.22 system, a quiet period consists of a series of consecutive spectrum sensing period using energy detection algorithm to determine if the signal level is larger than a predefined value, which indicates a non-zero probability of primary user transmission. The energy detection is followed by feature detection to distinguish whether the source of energy is a primary user or noise or some disturbance. This mechanism is repeated periodically to monitor the spectrum. Once the PU is detected, the SU abandons the spectrum for a finite period and select another valid spectrum band in the spectrum pool for communication. If the secondary user must periodically stop communicating in order to detect the emergence of the PU, two important effects should be studied. During quiet periods, the SU receiver may lose its synchronization to the SU transmitter which causes an overall degradation in the secondary network performance. This is a problem when the radical communication

technique is sensitive to synchronization errors as in OFDM. The throughput of the secondary network during sensing intervals is minimized to zero which degrades the Quality of Service for those real-time applications like Voice over IP (VoIP).
The impact becomes more severe if the duration of the sensing intervals is too large as the average throughput of the secondary network becomes very low. On the other hand, if this duration is too small, then the interference to the primary users is increased since spectrum sensing does not provide information about the frequency band of interest between consecutive sensing intervals. In this area, there have been researching efforts which attempt to reduce the time duration for spectrum monitoring by jointly optimizing the sensing time with the detection threshold. The primary user throughput statistics are considered to prevent the primary user while the sensing time is minimized.

II. CONVENTIONAL SYSTEM

In conventional systems, traditional spectrum sensing is applied once before the SU communication and is not be repeated again unless the monitoring algorithm indicates that a primary signal may be present in the band. If monitoring determines correctly that there is no primary signal in the band, then the time that would have been used performing spectrum sensing is used to deliver packets in the secondary network. Therefore the spectrum efficiency of the secondary network is improved. If spectrum monitoring identifies a primary signal in the band during a time period in which spectrum sensing would not have been scheduled, then the disruption to the primary user can be terminated more quickly and hence the effect of secondary communications on the Primary user is reduced. Based on this description, the SU receiver should follow two consecutive phases, specially sensing phase and monitoring phase, where the former is applied for a predefined period.

III. SYSTEM MODEL

The secondary user physical layer model is designed in order to investigate and verify our spectrum monitoring algorithm.
This model is very close to the OFDM system. At the transmitter side, data coming from the source is firstly segmented into blocks where each block is randomized, channel encoded, and interleaved separately. After interleaving, the data is modulated by the constellation mapper. The frequency domain OFDM frame is constructed by combining: (a) One or more training symbols or preambles that are used for both time and frequency synchronization at the receiver side. (b) The modulated data. (c) The BPSK Modulated pilots which are used for data-aided synchronization algorithms employed by the receiver. Each Ns encoded complex data symbols generated by the frame builder are used to construct one OFDM symbol by employing the IDFT block that is used to synthesize the OFDM symbol, where Ns denotes the number of sub-carriers per one OFDM symbol. Thus, the nth time-domain sample of the mth symbol can be expressed as given by (1) where C(k,m) is the modulated data to be transmitted on the mth OFDM symbol with the kth sub-carrier.

$$(s,m) = \frac{1}{\sqrt{Ns}} \sum_{k=-Ns/2}^{\frac{Ns}{2}-1} C(k,m) e^{j2\pi kn/Ns} \qquad \ldots (1)$$

To reduce the effect of Inter-Symbol Interference (ISI), the last Ng samples of the time domain OFDM symbol are copied to the beginning of the symbol in order to form a guard time or cyclic prefix. Therefore, the OFDM block has a period of Ts =(Ns + Ng)/Fs where Fs is the sampling frequency. At the receiver, the inverse blocks are applied. After timing synchronization (frame detection, start of symbol timing, and SFO estimation and compensation) and frequency synchronization (CFO estimation and correction), the cyclic prefix is removed. Then, the received OFDM symbol is transformed again into the frequency domain through an Ns point DFT. The channel is then estimated and the received data is equalized. The complex data output is then mapped to bits again through the De-mapper. De-interleaving, decoding, and De-randomization are applied later to the received block to recover the original source bits
In our model, the fusion node constructs OFDM frames in the downlink path such that the same pilots are transmitted to all slaves but the data sub-carriers are allocated in time and frequency for different users based on a predefined scheduling technique. For the return path, Orthogonal Frequency Division Multiple Access (OFDMA) is assumed to divide the spectrum and the time into distinct and non-overlapping channels for different slaves, so that interferences between the slaves is avoided. The fusion node fully controls the timing of each slave, possibly by letting the slave know the required time advance or delay, so that the combined signal from all slaves seem to be synchronized at the fusion node receiver. In this case, the fusion node can convert the signal back to the frequency domain in order to extract the data and control information from different slaves. A valid assumption is that the slaves can send important information such as spectrum monitoring decisions and channel state information over a logical control channel in the return path. The master node can simply apply a majority rule based on the received monitoring decisions to decide whether to stop transmission or not.

