Design and Implementation of OFDM system with Energy Detection Spectrum Sensing for Cognitive Radio Networks Using HDL Coder Technique

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Abstract:

Spectrum sensing (SS) performs important role in cognitive radio (CR) network. The wireless networking testify a quantum leap through appearance internet of things (IoT) and applications connected with cloud information's, and with cellular communication systems, spectrum is always a prime restriction, but still a massive bandwidth, is lost depending on improper used, influence the Quality of Services of the system. Spectrum sensing is a process used to detect the unused spectrum bands, holes, to enhance the utilization of scarce radio spectrum. The spectrum sensing merit expends more energy compared with functional blocks, as it bases on persistent detection of the attendance or non attendance of the primary user (PU). In this paper, we present FPGA architecture implementation of Energy Detection (ED) based spectrum sensing and Goodness of Fit (GoF) based spectrum sensing methods. The aim of these methods is to detect the presence of signal in cognitive radio network (CRN) environment. This scenario have been described in *VHDL* and implemented on Altera Cyclone II FPGA platform. We concentrated on integration of Cognitive Radio with various OFDM frameworks, while the performance is evaluated in the AWGN channel and simulated using a MATLAB. A Simulink model of the modulator and demodulator based spectrum sensing architecture is built to prove the system functionality. Probability of detection (P_d) versus Probability of false alarm (Pfa), Pd versus Signal to Noise Ratio (SNR) and Bit Error Rate (BER) versus SNR for each OFDM framework with energy detector is calculated and analyzed.

Key Words: Spectrum Sensing(SS), cognitive radio (CR) ,Orthogonal frequency division multiplexing(OFDM), Probability of Detection(P_d), field programmable gate array (FPGA),cycle Prefix(CP).

الخلاصة

يؤدي استشعار الطيف (SS) دورًا مهمًا في الشبكات الراديوية المعرفية او الادراكية (CR) حيث تشهد الشبكات اللاسلكية قفزة نوعية هائلة عبر تطبيق إنترنت الأشياء (IoT) والتطبيقات المتصلة بالمعلومات السحابية، وكذلك أنظمة الاتصالات المتنقلة، و يشكل الطيف (الحزم الترددية)دائمًا عامل رئيسيًا ومقيدا لشبكات الاتصال، حيث لا تزال هنالك حزم ترددية هائل يتم فقدها وفقًا للاستخدامات الغير صحيحة وهذا يؤثر على جودة الخدمات في أنظمة الاتصالات .وتقنية استشعار الطيف هي عملية تستخدم في الكشف عن حزم الطيف غير المستخدمة، والفجوات، وذلك لتحسين وتعزيز استخدام طيف الترددات الراديوية النادرة . وميزة استشعار الطيف انها تستهلك المزيد من الطاقة لأنها تعمل على الكشف المستمر حول وجود أو عدم وجود المستخدم الأساسي (PU).

في هذا البحث، تم تنفيذ تقنية FPGA لتطبيق استشعار الطيف على أساس اكتشاف الطاقة (ED) وأساليب استشعار الطيف القائمة على أساس ملاءمة الجودة (GoF). ان الهدف من هذه الطرق هو اكتشاف وجود إشارة في بيئة الشبكة الراديوية المعرفية (CRN). وتم وصف هذا السيناريو بلغة VHDL ومن تم تنفيذها باستخدام برنامج Altera Cyclone II FPGA. وقد تم التركيز على دمج تقنية (CR) مع تقنيات عمل OFDM المختلفة، بينما تم تقييم اداء النظام في قناة AWGN ومحاكاته باستخدام برنامج ال MATLAB. و بناء نموذج المحاكاة باستخدامٍ Simulink للبلوك الخاص بعملية التضمين وكذلك فتح التضمين لبنية استشعار الطيف لإثبات عمل النظام , وتم احتساب وتحليل احتمالية الكشف (Pd) في مقابل احتمال الإنذار الخاطئ (Pfa) واحتمالية الكشف (Pd) في مقابل نسبة الإشارة إلى الضوضاء (SNR) ومعدل (BER) مقابل SNR لكل حالات OFDM المستخدمة مع (ED).

1.Introduction:

Since wireless communication systems is utilized strongly nowadays, the radio frequency band has been exposed to force. Traffic in the limited recurrence band has consistently expanded because of its far and wide utilization of innovations such as Wi-Fi, Bluetooth and GPS. Based on the US Federal Communications Commission (FCC), the outcomes has indicated that the radio recurrence band is not utilized effectively and suitably [1]. Since this band having a place with the authorized client has not been utilized outside of a specific time, spectrum openings have showed up in the frequency band. If these bands that are not utilized much by the authorized client are took into account dynamic access, the utilization of these bands by other correspondence frameworks or by other communication systems may block the issue of spectrum inefficiency. The system to do this is called cognitive radio (CR) technology.

