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Game Theory based Hybrid Cognitive Radio Transmission

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Abstract

Background: Overlay based Cognitive radio can utilize only the primary user spectrum opportunistically for transmission. A hybrid overlay and under based cognitive radio is presented with game theory based decision making to facilitate continuous transmission support for the secondary user. **Methods:** The Hybrid Cognitive Radio (HCR) provides an optimum solution for effective utilization of the spectrum. A hybrid cognitive radio is designed to switch between overlay and under lay mode of transmission to continuously provide transmission opportunity with high data rate support for secondary user. The switching between the two transmission modes and frequency selection is formulated as a game. Decision making in the game is carried out by using the frequency utilization factor of the primary user as the utilization function of the game .Spectrally Modulated Spectrally Encoded (SMSE) framework is employed to efficiently generate the overlay Orthogonal Frequency Division Multiplexing signal and underlay Multicarrier Code Division Multiple Access (MCCDMA) signal with less overhead. **Findings:** This simple game theory based hybrid cognitive radio show improved bit error rate and throughput performance of the secondary user. The implementation of the hybrid cognitive radio is done using the LabVIEW and Universal Software Radio Peripheral (USRP) Software defined radio hardware platform. **Applications/Improvements:** The overhead of generation two different waveform in hybrid cognitive radio using Fast Fourier Transform (FFT) is reduced by sharing the common functionality between them under the frame work of the Spectrally Modulated Spectrally Encoded scheme which reduces the switching time and increases the spectral efficiency.

Keywords: Cognitive Radio, Game Theory, Hybrid Cognitive Radio, LabVIEW, Overlay, SMSE, Spectrum Hole, USRP, Underlay

1. Introduction

Radio Spectrum at present is facing the practical issue of spectrum scarcity[1] due to rapid advances in wireless technology. The spectrum is severely under-utilised in some bands and extremely congested in consumer radio communications bands[2]. Statistics show that in urban areas the spectrum utilization is just 6.5% and allocated spectrum which is unutilized makes up 78%[3]. Hence, it's is evident that the cause of such challenge is the inefficient allocation of the finite Radio-Frequency (RF) spectrum, rather than the scarcity of the Spectrum.

Cognitive radio is recent promising technology that can overcome this challenge by improving spectrum utilization significantly. The primary objective of such technology is to utilize the spectrum holes where bands may be unused or underused using either overlay or underlay transmission mode to share the available channels with the PU. A secondary cognitive radio network that tries to access dynamically the spectrum needs to do so without jeopardizing the licensed user services[4]. Usually, when the PU occupies the channel, the SU cannot transmit on the same channel since it would introduce interference to the primary receiver[5]. In finding a solution, Spectrally Modulated Spectrally Encoded (SMSE) framework[6], which is a multi-carrier transmission technology, can be used to maximize efficiency and spectrum utilization. If at a particular channel, the PU is known

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to be in an idle state, the SU would take advantage of an overlay mode transmission[7]. OFDM has a high spectral potency which can be a useful option for overlay transmission[8]. Otherwise, when the PU band is sensed busy, SU undergoes underlay transmission using MC-CDMA. In this underlay transmission scheme, both PU and SU can simultaneously use the available RF spectrum even though the band is not entirely idle. That is, the SUs transmit at a power level that is lower than the tolerable noise level of PUs. Such transmission by SU will appear as white noise to the PU[9].

For determining the mode of the transmission depending on the state of the PU channel, a spectrum sensing mechanism is required. Energy-based Detectors administer such processes efficiently with very limited information about the user characteristics. Other methods include cyclo-stationary feature-based sensing and matched filter-based sensing which require specific details of the spectral user[10]. It is evident that when the signal to noise ratio is very low, a sensing system is likely to find it difficult to distinguish the radio signal from the noise. Hence, the knowledge of the noise power will is vital to the detector to enhance its detection performance.

Although the best mode of transmission can be accomplished using spectrum sensing mechanism, the best channel in which the transmission should occur to optimize the spectrum utility requires further processing. Game theory is a mathematical model providing to any situation where both co-operation and conflict co-exist between the individual decision makers called players[11]. During the mathematical evaluation, each player must consider all the possible interactions and follow a set of rules for determining their maximum payoff[12]. In complex situations like the one present in dynamic wireless communication, a non-cooperative gaming model for selecting the best channel for transmission[13] is achieved by determining the utility function of each channel present in the spectrum.

