Journal of
Electrical & Electronic Systems

Kang and Vig, J Electr Electron Syst 2014, 3:3
DOI: 10.4172/2332-0796.1000128

Research Article Open Access

BER Performance Analysis of Filter Bank Multicarrier Using Sub band Processing for Physical Layer Cognitive Radio

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Rec date: Apr 05, 2014; **Acc date:** May 19, 2014; **Pub date:** May 29, 2014

Abstract

Cognitive Radio (CR) Technology has emerged from software defined radios wherein the key parameters of interest are frequency, power and modulation technique adopted. The role of Cognitive Radio is to alter these parameters under ubiquitous situations. The Spectrum Sensing is an important task to determine the availability of the vacant channels to be utilized by the secondary users without posing any harmful interference to the primary users. In Multicarrier Communication using Digital Signal Processing Techniques, Filter Bank Multi Carrier has an edge over other technologies in terms of Bandwidth and Spectral Efficiency. The present paper deals with the Multi Rate FIR Decimation and Interpolation Filter along with Usage of two band Analysis and Synthesis sub band processing approach for physical layer of Cognitive Radio under fading channel environment.

Keywords: Cognitive Radio(CR) technology; Digital signal processing techniques; Spectral efficiency; Bandwidth; Filter bank multi carrier; Transmit-power control; Radio frequency

Introduction

The radio frequency spectrum is a multi-dimensional concept having features useful for Dynamic Spectrum Access and Transmit-Power Control. Radio Frequency, Bandwidth, Modulation technique, Power Allocation Scheme and Transmit Diversity etc. influence the performance enhancement of any wireless communication system based on 4G. There are immense areas having vital applications of radio spectrum in defense, public safety and emergency network situations. For the sake of achieving the higher efficiency of a communication system, the following two important physical characteristics play a crucial role in wireless domain. Effective communication of two radio stations at same frequency and the susceptibility of two stations operating within same geographical area to the mutual interference leading to the degradation in the quality of communication taking place between them. Cognitive radio was invented with brain for intelligence of its own with capability of decision making to provide a unique solution to the problem of spectrum underutilization.CR can sense the surrounding environment and depending upon the information as well as requirement of situation needs and alters its physical layer parameters after reconfiguration [1].

Cognitive cycle

The major tasks in a cognitive radio include: Radio Scene Analysis, Channel Identification, and Dynamic Spectrum Management & Transmit Power Control [Figure 1]. Radio Scene Analysis performed in the receiver comprises of estimation of interference temperature of the surrounding radio environment of the receiver, detection of spectrum holes and predictive modelling of the environment. Channel Identification performed in the receiver is needed for coherent detection of message signal as well as for improving the spectrum utilization. Dynamic spectrum management and transmit power control performed in the transmitter make decision on transmission parameters based on the information provided by radio scene analysis and channel identification [2,3].

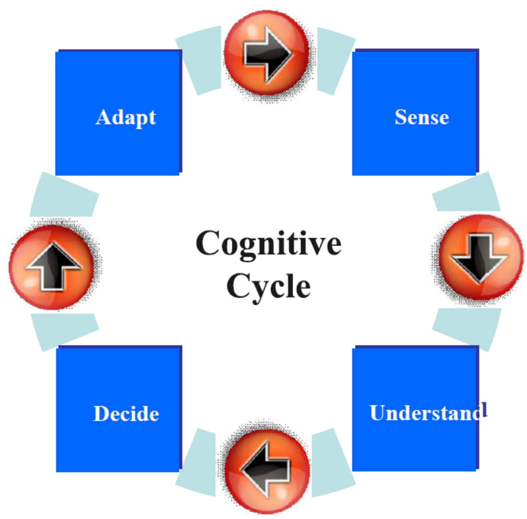

Figure 1: Generic Cognitive Cycle.

Capabilities of cognitive radio

The following capabilities are needed for the functionality of cognitive radio. Flexibility and Agility, Sensing, Learning &

Adaptability. The following four functions are mainly performed by cognitive radio.

[1] Spectrum Sensing: It determines the status of the spectrum and detects the presence of primary users.

[2] Spectrum Management: It allocates the available frequency channels to unlicensed secondary users.