IV. ENERGY RATIO ALGORITHM

On the time-frequency grid of the OFDM frame and before the IDFT, a number of tones, NRT, are reserved for the spectrum monitoring purposes. These tones are reserved for the whole time except the time of the training symbol(s) in order not to change the preamble waveform, which is used for synchronization at the receiver. Notice that we allocate the reserved tones dynamically so that their indices span the whole band when successive OFDM symbols are considered in time. The tones are advanced by Δr positions every OFDM symbol. When the last index of the available sub-carriers is reached, the spanning starts again from the first sub-carrier. Hence, by considering small values for Δr, the reserved tone sequence injected to the energy ratio spans the whole band. The reasons for this scheduling are: (1) the primary user may have some spectrum holes because of using OFDM as well. If the reserved tones from the SU are synchronized with those spectrum holes in the PU side, then the algorithm will fail. On the contrary, if the PU uses a traditional single carrier modulation technique like QAM, this issue does not have a harm effect on the algorithm since the PU signal has a flat spectrum over the entire band. (2) The reserved tones typically occupy narrow band

and the primary to secondary channel may introduce notch characteristics to this narrow band resulting in detecting lower primary power level, which is referred to the narrow band problem. Therefore, it is recommended that the reserved tones are rescheduled by changing the value of Δr over time to mitigate the channel effect and to protect the reserved tones from falling into primary holes. Of course, all SUs should know the code for this scheduling in prior.

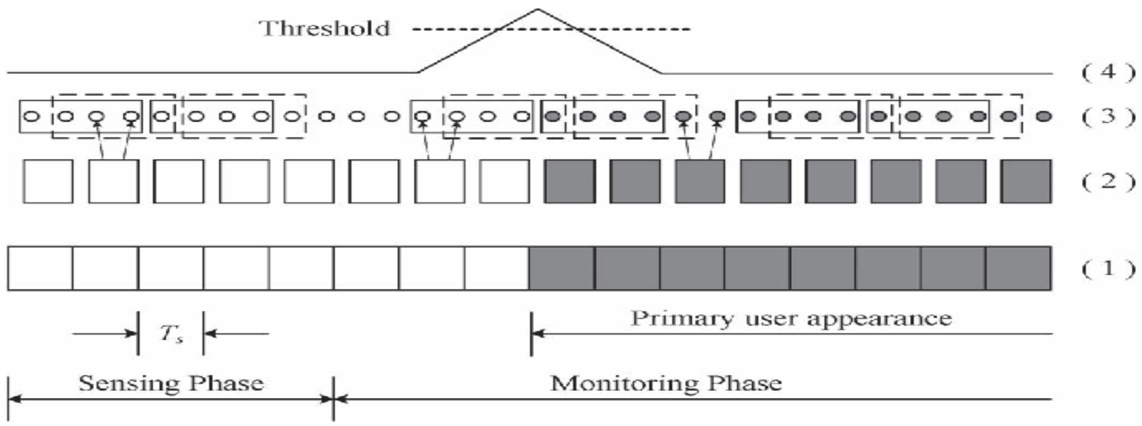


Fig.1. Energy ratio processing details (1) the time domain sequence for the OFDM blocks (2) frequency domain sample (3) reserved tones processing with two sliding windows for N_{RT} = 2 & N= 4.(4) Decision making variable X_k

Based on the signal on the reserved tones at the receiver, the secondary user can monitor the band and test the primary user appearance. In fact, the traditional radiometer may be employed to measure the primary signal power and the secondary noise power by accumulating the energy of those reserved tones. As a consequence, the primary signal power can be detected if this energy exceeds a predefined threshold. However, this approach does not necessary guarantee the primary user detection as the spectral leakage of the neighboring sub-carriers will affect the energy at the reserved tones even for no in-band primary signal . Here, we propose another decision making criterion that has a powerful immunity for this power leakage. In fact, the power leakage, the ICI resulted from the residual CFO and SFO errors, and even the effect of NBI can be overcome by our approach. The overall algorithm is illustrated by Fig. 1. It is assumed that the primary signal appears after some time during the monitoring phase. At the secondary receiver, after CP removal and frequency domain processing on the received signal, the reserved tones from different OFDM symbols are combined to form one sequence of complex samples. Two consecutive equal-sized sliding windows are passed over the reserved tone sequence in the time direction. The energy of the samples that fall in one window is evaluated and the ratio of the two energies is taken as the decision making variable and hence the name energy ratio. The algorithm aims to check the change in variance on the reserved tones over time. In a mathematical form, let Zi be the ith sample of the reserved tone sequence. The decision making variable, Xk, can be defined as given by (2) where N is the number of samples per window, Uk is the energy of the second window, Vk is the energy of the first window, and k is an integer such that k = 1, 2, 3, ...

$$Xk = \frac{Uk}{Vk} = \frac{\sum_{i=N+k}^{2N+k-1} | | zi |^2}{\sum_{i=N+k}^{k+N-1} | | zi |^2} \qquad \text{.................... (2)}$$