Cognitive radio is a method that empowers clients to investigate the electromagnetic spectrum to astutely communicate in accessible frequency bands. Spectrum sensing is the progression liable for assess frequency bands that can be utilized by non-approved users [1].

The spectrum sensing capacity empowers the cognitive radio to adjust to its current circumstance by distinguishing spectrums holes. The most productive approach to identify spectrums holes is to distinguish the essential clients that are getting information inside the correspondence scope of a client. Actually, notwithstanding, it is hard for an CR to have an immediate estimation of a channel between an essential recipient and a transmitter. Consequently, the latest work centers around primary transmitter recognition dependent on neighborhood observations of users or clients [2].

Spectrum sensing includes portability of the authorized client and the control of the spectrum by continually breaking down the frequency. It decides the entrance strategies to the spectrum without meddling with primary users by recognizing unused spectrum with spectrum holes. It must inspect the presence of authorized users while the spectrum is investigated occasionally [3].

There are numerous procedures by performing range detecting. The speed and precision of the outcomes are the two most significant factors in deciding the optimum SS algorithm.

Contingent upon data acquired from the spectrum sensing, spectrum administration is a decision-making operation with time when the spectrum will be proper and parameters identified with frequency and spectrum to be utilized. These parameters are the boundaries that comprise administration quality, for example, obstruction level or interference, blunder channel ratio, path loss, interface layer delay [4]. One of significant basis in cognitive radio innovation is to permit the frequency to be utilized without uncovering the licensed user to interference when the spectrum is unfilled [5]. Two sections are formed Spectrum management. The primary segment is to gather data about spectrum bands thinking about the statistical information of authorized networks. The second section is to determine which

channel is empty and to allot it as per this got outcome. One of the issues experienced is to be incorrect outcomes in the computation of the spectrum limit utilizing SNR data.
Usually, the spectrum sensing arranged in classes or categories. arranged in classes or categories. as shown in Figure 1.

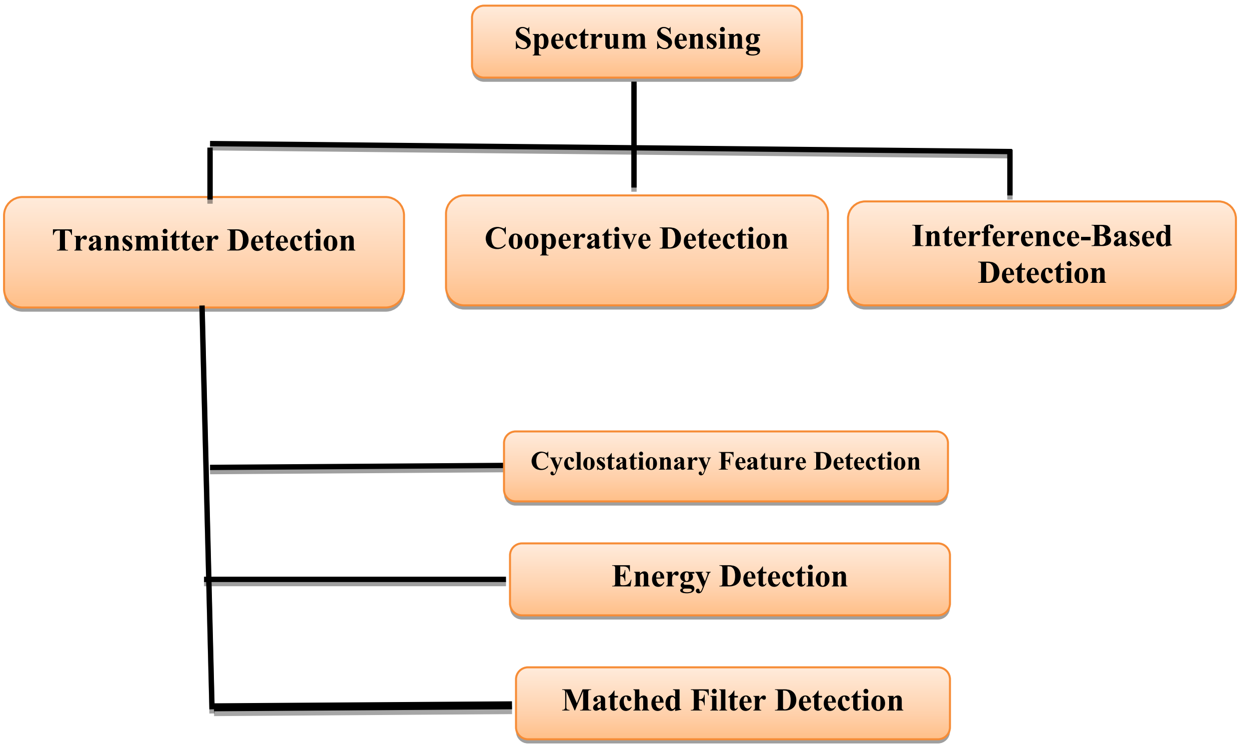

Figure1: Classification of spectrum sensing techniques.