This Paper discusses a Hybrid Cognitive Radio model generated in LabVIEW, where an Energy Detector selects the overlay and underlay mode transmission acknowledging the signal energy present in the channel. This spectrum sensing mechanism along with a mathematical model for the Utility function, continuously analyze the behavior of the cognitive nodes in the proposed system. The SU on listening to the nodes decides if a channel is unused or under used. Accordingly if a PU band is free it will enable the SU to transmit in overlay mode; else when no PU bands are free underlay mode transmission is adopted. A Channel Allocation Algorithm simultaneously decides the best channel onto which the transmission may proceed. The SDR implementation of the proposed system will be appropriate one to switching and reconfiguring between the two waveforms [14]. The spectral efficiency of the cognitive is usually improved by full duplex system[15]. But here we use hybrid mode of the transmission to increase the spectral efficiency.

2. System Model

This paper constitutes the system model which includes the transceiver block as shown in Figure 1. The structure of the transceiver module of hybrid cognitive radio comprises of transmitter and receiver antennas, RF hardware, up and down converter, Spectrum sensing unit and SMSE block. The transceiver is designed to utilize the best wireless channels to avoid spectrum congestion. To accomplish dynamic spectrum management, this automatic detection of available channels in the wireless spectrum is being done. It is required to use vacant spectrum resource sharing to primary users. This transceiver scans the spectrum to find white spaces and transmit adaptive signals. After the successful implementation of hardware and simulation codes in LABVIEW software which includes the SMSE (Spectrally Modulated Spectrally Encoded) control variable detector generator, overlay generated waveform using Orthogonal Frequency Division Multiplexing which is the digital multi-carrier modulation technique used for the primary transmitter, underlay generated waveform using Multi-Carrier Code Division Multiple Access used for the secondary transmitter by multi-path propagation access, and addition of game theory the successful transmission and reception of hybrid cognitive waveform is generated thus resulting in an intelligent Software defined radio system, Hybrid cognitive radio along with game theory. Continuous sensing

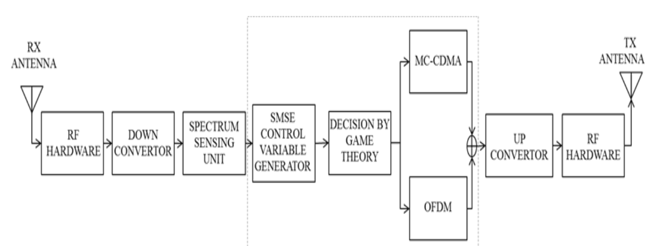


Figure 1. Transceiver module of Hybrid Cognitive radio.

of the spectrum occupancy is essential in cognitive radio systems; hence, the spectrum sensing unit is utilized in the transceiver block. SMSE is an analytical mathematical framework capable of designing a variety of waveforms. It is capable of constructing signals in frequency domain but converts into time domain in the channel and then decodes it. The up and down converter performs the Analog to digital and the vice versa conversions for the transmission and reception of signals. The RF hardware is the USRP294R, which is implemented to demonstrate the hybrid waveform obtained.

Spectrum sensing is one of the crucial functionalities of a cognitive radio to learn the radio environment. The key objective behind spectrum sensing and detection is to see how reliable one could detect the radio users given say, an acceptable threshold level. The energy based spectrum sensing and detection is the simplest method for detecting primary users. It estimates the signal power in the channel and compares that estimate to a threshold. The most challenging task in the implementation of cognitive radio is that the secondary user should identify and detect the presence of the primary user in licensed spectrum and if there is already a transmission occurring in the primary user spectrum then the secondary user should sense it and stop its transmission of data thereby switching to the next available channel. This process is known as spectrum sensing and is achieved by many methods. The method which is adopted is the primary transmitter detection method known as energy detector method. It is a noncoherent method where the detector detects the presence of a primary signal by sensing the amount of energy obtained from the received signal. It is easy to implement because it doesn't need any prior information about the primary signal and also ignores the structure of the signals. Energy Detector compares the output with a pre-fixed threshold value. This comparison is made to detect the absence of primary signal and the value of the threshold can be fixed or variable according to the channel conditions. The energy detector which we have implemented using LABVIEW is given in Figure 2(a) and (b). The game theory constitutes of the utility function which plays a vital role in the game. However, the choice of the utility function is not unique. Several parameters such as data rate, delay, transmit power, etc. can be considered for this purpose.