[3] Spectrum Sharing: It shares the resources for secondary users.

[4] Spectrum Mobility: Whenever the primary user wants to have the access to channel that secondary user is using, then secondary user immediately vacates that channel for Primary user, thereby switching on to some other vacant channel available nearby [4,5].

Signal processing perspectives in cognitive radio-related work done

Multi-rate DSP is required in digital systems where more than one sampling rate is required. The applicability of multi-rate signal processing approach is in the areas of Communication Systems, Speech & Audio Processing systems, Antenna & Radar Systems. Advanced technique on multi-rate signal processing can be applied for information processing digitally due to the advantages like lesser computational requirements, less storage for filter coefficients, less finite arithmetic effects, Low requirement of filter order in multi-rate application, less sensitivity to filter coefficient length.

Satwant Kaur presented the wireless networks with cognitive radio technology and discussed its various functions and capabilities as a new networking arena for future wireless communication systems [2].

Shaat discussed the efficient resource allocation algorithms for uplink in multicarrier based cognitive radio networks with fairness consideration. The author also compared OFDM and FBMC based cognitive radio systems [3].

William Krenick described in detail the various spectrum sensing techniques for Cognitive radio and their applicability for wide area networks [6].

Zhang did comparative performance analysis of OFDM and OFDM-OQAM based cognitive radio techniques in terms of spectral efficiency and capacity [7].

Laddomada presented a multi rate approach for the recovery of wideband global navigation satellite system signals. Two or more narrow band front ends were used for collecting the different portions of spectrum of wideband navigation signal that was then reconstructed from its sub band components [8].

Mohamed Hamid et al. investigated the MAC layer sensing schemes in CR. Simulated results show that to guarantees as low idle channel search delay as possible a proactive sensing is the best scheme to be used [9].

Farhang-Boroujeny and (George) Yuen presented a tutorial review relating the classical works on FBMC systems, developed prior of the era of OFDM, to the main filter bank design approaches used today for FBMC systems. The author also reviewed the recent novel developments in the design of FBMC systems that are tuned to cope with fast fading wireless channels [10].

Moret and Tonello addressed the efficient realization of a filtered multi-tone (FMT) modulation system. The author analyzed three different realization structures, presenting also numerical comparisons, and compares the best FMT approach with a cyclically prefixed OFDM system in the IEEE 802.11 wireless LAN channel [11].

Ziyang Ju et al. developed a method to diagonalize a doubly dispersive channel in the time-frequency domain using a filter bank approach. The related paraunitary filter bank design problem is formulated as a convex optimization problem, and the performance of the resulting window is investigated under different channel conditions [12].

Jun Ma et al. discussed the practical issues involved to build a CR network from perspective of signal processing. The author identified spectrum sensing and spectrum sculpting as the two fundamental capabilities for any CR network to adapt to its environment and provide resilience under adverse conditions [13].

Zhang et al. studied channel capacity of cognitive radio (CR) networks using CP-OFDM and FBMC waveforms, taking into consideration the effects of resource allocation algorithms, intercell interference due to timing offsets, and Rayleigh fading. Final results show that FBMC can achieve higher channel capacity than OFDM because of the low spectral leakage of its prototype filter [14].

Amini and Farhang-Boroujeny developed a packet format for FBMC systems together with algorithms for carrier frequency and timing recovery. Also methods for channel estimation as well as carrier and timing tracking loops are proposed [15].

Stitz et al. presented a detailed analysis of synchronization and channel estimation methods for FBMC based on scattered pilots. The special problems related to using scattered pilot-based schemes in FBMC are highlighted. The channel parameter estimation and compensation are successfully performed totally in the frequency domain, in a sub channel-wise fashion, which is appealing in spectrally agile and cognitive radio scenario [16].

Tero Ihalainen introduced a new low complexity per-subcarrier channel equalizer for FBMC transceiver for high-rate wideband communication over doubly-dispersive channel and analyzed its performance. It was shown that the coded error-rate performance of FBMC is somewhat better than that of the OFDM reference [17].

Linnea Rosenbaun et al. introduced an approach for synthesizing modulated maximally decimated FIR FBs using the FRM technique. Each of the analysis and synthesis FBs was realized with aid of three filters, one cosine modulation block and sine modulation block. The overall FBs achieve nearly PR with a linear phase distortion function [18].