Spectrum bandwidth designation in single carrier system is much when contrasted with the multicarrier framework. By utilizing multicarrier framework like OFDM (Orthogonal Frequency Division Multiplexing) and FBMC (Filter Bank Multicarrier), a similar bandwidth is circulated among more subcarriers contrasted with classical multiple-carrier system, which guides a reliable data rate and the less utilization of band width. In ordinary cellular communication medium, there is no specific scanning plan for identifying ideal clients, so there is no special inception for getting data of accessible available bandwidth. Cognitive radio innovation will consequently filter the ideal users and unused bandwidth make it available and can be used it for various users.

2.Cognitive radio and OFDMTechniques:

Energy Detection sensing scheme (radiometric detection) is considered with OFDM system considering in the existing work. One of the serious problems related with Energy Detection is that it gives a decent performance just under higher SNR stipulations. In the event that the SNR is low, at that point the efficiency will be poor [6].
Channel quality estimation is another Challenging errand in Cognitive Radio (CR). Different users are permitted to get to the essential channel with no interference. Be that as it may , the channel quality may contrast significantly and the great quality channels definitely decline

the proficiency of spectrum thus the significant drawback emerges, similar to how to estimate the channel quality to boost the dynamic spectrum, efficiency.
OFDM techniques uses the Cyclic Prefix (CP) to diminish the Inter Symbol Interference (ISI) among the symbols which is deemed as one of the most serious issue in wireless systems, but utilization of CP additionally brings about wastage of data transfer capacity.
Everywhere on the world, analysts are attempting to remunerate the wastage of spectrum happening in OFDM techniques. Energy detection is one of the SS techniques of CR methods which is considered as one of things to come advancements in technologies to defeat the wastage of efficiency in OFDM framework and furthermore uses the unused spectrum designated to the subscribers.
In this paper an OFDM techniques with CP and without CP, with use type of filter at transmitter and with transmitter and collector the two sides, is coordinated with Energy detection, and analysed by deciding the proficiency and throughput of the system. dual threshold Feature Detector strategy is proposed in[7] to discover the essential user at low SNR and to create CR network on an AWGN channel. The performance of this techniques is expanded on account of utilizing the dual threshold for detection. A low temperature handshake between sensing devices the unlicensed client in the CR is proposed in[8].
An OFDM based CR is proposed in[9], utilizing a complicated scheme to decline out-of-band power and what's more, Peak to Average Power Ratio(PAPR) so that the transmission achievement is improved. A pattern and network design of cognitive crisis communication system is proposed in [10] to increase the social assistance efficiency of crisis communication in free space and ground, which make the performance of the network improved. An iterative synchronization helped discovery of OFDM signal in CRN is suggested in [11] to identify a OFDM signal and synchronized dependent on cyclic prefix utilizing an iterative synchronization pattern for diminishing the Synchronization mistake, which provides a preferable detection performance.

3. Mathematical Equations:

The model is implemented by using a MATLAB 2015. The parameters take into account in this model are briefly shown below:
The information symbols of OFDM model are expressed as

$x(n) = x(0)\ x(1)\ x(2) \dots \dots \dots x(N-1) \qquad 0 \le n \le N-1$

Sequential form of symbols alter into parallel for processing and IFFT is used for all symbols as given below

$X(n) = X(0)\ X(1)\ X(2) \dots \dots \dots X(N-1) \qquad 0 \le n \le N-1$

The mathematical expression composite OFDM, modulated signal is demonstrated by following

$$S(t)= \sum_{k=0}^{N-1} X(t)k e^{j2\pi k\Delta f t} \qquad 0 \le t \le T_q \qquad \dots\dots\dots(1)$$

Where S(t) = Composite OFDM modulated signal.
X(t) = IFFT, of information, signal.
Δf = Spacing, between carriers.
Tq = Symbol time.

If the condition of orthogonality (Tq Δf = 1) is satisfy then the OFDM signal is orthogonal, and to keep away from ISI, Cyclic Prefix is utilized between the symbols. Therefore, OFDM modulated signal with CP can be described as

$S_{cp}(t)= \sum_{k=0}^{N-1} X(t)ke^{j2\pi k\Delta ft} + cp \qquad 0 \le t \le T_q$ ……(2)

The received signal is written as

$R(t) = H(t)\, S_{cp}(t) + N(t)$ ……………………………………………………..(3)

Where $S_{cp}(t)$ = Received signal across t^{th} subcarrier.
H(t) = Channel co-efficient of t^{th} subcarrier.
N(t) = Noise across t^{th} subcarrier.
The impulse, response of the channel, is written as

$h(t) = \sum_{i=0}^{L-1} F_i\, \delta(t - \tau_i)$ ………………………………………………(4)

Where Fi = Attenuation factor.
τ_i = Delay.
L = No. of Path.