The utility function mathematical equations are:

$$U_i\left(S_a\right)=\frac{\log_{10}(B_{s_a}/k_{s_a})}{\log_{10}(k_{s_a}-1)} \qquad (1)$$

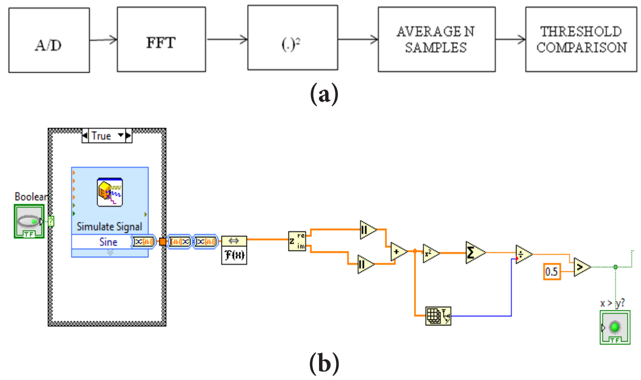


Figure 2. Energy detector **(a)** block diagram **(b)** LABVIEW code.

$$U_i\left(S_{-a}\right)=\frac{\log_{10}(B_{s_{-a}}/k_{s_{-a}})}{\log_{10}(k_{s_{-a}}+1)} \qquad (2)$$

Where $U_i(S_a)$ and $U_i(S_{-a})$ are the utility functions of various strategy profile

S = [s1, s2....sN], B_{s_a} and $B_{s_{-a}}$ are the achievable channel bandwidth relative to strategy Sa and S–a respectively. K_{s_a} and $K_{s_{-a}}$ denote the number of users in the channels.

The algorithm to implement this game theory is as follows:

1. Begin with random channel allocation.
2. While channel<C Calculate utility of the channel from the received packet date rate
   Channel = Channel + 1
   End
3. Compute Max sa (Ui(sa)), ∀a∈C to select best channel.
4. Set the channel to transmit packet.
5. Repeat step 2 to 4 for every packet.

3. Overlay Waveform Generation by OFDM

For the generation of overlay waveform OFDM (Orthogonal Frequency Division Multiplexing technique is used along with the Quadrature Phase Shift Keying modulation technique. OFDM is a digital multi-carrier modulation method of encoding data's which gives the information of input bits on multiple carrier frequencies. Each sub-carrier is modulated by Quadrature phase shift keying. Each signal is orthogonal to each other in this technique. It does not allow multipath propagation thus, avoiding interference.

It provides a steady flow of data for primary (licensed) users. It is bandwidth efficient, thereby providing data to each user. The advantages of OFDM techniques includes attenuation of high frequency, channel equalization, signal to noise ratio improvement, etc. It is sensitive to spectrum sensing and loses its efficiency due to the addition of a cyclic prefix. The block diagram of OFDM transmitter and receiver section is given in Figure 3(a) & (b).

The block diagram constitutes the input and output data bits, QPSK modulation, demodulation, fast Fourier and inverse fast Fourier transform, cyclic and de-cyclic prefix, analog to digital converter and digital to analog converter. QPSK is a bandwidth efficient modulation technique where the input bit steam is break up into two bits and later these two bits. It converts two binary bits into the complex signal output. This complex signal selects one of the four phases based on two binary digits where each state of complex signal or waveform is a symbol. The FFT (Fast Fourier Transform) is a discrete Fourier transform algorithm which is used to reduce the number of computations needed to interleave, encode and retrieve the symbols successfully. The IFFT (inverse fast Fourier transform) provides the inverse function to receive the demodulated output signal. The cyclic prefix a with OFDM systems which refer to the prefixing of a symbol with a repetition at the end. It is used as guard interval and eliminates intersymbol interference. It also allows linear convolution of frequency selective multipath channels. The de-cyclic prefix is used to convert the signal back to the form suitable to perform the fast Fourier transform in the receiver section.

The mathematical equation for the OFDM-based overlay waveform description is as follows.