Christian Feldbauer et al. described that in single rate systems; only one sampling rate is used whereas in multi-rate systems the sampling rate gets changed at least once. The paper deals with the realization and analysis of multi-rate systems [19].

Mohammad Abo Zahhad (2003) provided an overview of basic concepts, current state and future directions of uniform and non-uniform multi-rate filter banks and their applications. Different design techniques and algorithms that were of interest were investigated from hardware complexity and reconstructed signal's quality point of view [20].

Problem formulation

Cognitive Radio is able to work in different frequency bands and various wireless channels and supports multimedia services such as

Citation: Kang AS, Vig R (2014) BER Performance Analysis of Filter Bank Multicarrier Using Sub band Processing for Physical Layer Cognitive Radio. J Electr Electron Syst 3: 128. doi:10.4172/2332-0796.1000128

voice, data and video. Reconfigurable radio architecture is proposed to enable the evolution from the traditional software defined radio to cognitive radio. The present study has its focus on Performance Analysis of Filter Bank Multicarrier (FBMC) based Cognitive Radio (CR) in adaptive, opportunistic, autonomic domain under different strategic conditions of AWGN Channel.

By introducing the techniques to improve the spectral efficiency and minimize the spectrum underutilization and interference along with minimum power consumption and Bit Error Rate (BER), the overall performance of FBMC based CR can be improved.

The AWGN fading channel has been used for facing the different fading phenomenon during signal transmission. The main cause of fading is multipath propagation. The signal reaches the receiver from different paths which have different delays and different path gains. The paths of propagation can be constructive or destructive. The received signal is the algebraic sum of the different paths of propagation.

Performance analysis

The flowchart for initializing the five carrier frequencies for five users at a sampling frequency with a suitable modulation technique for modulating the user's data over a respective frequency band [Figure 2]. All the modulated signals are added to create a carrier signal and then spectrum periodogram output plot is obtained for estimating the power spectral density. Further, empty slot allocation is done which is clear from the output plot. When a new user arrives, it is assigned a first spectral hole. If all the slots are reserved, then the user is asked to empty a particular slot. After emptying a slot for allocation, certain amount of noise is added to the user slot just for the sake of analyzing the percentage of attenuation required. Ultimately, the final output plot is observed for this simulation. This process can be repeated a number of times with different empty slot allocations to different users with different amounts of noise proportions to be added for getting a huge variation in the power versus frequency allocation graphic output plots.

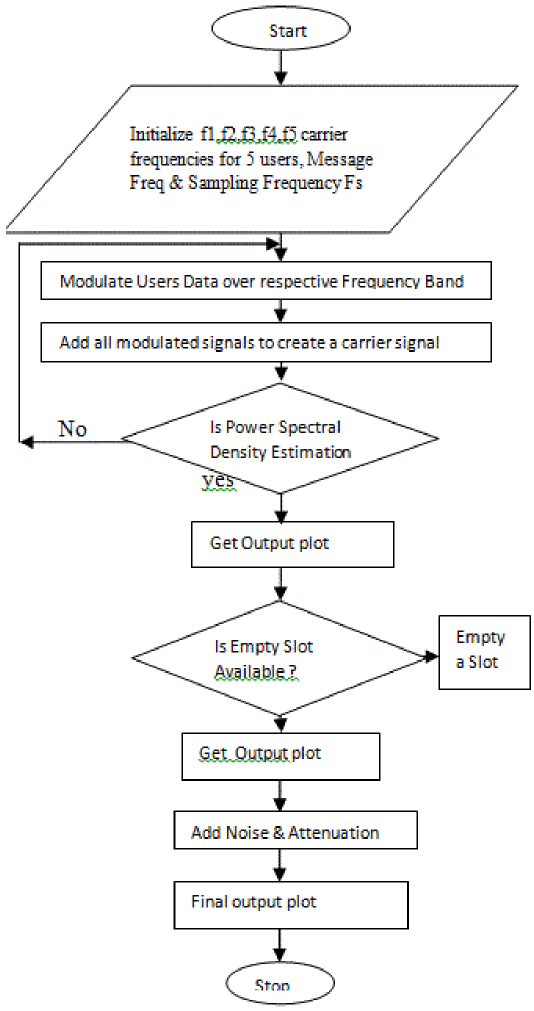

Figure 2: Flowchart for simulation set up.