The second parameter is Energy Detection (ED). ED is a common approach in CR for spectrum sensing and it determines the presence, of spectrum, hole and optimizes, the detection, probability. It compares, the energy signal that received with threshold, amount (λ), following the SNR to obtaint two speculations - regardless the signal is missing or present.

B(t) = {n(t)} H_0
B(t) = {h * A(t) + n(t)} H_1

Where B(t) = Secondary User
A(t) = Primary User's transmitted signal
n(t) = Additive White Gaussian Noise
h = Channel Amplitude gain of
H_0 = absent Primary user
H_1 = present Primary user.

4. SimulinkModel and Simulation Results:

This section shows the results of a simulation of the energy detector's performance using the Receiver Operating Characteristic (ROC) curve, and energy consumption for a single user CR in AWGN, with the two methods proposed applied.

This section shows the results of a simulation are thoroughly analyzed by using a mathematical model of cognitive OFDM system and implementing a code in MATLAB Simulink as in the Figure (2):

The simulation parameters used are given in Table 1

Table 1: Simulation parameters

Name of Parameter	Value of Parameter
Transmission mode	2k
No. of carriers	20000
Bit rate	4Mbps
Carrier frequency	40MHz
Modulation type	124QAM
Probability of false alarm	10^{-3}
Spectrum band	0-200MHz
Code rate	2/3
Sampling frequency	400MHz

Bits per symbol	4
Sample per symbol	200
Observed time	5.4usec

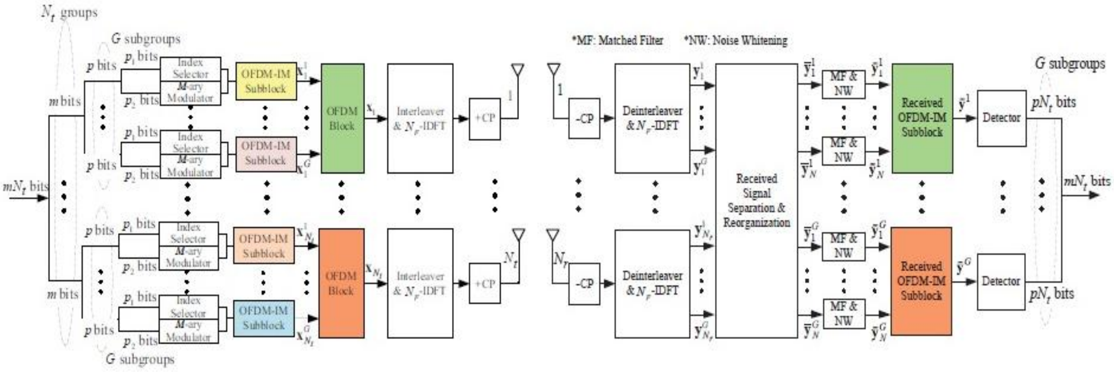

Figure 2: Simulink Model Of OFDM CR.

The results of Simulink model Of OFDM CR are shown in the Figures 3,4,5,6

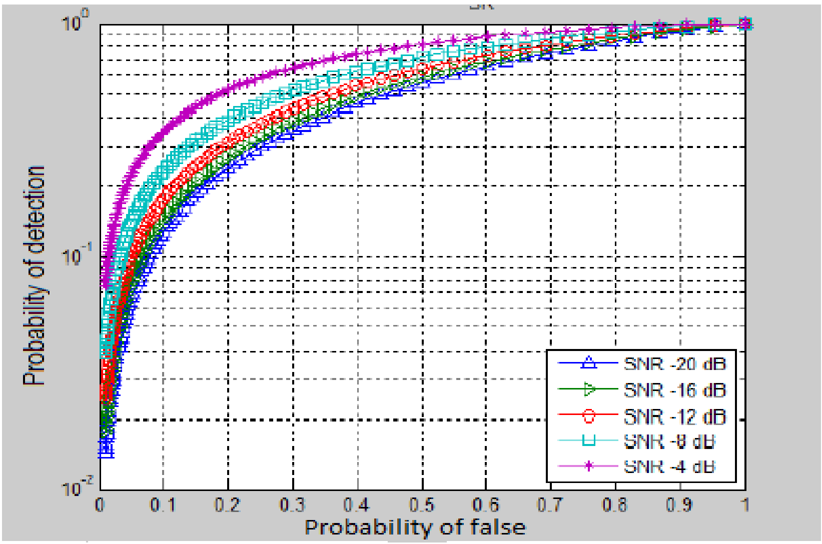

Figure 3: P_d versus P_{fa}, for OFDM CR for different SNR.

Figure.3 demonstrate that ROC of spectrum sensing for various number of probability of, false alarm, with AWGN channel where time bandwidth factor 1000 is used. The probability of detection is calculated in Figure 3 upon on the probability of false alarm. It demonstrate that P_d is also change upon on SNR and SNR 18, 19, 20, and 21 are used for this simulation. Here P_{fa} is utlized from 0.01 to 1 by increasing 0.01, where 100 P_{fa} is used. From the simulation result we saw that when SNR=18 and P_{fa} is 0.0200, the detection probability is about 0.4412. But after this P_{fa} and before P_{fa}=0.9700, the detection probability is approximately good.