The general QPSK modulation waveform is expressed as

$$S(n) = (2E_s/T_s)^{1/2} \cos((i-1)\pi/2) \cos(2\pi f_c n) - (2E_s/T_s)^{1/2} \sin((i-1)\pi/2) \sin(2\pi f_c n),\ 0 \le n \le T_s \quad (3)$$

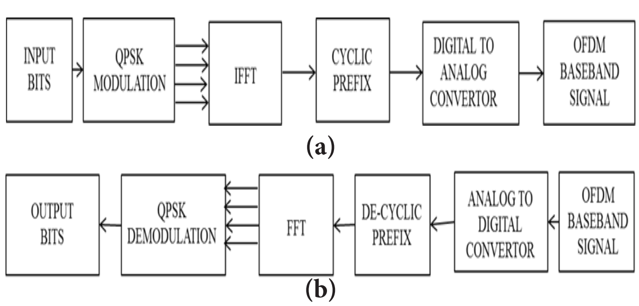


Figure 3. OFDM block diagram **(a)** transmitter **(b)** receiver.

where T_s is symbol duration, twice the bit period.

The N point IDFT i.e. IFFT equation is expressed as

$$Y(n)=1/N\sum_{n=0}^{N-1} S(n)e^{j(\frac{2\pi}{N})}Kn \quad (4)$$

The OFDM waveform along with guard interval i.e. cyclic prefix is expressed as

$$O(n) = [C(n)\ Y(n)] \quad (5)$$

$$O(n) = [Y((N-1)-10)\ Y(N-1)-9)\ldots.\ Y((N-1)-1)\ Y(N-1)\ Y(0)\ Y(1)\ Y(2)\ldots Y(N-1)] \quad (6)$$

where C(n) is the cyclic prefix which is $C(n)=\sum_{K=N-1-10}^{N-1} Y(n)$

At the receiver section of the obtained OFDM waveform after removing the cyclic prefix C(n) the output is expressed as

$$Y(n) = [Y(0)\ Y(1)\ Y(2)\ldots Y(N-1)] \quad (7)$$

The FFT applied waveform is given as

$$F(n)=\sum_{n=0}^{N-1} Y(n)e^{-j(\frac{2\pi}{N})}Kn \quad (8)$$

The waveform is demodulated and the required output bit is obtained at the receiver and is expressed as

$$\text{Output bits } B(n) = \text{decod}\,[F(n)] \quad (9)$$

4. Underlay Waveform Generation by MC-CDMA

For the generation of underlay waveform, MC-CDMA technique is being used. It is majorly utilized in OFDM-based systems, allowing the systems to utilize the same frequency band by multiple users at same time. In this technique, each symbol is phase shifted to 0º or 180º based on a code value. The receiver undoes the code shift and also combines all the sub- carrier signals after weighing them and it will also separate signals to each user because of having different code values. It is mainly a form of direct sequence multiple access where the orthogonal operation can be applied to the user bits. It includes spreading and de- spreading of codes at the transmitter and receiver parts respectively. It applies these spreading sequences in the frequency domain and original information being spread directly in frequency domain where each bit can be transmitted simultaneously to many users. It spreads the energy obtained by the user data symbols over the channel and offers frequency diversity by providing multiple access to various channels. It further avoids interference in the transmission channels due to the spreading codes and assignment to individual users respectively. It spreads data symbol on different sub – carriers in a parallel manner and nearly gathers all energy scattered in sub-carriers. This technique is suitable for the indoor wireless environment where there will be a small delay and Doppler spread. Figure 4(a) & (b) illustrates the block diagram of the transmitter and receiver section of multi-carrier code division multiple access. This block diagram constitutes the spread symbols and de-spread symbols, serial to parallel and parallel to serial converters.

The mathematical representation of underlay waveform can be given as:

Since the OFDM structure is used in MC-CDMA similar equations are applicable for underlay waveform as well .In this system there is an addition of spread symbol before applying Inverse Fast Fourier Transform. Given that the output of QPSK is S(n), along with addition of the spreaded symbol G(n) the obtained waveform equation P(n) is given as

$$L(n) = S(n) \oplus G(n) \tag{10}$$

The N point IDFT i.e. IFFT equation along with the added spread symbols G(n) is expressed as

$$X(n)=1/N\sum_{n=0}^{N-1} L(n)e^{j(\frac{2\pi}{N})}Kn \tag{11}$$

At the receiver section, the received MC-CDMA waveform is applied an FFT operation after removing the cyclic prefix. This signal is de-spread and demodulated to retrieve back the original signal.