It should be mentioned that the reserved tones processing done by the energy ratio algorithm starts from the beginning of the sensing phase. Meaning that, the decision making variable is evaluated during both sensing and monitoring phases. However, it provides decisions only during monitoring phase. During the sensing phase, if the decision from the spectrum sensing algorithm is that the PU is inactive, then the energy ratio algorithm has been properly calibrated to be able to detect the appearance of the PU during monitoring phase. Calibration means that both sliding windows are filled with pure unwanted signals. During the monitoring phase, the receiver monitors the reserved tones by evaluating the parameter, Xk. If it exceeds a certain threshold, then the secondary user assumes that there is a power change on the reserved tones which perhaps due to the primary user appearance and it is time to vacate the band. If not, the secondary user can continue transmission. Indeed, if there is no primary user in band, then the energy of each window still involves only the strength of the unwanted signals including the noise, the leakage from the neighboring sub-carriers, and the effects of ICI produced by the residual synchronization errors. Therefore, if N is large enough, the ratio will be very close to unity since the strength of the unwanted signals does not offer significant changes over time. Once the primary user appears, the second window will have two types of signaling which are the primary user interference and the unwanted signals. Meanwhile, the first window will only maintain the unwanted signals without the primary user interference. The ratio of the two energies will result in much higher values when compared to one. The value will of course depend on the primary user power. When the two windows slide again, the primary signal plus the unwanted signals will be observed by the two windows and the decision making variable returns to the initial state in which the ratio is close to unity. Thus, we can expect that the decision variable produces a spike when the primary user is detected. Otherwise, it changes very slowly maintaining the energy ratio close to one as shown in Fig. 2 part (4).

In the proposed architecture first, the reserved tone sequence is injected to be squared. Next, two first-In first-Out (FIFO) memories are used to store the squared outputs to manage the energy evaluation for the two windows. The idea depends on the sliding concept for the windows where the total energy enclosed by one window can be evaluated by only adding the absolute squared of the new sample and subtracting the absolute squared of the last sample in the previous window as given

$$v(k) = \sum_{i=k}^{N+k-1} |Z_i|^2$$

$$v(k) = v(k-1) + |\ Z_{N+k-1}\ |^2 - |\ Z_{k-1}\ |^2$$

The ratio may not be evaluated directly, instead we can multiply the energy of the first window by the threshold and the multiplication output is then compared to the energy of the second window.

To verify the algorithm the secondary user physical layer model must be considered. For this the data coming from the source is segmented into blocks [1]. In CR networks there are k secondary users and one primary user. The primary user occupies a spectrum and it also share the same spectrum with the secondary users. The spectrum shared by the secondary user is called master node and it gives information to all others The timing of each slave is controlled by the master node by allowing time delay in advance. The master node have the capacity to convert the signal back to the frequency domain and the control the information from the slaves. The slaves are able to send the decisions over the channel. In this algorithm number of tones are reserve for the spectrum monitoring purpose. The secondary user can monitor the band and test the primary user appearance, based on the signal on the reserved tones at the receiver. Over the reserved tone sequence two windows are passed. The energy of the samples that fall in one window is calculated and the ratio of the two energies is taken as the decision making variable and therefore it's named as energy ratio algorithm. The energy ratio algorithm is mainly used in OFDM based cognitive radio networks.

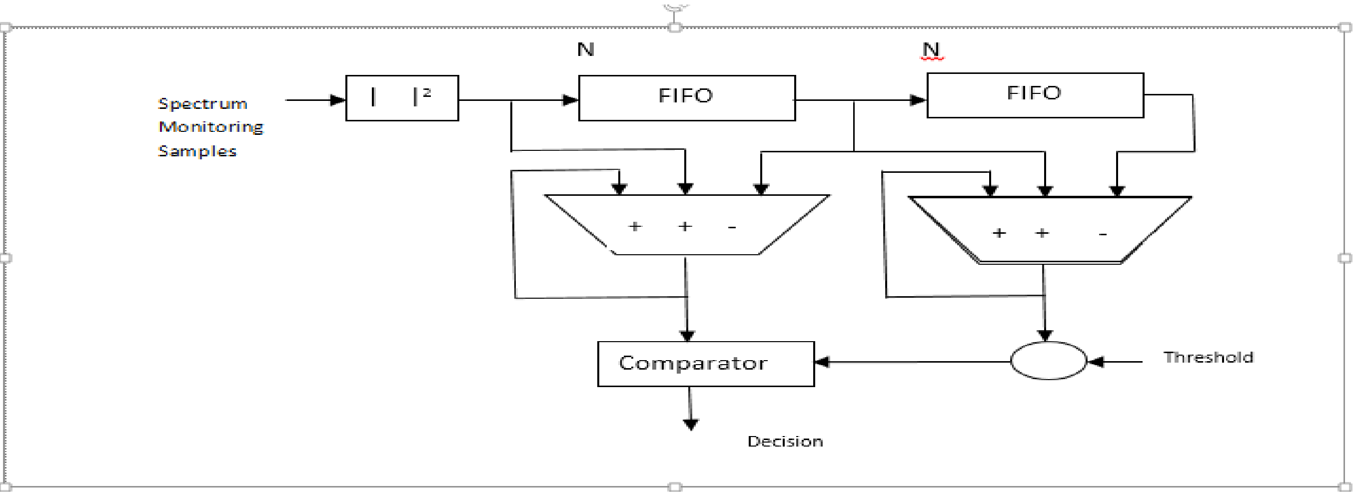


Fig. (2): Proposed architecture for the energy ratio algorithm.