The analyzing of BER versus SNR for OFDM, with and without, cyclic prefix is appeared in Figure 4. The BER In both case, diminishes with increment of SNR. For 0 to 3 dB, BER for OFDM with CP and OFDM without CP is roughly equivalent though with the expansion of SNR, BER performance of OFDM with CP is obviously superior to OFDM without CP. Investigative outcomes demonstrate that the previous framework is a lot of productive (efficient) and dependable with less ISI and BER when compared with last one.

While the analyzing of BER versus SNR for OFDM with filter at transmitter and receiver is appeared in Figure 5. In OFDM with filter, at transmitter the BER diminishes with increment of SNR. Be that as it may, OFDM with filter, at both transmitter and beneficiary side gives a steady BER for all SNR. So it demonstrates OFDM with filter at transmitter is more efficient when compared with first state.

Figure 6 demonstrate the behavior of OFDM with and without cyclic prefix from analysis of P_d versus SNR, for OFDM with and without cyclic prefix. The Probability of detection (P_d) increases with the expansion of SNR in both states. As shown below the detection in OFDM with CP is workable for smaller SNR in other hand detection for OFDM without CP requires a more SNR.

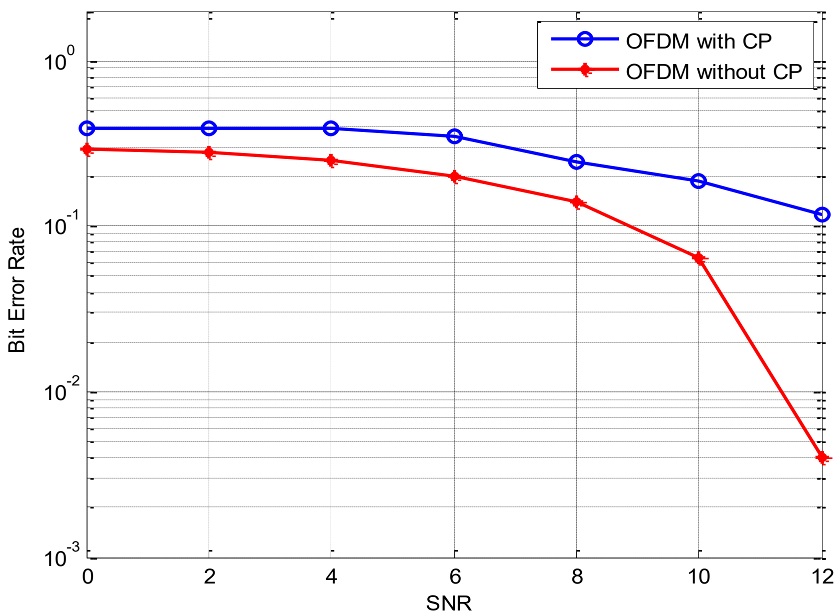

Figure 4: SNR versus BER, for OFDM in two cases with and without CP.

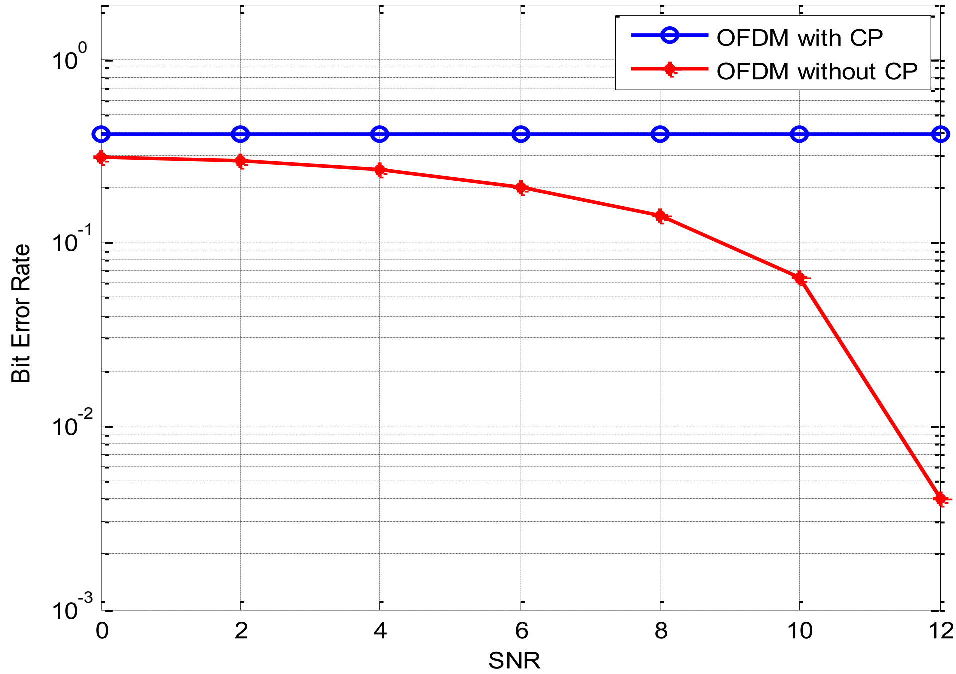

Figure 5: BER versus SNR, for OFDM with filter at Tx and Rx.