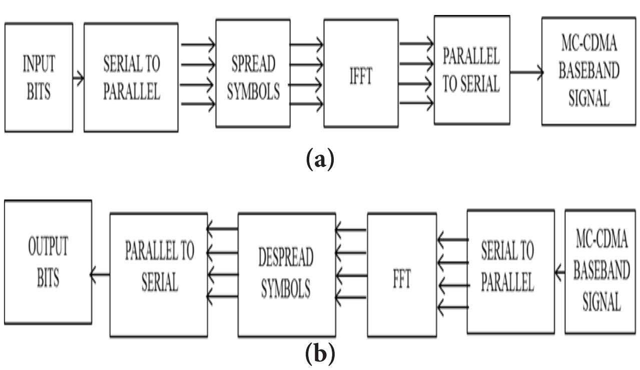


Figure 4. MC-CDMA block diagram **(a)** transmitter **(b)** receiver.

The FFT applied waveform is given as

$$F(n)=\sum_{n=0}^{N-1} X(n)e^{-j(\frac{2\pi}{N})}Kn \tag{12}$$

The waveform obtained after the removal of spread symbols is expessed as

$$D(n) = F(n) \oplus G(n) \tag{13}$$

The original bits is retrieved by demodulating the obtained waveform which is expressed as

$$\text{Output bits } B(n) = \text{decod } D(n) \tag{14}$$

The waveform is demodulated and the required output bits are obtained at the receiver.

5. Hardware Implementation

The hardware used to accomplish this implementation of hybrid cognitive radio is Universal Software Radio Peripheral (USRP) 2943R and vertical omnidirectional antennas for obtaining the hybrid waveform. Figure 5 shows the picture of the USRP 2943R. The universal software radio peripheral is an open source hardware which was designed for connecting a host computer through a high-speed link, which can be utilized by the host based software control the USRP hardware. It has an LABVIEW programmable FPGA on board which enables it to be used in applications related to cognitive radio, spectrum sensing, wireless prototyping, etc. Field programmable gate array being an integrated circuit is designed to be configured after manufacturing by a customer. It constitutes of an array of programmable logic blocks and reconfigurable interconnects that wires the blocks together like logic gates in a different configura-

Figure 5. National instruments universal software radio peripheral 2943R.

tion. USRP2943R uses the kintex-7 family of FPGA. Other applications of USRP being RFID reader, Frequency modulated radio transmitter and receiver, Global positioning system receiver, etc. It offers some of the features like complete ready-to-use teaching solution with lab ready courseware for wireless communication, affordable platform for hands-on learning with real-world wireless signals and programmable FPGA for advanced research applications. It enables transmission and reception of wireless signals up to 20MHz bandwidth, multi-device synchronization options, contains Gigabit Ethernet port for connection to host PC, contains options for GPS disciplined clock. This USRP hardware is provided by National Instruments. Figure 5 illustrates the model of USRP being used.

6. Results and Discussion

The simulation is done using LABVIEW software, which is the acronym for Laboratory Virtual instrumental engineering work bench. It is cross-platform software which uses the graphical language known as G. The LabVIEW files have a .vi extension. It includes features including instant compilation, inherent parallelism, signal processing analysis, seamless hardware implementation, combine and reuse various forms of files control and simulation models. Both the blocks of OFDM and MC-CDMA along with the SMSE mechanism and spectrum sensing by energy detector method are implemented using LabVIEW. The SMSE mechanism is implementing by formulating a case structure in LABVIEW. The energy detector block diagram is implemented for the spectrum sensing unit. In the OFDM and MC-CDMA transmission setup, the required Bit error rate characteristic output i.e. BER vs. Eb/No graph is plotted and for the end value of SNR as 30, the EB/No is obtained as 24.The eye diagram graph and constellation outputs are also shown as the result of the required values. The necessary input terminals and parameters are assigned to the PSK modulator block in LabVIEW for the OFDM. The constellation graph and eye diagram blocks in LabVIEW are added for both overlay and underlay waveform, and the required output is obtained as given in Figure 6 along with the BER vs. Eb/No graph. The start and end values of SNR are provided by implementing two for loop structures in LabVIEW to execute it as many times required for the proper structure of BER vs. Eb/No graph. The SMSE mechanism is achieved by