The fig. (2) Shows the architecture of the algorithm and in this the reserved tone sequence is injected to be squared. Then two FIFO memories are used to store the squared outputs to manage the energy evaluation for the two windows. The idea depends on the sliding concept for the windows where the total energy enclosed by one window can be evaluated by only adding the absolute squared of the new sample and subtracting the absolute squared of the last sample in the previous window. The ratio may not be evaluated directly, instead we can multiply the of the first window by the threshold and the multiplication output is then compared to the energy of the second window. Here we have to calculate threshold values which is obtained from ROC curve to evaluate ER algorithm.

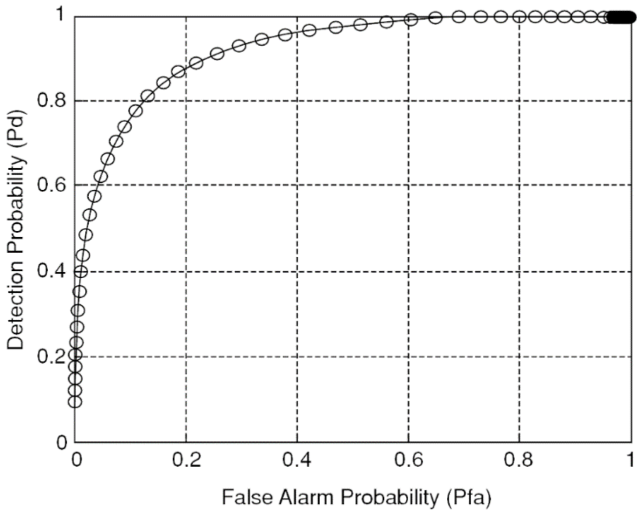
V. ENERGY RATIO ANALYSIS FOR AWGN CHANNELS

The target of this analysis is to find the receiver operating characteristics (ROC) represented by the probability of detection, PD, and probability of false alarm, PFA. The detection probability is the probability of detecting a primary signal when it is truly present while the false alarm probability is the probability that the test incorrectly decides that the primary user is present when it is actually not .Since we are dealing with a two state model in which the channel is assumed to be idle or busy by the primary user ,then we wish to discriminate between the two hypotheses H0 and H1 where the first assumes that the primary signal is not in band and the second assumes that the primary user is present .Using the energy ratio algorithm, one can define these hypotheses as given by (3) where it is assumed that the samples contained in the first window have a variance of $\sigma^2 v$ and the samples enclosed by the second window have a variance of $\sigma^2 u$.

$$H0: X = \frac{U}{V}, \quad \sigma^2 u = \sigma^2 v$$
$$H1: X = \frac{U}{V}, \quad \sigma^2 u > \sigma^2 v$$

VI. RECEIVER OPERATING CHARACTERISTICS

This graph is plotted between probabilities of false alarm vs probability of detection. Graph is calculated with SNR value -10 db. Graph shows that probability of false alarm should be minimum for better throughput and probability of detection should be maximum shows better detection of primary user. From ROC Curve the value of threshold parameter is evaluated & provided to ER algorithm.



The performance of the detector is quantified in terms of its ROC curve, which represents the probability of detection as a function of the probability of false alarm. By varying a certain threshold γ, the operating point of a detector can be chosen anywhere along the ROC curve. PFA and PD can be defined as given by (4) and (5), respectively.

P_{FA} = Prob [X > γ | H0] .... (4)
P_D = Prob [X > γ | H1] .... (5)

Clearly, the fundamental problem of detector design is to choose the detection criteria, and to set the decision threshold γ to achieve good detection performance. Detection algorithms are either designed in the framework of classical statistics, or in the framework of Bayesian statistics. In the classical case, either H0 or H1 is deterministically true, and the objective is to maximize PD subject to a constraint on PFA; this is known as the Newman-Pearson (NP) criterion. In the Bayesian framework, by contrast, it is assumed that the source selects the true hypothesis at random, according to some priori probabilities. The objective is to minimize the so-called Bayesian cost

VII. RESULTS

Simulations for spectrum monitoring & sensing are carried out in MATLAB2018a, Project simulation is carried out in three part, first part is for spectrum sensing in this part depending upon probability of detection and probability of false alarm we will decide whether the spectrum is available or not. If spectrum is available then spectrum is used for secondary user. In second part of simulation we are transmitting the actual data over the CRN channel. OFDM trans-receiver is used for data transmission and for data reception. In third part we calculate the graph for throughput versus total error rate. This graph shows the optimized threshold value for the energy detection algorithm.