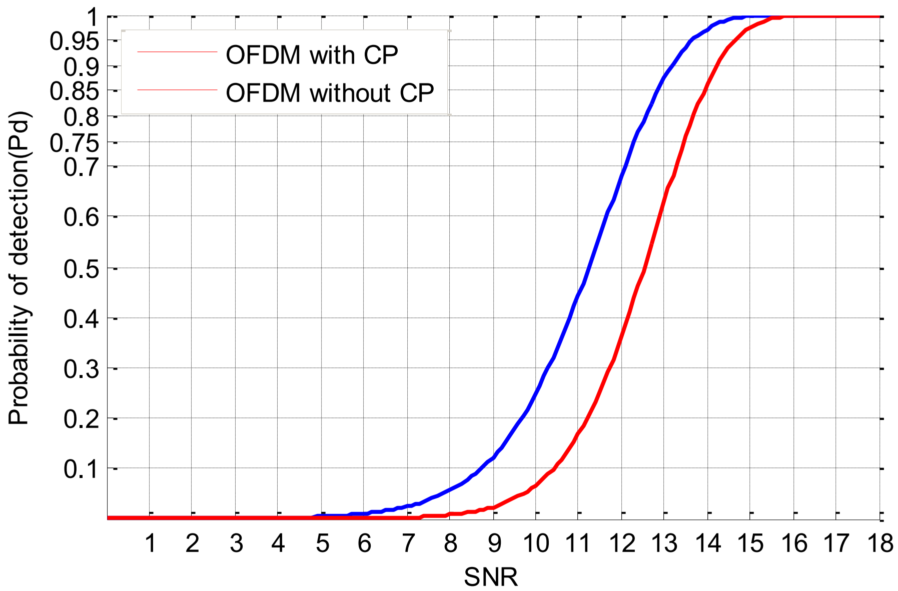

Figure 6: P_d versus SNR for OFDM in two cases with and without CP.

5.FPGA Platform results of Spectrum Sensing with OFDM Techniques:

The design procedure demonstrates in Figure 7, which depended upon to execute the spectrum sensing techniques with energy detection for CR by utilizing FPGA. It comprises of five successive steps. First, the characterized system are set up, then the VHDL code, and the test benches of conventional and proposed strategies are composed. Usefulness of the design is then tried indeed, utilizing ModelSim. After fruitful verification, the created VHDL, is synthesized utilizing the Quartus II tool for FPGA platform.