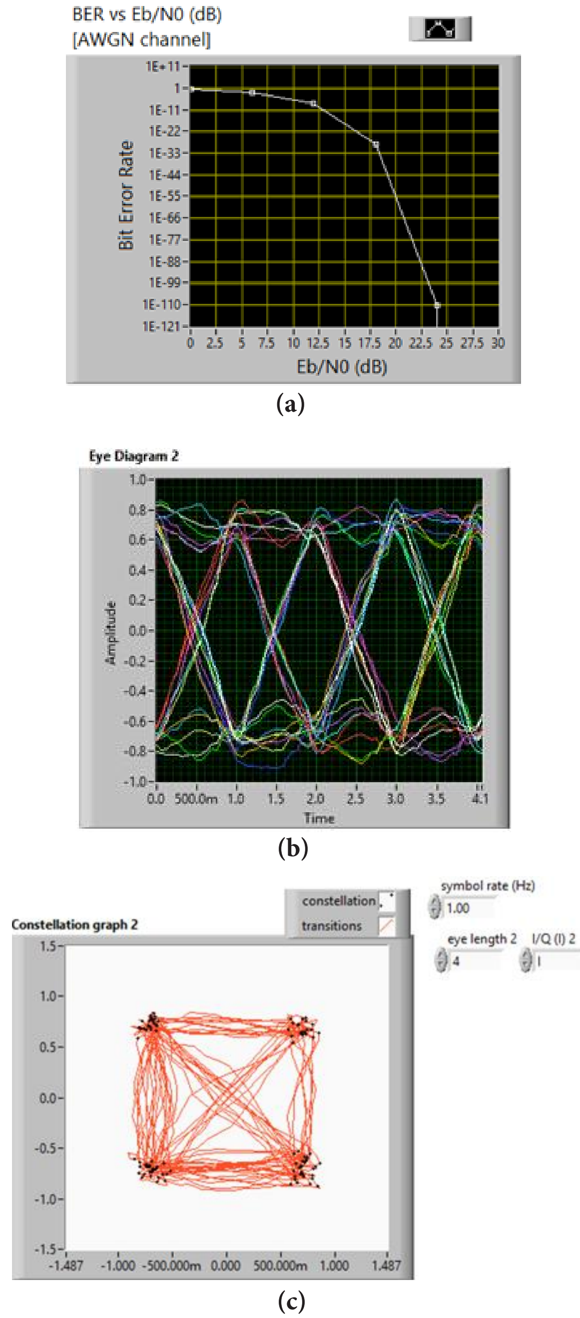


Figure 6. **(a)** BER Vs Eb/No characteristic graph **(b)** Eye diagram graph **(c)** Constellation graph.

implementing the case structure where a Boolean logic is added in which for false overlay waveform is generated likewise for true underlay waveform is generated. The energy detector generates the signal which is compared with the pre-defined threshold value say 1.5 and if the compared value obtained as a result is false the overlay waveform is obtained and for true underlay waveform is obtained. In other words while running the setup in idle mode the energy detector senses and detects the primary spectrum i.e. OFDM transmission of overlay waveform is obtained whereas if the setup is run in active mode the detector senses the spectrum of secondary user and allows the flow of underlay waveform by MC-CDMA technique thus in situations obtaining hybrid waveform consisting of both overlay and underlay waveform. The various parameters that have been changed for the generation of waveforms are listed in the Table 1.

The BER Vs Eb/No graph obtained for the start and end values of SNR as 0 and 30 respectively. From the obtained output the BER reduces exponentially as the SNR increases and once it reaches the value of 24, there is no traces of bit error hence producing the full recovery of signal without any noise.

Eye diagram obtained from the LABVIEW output with proper opening depicting less noise available in channel with no inter symbol interference.