A) ROC CURVE FOR ENERGY DETECTION

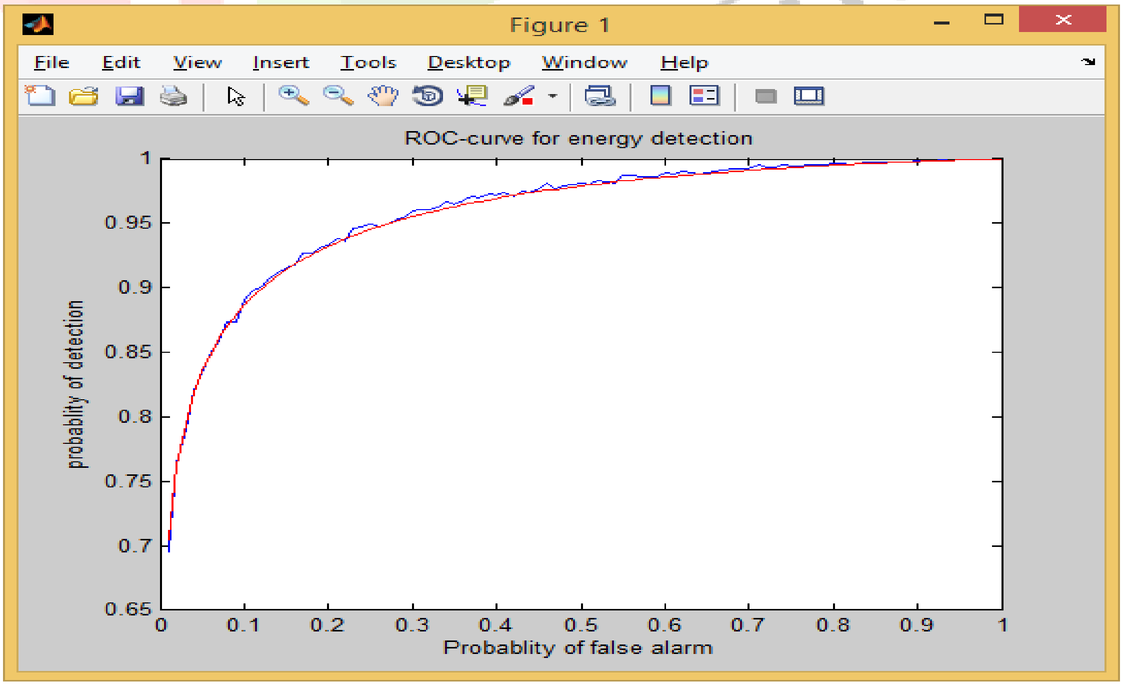
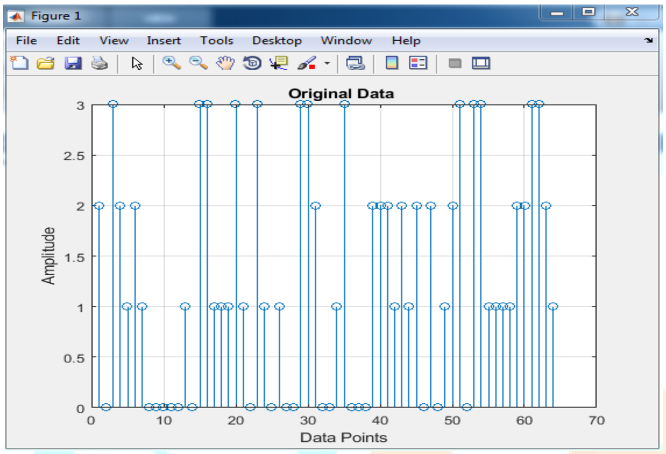


Fig. (4) ROC-curve for energy detection

This graph is plotted between probabilities of false alarm vs probability of detection. Graph is calculated with snr value -10 db. Graph shows that probability of false alarm should be minimum for better throughput and probability of detection should be maximum shows better detection of primary user.

B) OFDM SIGNAL THROUGH THE CHANNEL SPECTRUM SENSING

Input signal transmitted through OFDM transmitter Fig. (5.1) shows input data to transmitter, Fig. (5.2) shows modulated data, Fig. (5.3) shows subcarriers used in OFDM process, IFFT of subcarrier shown in fig.(5.4), modulated data is timing synchronized , cyclic prefix is added as shown in Fig. (5.5), Fig. (5.6) shows the OFDM signal which is transmitted to secondary user receiver. To recover modulated data exact opposite processes of transmitted data are applied as shown in below fig.



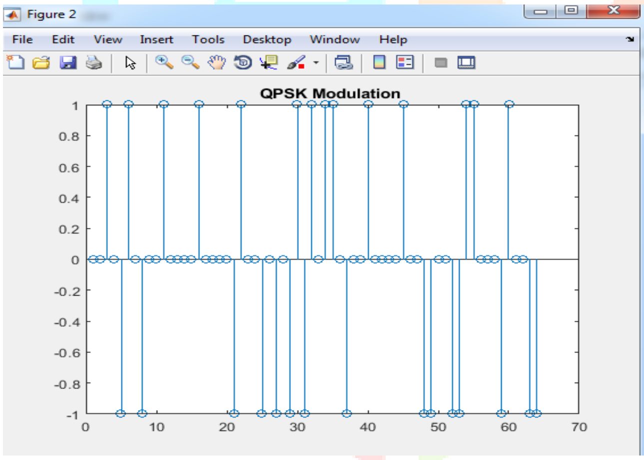
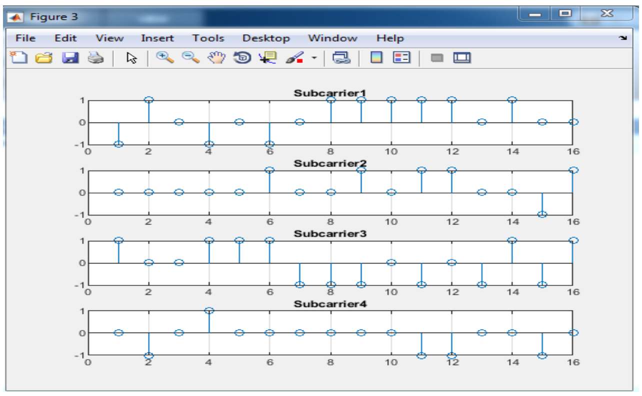