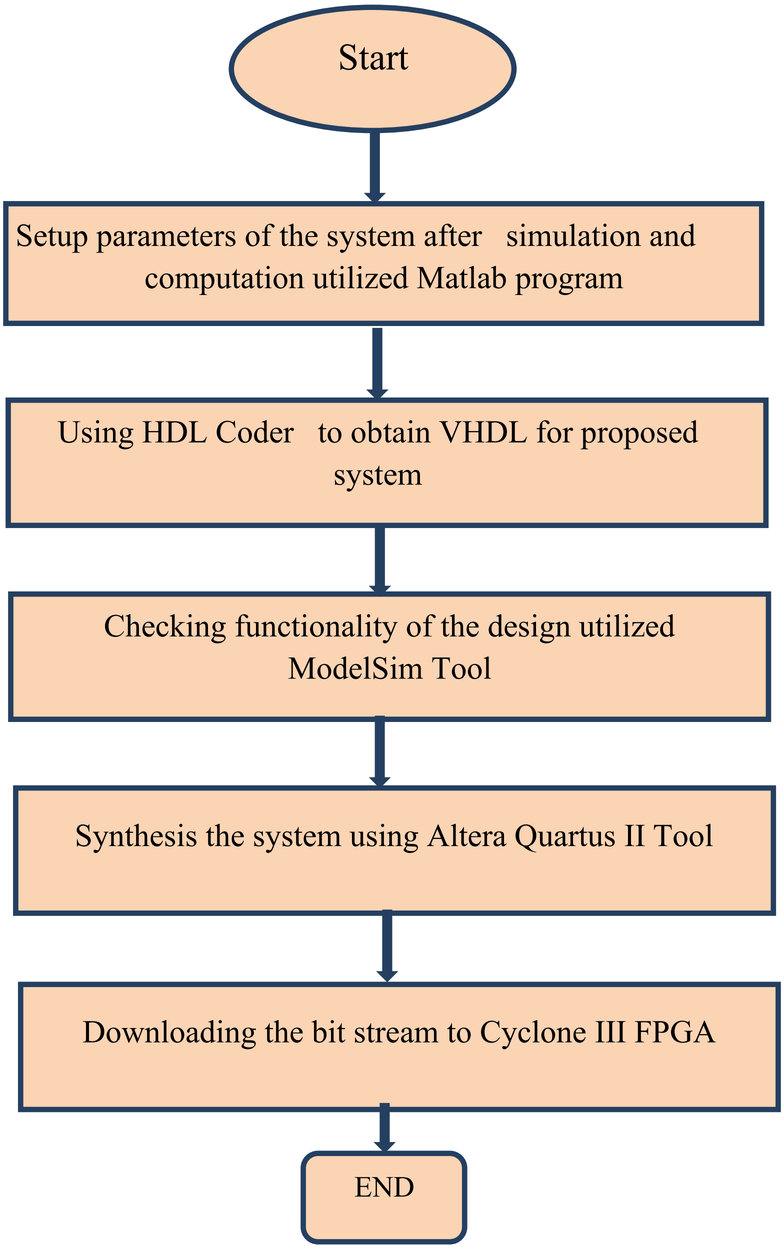

Figure 7: Chart flow of spectrum sensing techniques for CR design using FPGA.

Can utilize HDL Coder to implement SS with OFDM techniques on FPGA platform, which is high level design tool, and faster method which obtain VHDL code from utilize Simulink blocks and State flow finite state machines, as well as Simulink HDL coder provides interfaces to gather physically composed HDL codes, HDL mimicry squares and RAM blocks in its environment [12].
Figures 8, 9 show the ModelSim results of the SS with OFDM techniques with CP and without using CP, respectively. In all results outcomes from run the ModelSim program, the

clock signal (CLK) drives the process of sensing samples, therefore, at each positive edge of the clock, one sample is sensed. It tends to be seen that in Figure 8 dec3, 4 and 8 equal to 1. This means that channels 3, 4 and 8 have a PU signal . In Fig. 9, the PU signal with OFDM techniques is present in channel 3 only, because of the reduction in detection performance when decreasing the number of sensed samples.

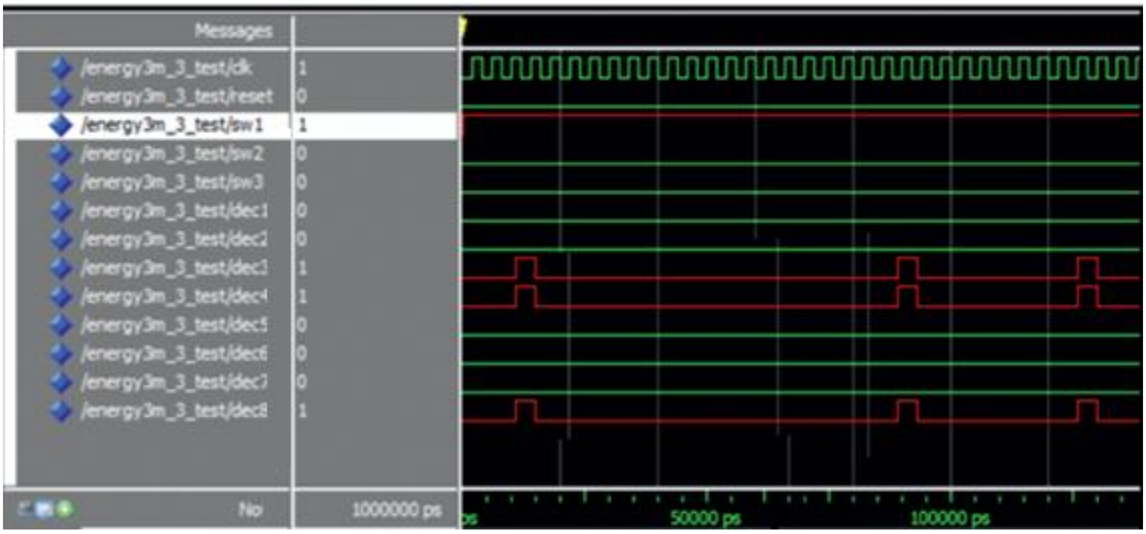

Figure 8: Waveform Simulation of spectrum sensing techniques for CR .