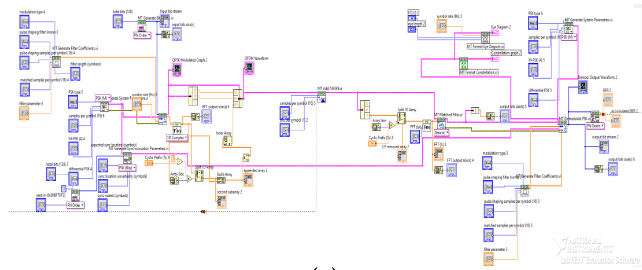
Constellation graph obtained with four points depicting the reliable decoding in channel.

7. LABVIEW Code

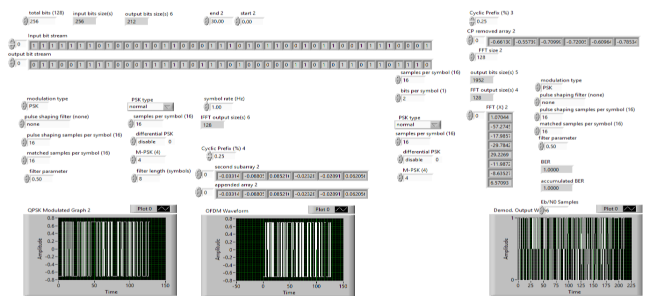
The LABVIEW code including block diagram and front panel for OFDM and MC-CDMA is illustrated below where the OFDM LABVIEW code constitutes of the necessary input and output blocks with a proper system and synchronization parameters along with the waveform graphs and output graphs including BER Vs Eb/No, Eye diagram and constellation graph. A similar arrangement is shown in MC-CDMA code including the spreading and de-spreading code blocks. The LABVIEW codes are illustrated in Figures 7 & 8.

Table 1. Parametric values included in LABVIEW code

SNO	PARAMETERS	VALUES or DESCRIPTION
1	Modulation type	Phase shift keying
2	M-PSK	4
3	Filter parameter	0.50
4	Symbol rate	1
5	Sync indent	1
6	Filter length (symbols)	8
7	Cyclic prefix %	0.25
8	Bits per Symbol	2
9	Samples per symbol	16
10	Start Signal to Noise Ratio	0
11	End Signal to Noise Ratio	30
12	Eb/No samples	6

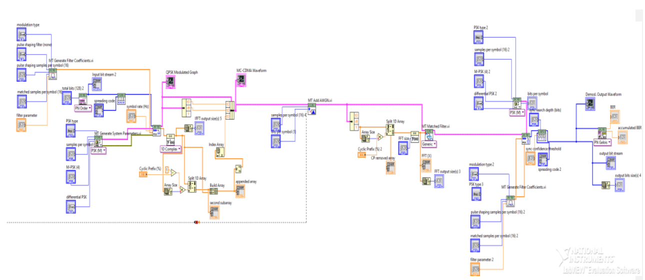


(a)

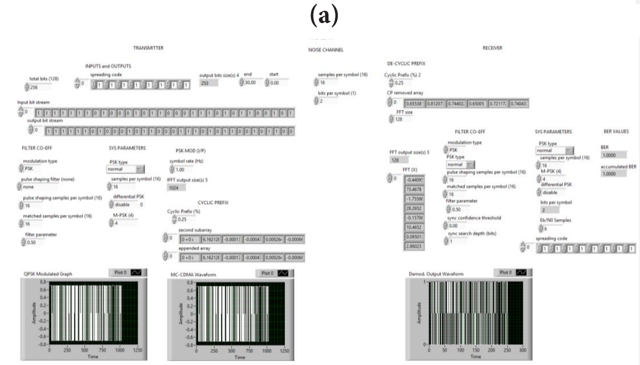


(b)

Figure 7. OFDM LabVIEW Code **(a)** block diagram **(b)** front panel.



(a)



(b)

Figure 8. MC-CDMA LabVIEW code **(a)** block diagram **(b)** front panel.

8. Conclusion

Hybrid Cognitive Radio is an emerging tool in Wireless Communication Networks for maximizing the utilization of RF spectrum. It provides an effective solution for secondary users to access an available channel through both overlay and underlay modes of transmission. The implementation of this Hybrid CR in real-time using a simple game theory function would enable secondary users to achieve maximum throughput. Hence, can potentially increase the transmission rate and solve the current challenge of spectrum congestion.

9. Acknowledgement

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