Fig.(5.1) : Input data to be transmitted fig.(5.1) : QPSK modulated data



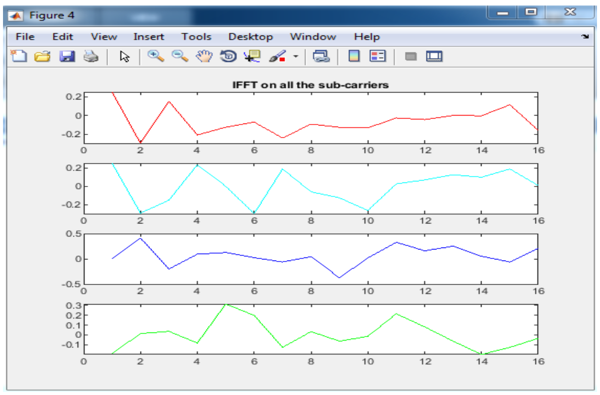


Fig. (5.3) : Subcarriers used in OFDM Fig. (5.4) : IFFT of subcarriers

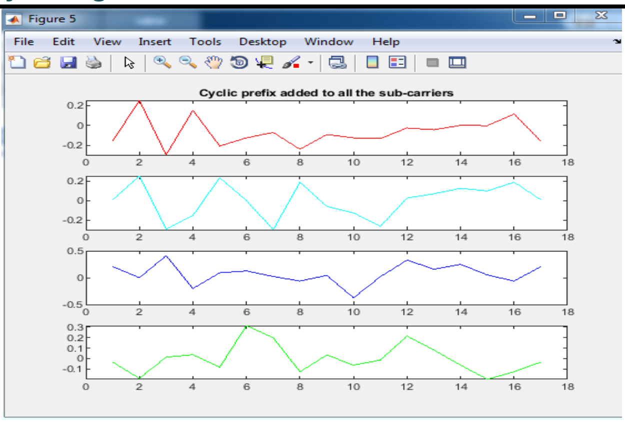


Fig. (5.5) : Addition of Cyclic prefix

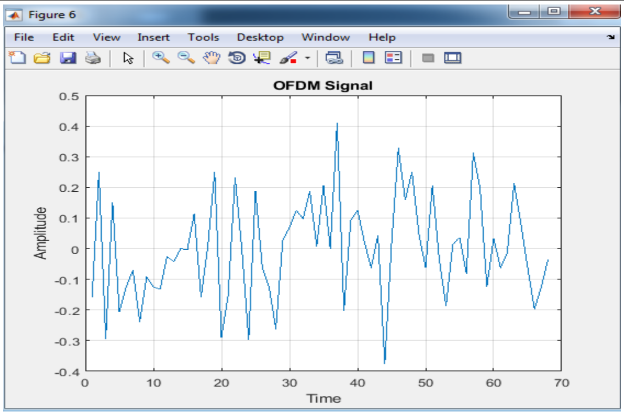


Fig. (5.6) : OFDM signal

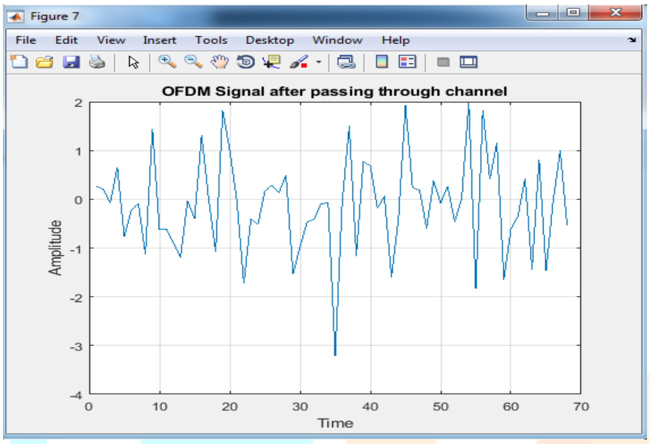


Fig. (5.7) : OFDM signal after passing through channel

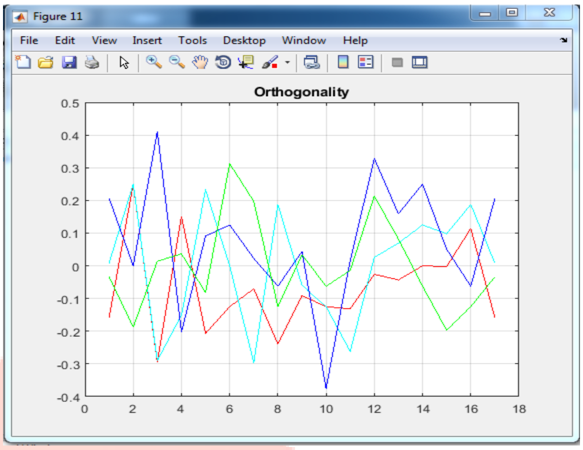


Fig. (5.9) : Orthogonality

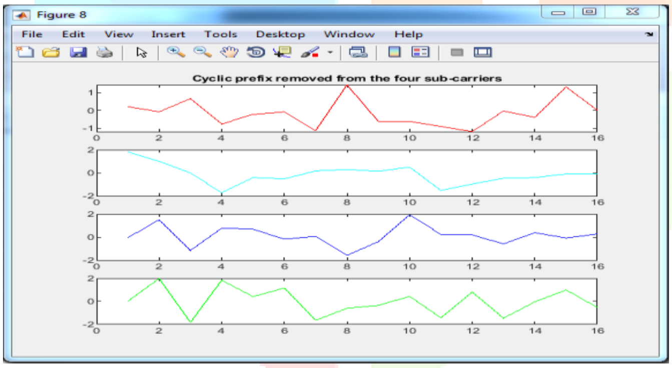


Fig. (5.10) : Removal of Cyclic prefix

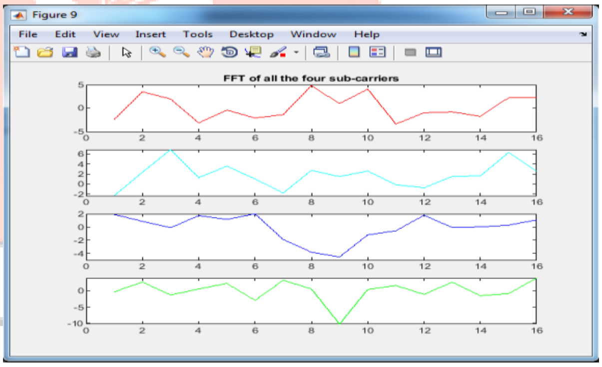


Fig. (5.11) : FFT of subcarrier

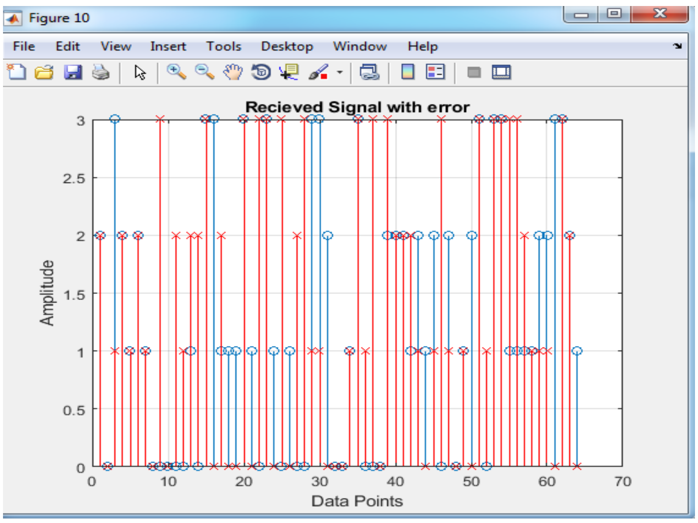


Fig. (5.12) : Demodulated data signal

C) SPECTRUM SENSING ON OFDM BASED COGNITIVE RADIO NETWORK

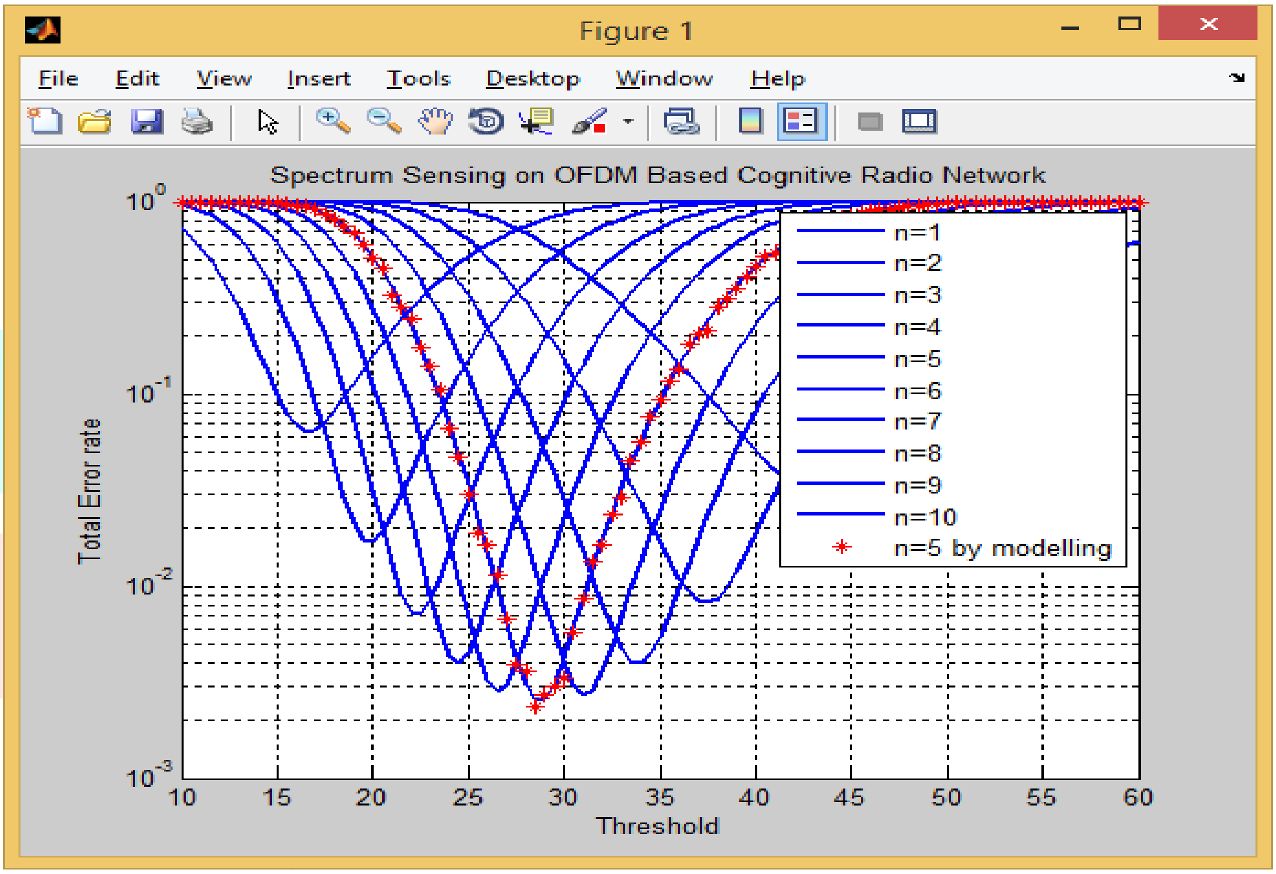


Fig. (6) Spectrum Sensing on OFDM Based Cognitive Radio Network

Fig. (6) shows the graph for threshold vs total error rate, x-axis shows logarithmic scale for threshold value and y- axis shows linear scale for total error rate. Graph shows for number of sample (n) varying from 1 to 10. For n=1 threshold is maximum than n=10, n is varying from right to left. For n=1 graph shows OR ovation rule for n=10 it shows AND ovation rule. At n=5 it shows optimum threshold value at which total error rate is minimum.

VIII. CONCLUSION