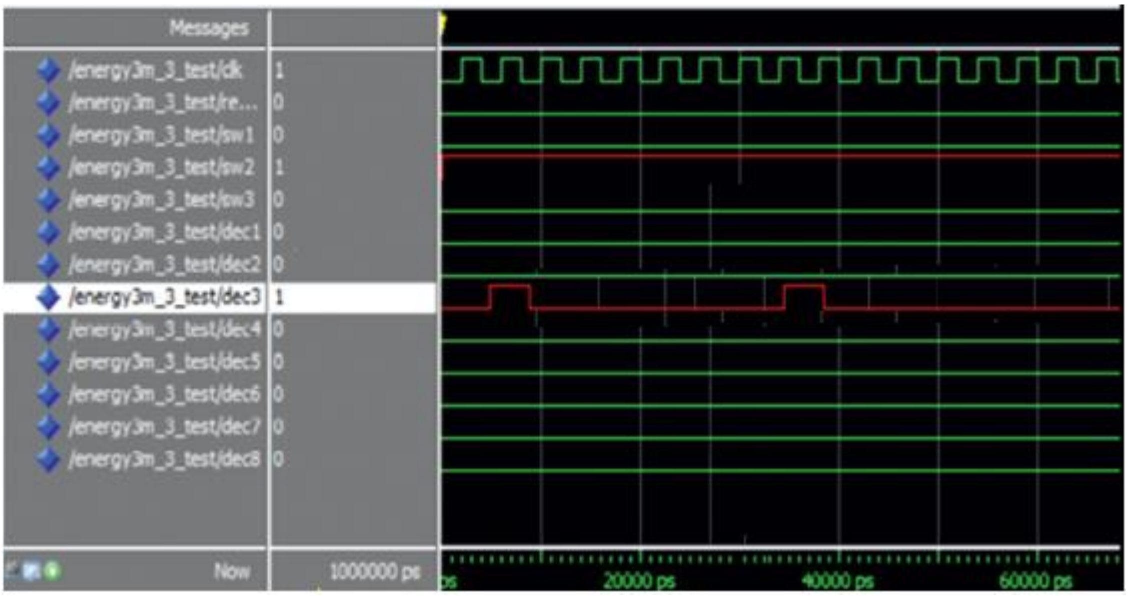

Figure 9: Waveform Simulation of spectrum sensing techniques for CR using CP.

Figure (10) demonstrates the block diagram of register transfer level (RTL) of internal structure of the SS with OFDM. RTL glimmer is used in hardware description languages (HDLs) like VHDL to produce high-level submitting of a system, from which lower-level submitting and eventually active wiring will be obtained, and logic optimization can be obtained by using synthesis tools .

The maximum operating frequency of FPGA implementation is 100MHz and master clock frequency is used 110MHz.

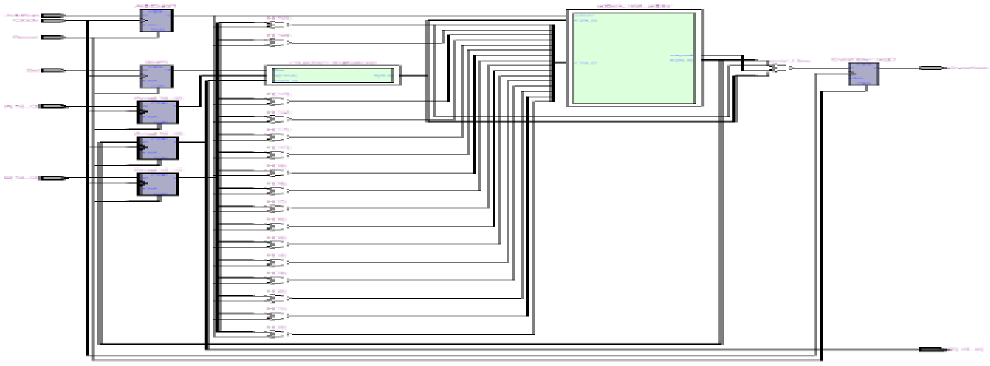

Figure 10: Shows the block diagram of register transfer level (RTL).

6. Conclusion

The combination of energy detection with an OFDM system is implemented as well as analyzed. The essential purpose is to implement a cognitive radio to employ the bandwidth and get better spectral efficiency and quality of service(QoS). So, the spectrum-detection performance is analyzed when employing the cycle prefix a CP with and without OFDM. Further, spectrum detection is investigated by employing the filter at the transmitting and both transmitting and recipient, or transceiving, side of the OFDM system, using energy detection for spectrum sensing techniques. The BER versus SNR and P_d versus SNR. SNR results indicate that the performance and efficiency of OFDM techniques with CP is superior to that of OFDM without CP. Further, spectrum detection is investigated by applying the filter at the transmitting and transceiving side of the OFDM system. However, results of P_d versus. P_{fa} indicate that behavior of OFDM without CP is better when compared with different approaches executed previously, and the analysis indicate that the probability of detection increases significantly when signal to noise ratio increases. It is also observed that the detection probability decreases when the factor of bandwidth increases. The implementation of the SS with OFDM algorithm with CP and without CP are accomplished via field programmable gate array (FPGA) design was done through generate connection link between block of simulink design and VHDL by utilize HDL coder tools techniques which is straightforward and active approach for control users. The speed, capacity used, and complexity are clear in the compilation, report, and complexity can be perfected by using multiplex multiplier, so the multipliers that used in the implementations can be lessen.

7. References:

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