We proposed a spectrum monitoring algorithm that can sense the reappearance of the primary user during the secondary user transmission. This algorithm, named "energy ratio" is designed for OFDM systems such as Ecma-392 and IEEE 802.11af systems. We also derived the detection probability and the probability of false alarm for AWGN channels to analyse the performance of the proposed algorithm. This shows that probability of false alarm should be minimum for better throughput and probability of detection should be maximum shows better detection of primary user.

Our proposed spectrum monitoring algorithm can greatly enhance the performance of OFDM-based cognitive networks by improving the detection performance with a very limited reduction in the secondary network throughput.

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X. REFERENCES :

[1] S. Haykin, ―Cognitive radio: Brain-empowered wireless communications,‖ *IEEE J. Sel. Areas Commun.*, vol. 23, no. 2, pp. 201–220, Nov 2013.
[2] A. Ghosh and W. Hamouda, ―Cross-layer antenna selection and channel allocation for MIMO cognitive radios,‖ IEEE Trans.wireless Communication., vol. 10, no. 11, pp.3666
[3] W. S. Jeon, D. G. Jeong, J. A. Han, G. Ko, and M. S.Song,―An Efficient quiet period management scheme for cognitive radio Systems,‖ IEEE Transmission Wireless Communication, vol. 7, no. 2, pp. 505–509, Feb. 2014.
[4] W. Huetal., ―Cognitive radios for dynamic spectrum access Dynamic frequency hopping communities for efficient IEEE8 02.22 operation IEEE Communication.Mag. vol. 45, no. 5, pp. 80–87, May 2012
[5] S. W. Boyd, J. M. Frye, M. B. Pursley, and T. C. Royster, ―Spectrum Monitoring during a reception in dynamic spectrum access cognitive radio Networks,‖ IEEE Trans. Commun., vol. 60, no. 2, pp. 547–558, Feb. 2012.
[6] H. Mahmoud, T. Yucek, and H. Arslan, ―OFDM for Cognitive radio: Merits and challenges,‖ IEEE Wireless Communication, vol. 16, no. 2, pp. 6–15, Apr. 2010.
[7] D. Cabric, S. M. Mishra, and R. W. Brodersen, ―Implementation issues in spectrum sensing for cognitive radios‖, in Proc. Conf. Rec. 38thAsilomar Conf. Signals, Syst. Comput., vol. 1, pp. 772–776, Nov. 2013.
[8] R. Saifan, A. Kamal, and Y. Guan, ―Efficient spectrum searching and monitoring in cognitive radio network‖, in Proc. IEEE 8th Int.Conf.MASS, pp. 520–529, 2014.
[9] H. Mahmoud, T. Yucek, and H. Arslan, ―OFDM for Cognitive radio: Merits and challenges‖, IEEE Wireless Communication .vol. 16, no. 2, pp. 6–15, Apr. 2011.
[10] D. Galba and H. Rohling, ―Narrow band interference reduction in OFDM based power line communication systems‖, in Proc. IEEE ISPLC,pp.345-351-Apr.2011.
[11] R. Xu, M. Chen, C. Tian, X. Lu, and C. Diao, ―Statistical distributions of OFDM signals on multi-path fading channel‖, in Proc. Int. Conf.,pp1-6,2010
[12] H. Mahmoud, T. Yucek, and H. Arslan, ―OFDM for cognitive radio: Merits and challenges‖, IEEE Wireless Commun., vol. 16, no. 2, pp. 6–15, Apr. 2011.