Simulation study of two channel analysis sub-band and synthesis sub-band filter processing

The Simulink based FBMC-CR Model using AWGN Channel with FIR Decimation and Interpolation Multi-rate Filters has been developed and implemented as a CR system design [Figure 3]. The effect of various parameters given in the blocks of this Simulink model has been studied which is further helpful for achieving our goals as per with our Simulation test bed block diagram.

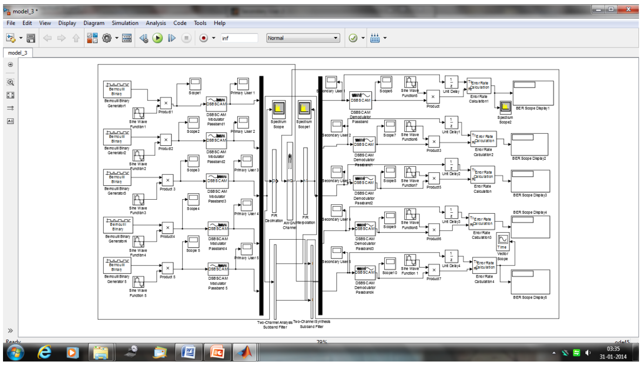

Figure 3: FBMC-CR Simulink Model for physical layer under AWGN channel prior to run.

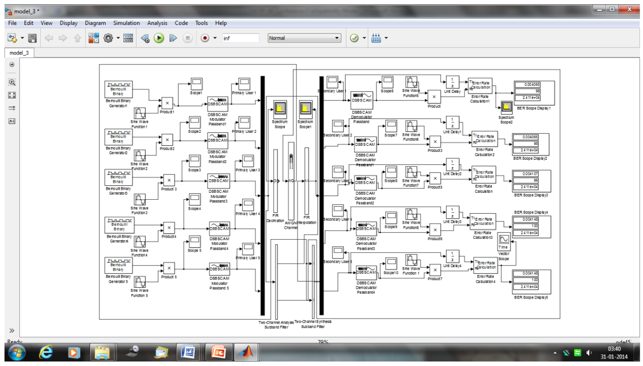

Figure 4: FBMC-CR Simulink Model in running mode.

Results and Discussion

Simulation model was run over several iterations [Figure 4] and output scopes for five primary users as input and five primary users output along with secondary users output scope displays have been obtained which clearly depicts the propagation of sharp spike pulse as input from product modulated output of Bernoulli Binary Generator and Sine wave .Then the primary user input signals are passed through DSBSC AM Modulator Pass band whose output is further made to pass through Multiplexer and DE multiplexer. Now in between Multiplexer and De-Multiplexer there is a cognitive radio environment composing AWGN channel with pre and post processing devices in form of FIR Decimation and FIR Interpolation Filters with two band analysis and synthesis sub band processing. The output Spectra of these multi-rate filters used is analyzed with the help of Buffered FFT Scopes. Then, their output passes through all the counter blocks analogous to the Transmitter side of this model. A Unit delay block is introduced for taking into consideration the Tx and Rx error rate calculation block to which a set of five product demodulated outputs is fed as another input. Ultimately, Bit Error rate of the order of 0.004065 (4*10-6) is computed for showing the effect of attenuation and other technical parameters set in the various Simulink parameter blocks on Secondary users. Figures 5-7 show the spectrum scopes of the output signal while Figures 8-12 are the primary user input signals. Figures 13-16 show the function block parameters of the present study. Figures 17-21 show the secondary users output.

A Code for the proposed study on Cognitive radio has been generated in Matlab R2013a version.

Conclusion

The present study shows the simulation of cognitive radio system for assessing the dynamic spectrum at the run time. The Magnitude squared (dBW/Hz) versus Frequency (hz) plots at two instants prior to decimation and after interpolation show the more places of spectrum that are prone to underutilization. At the third instant, after the secondary users, there is a lesser side lobe tail attenuation, also showing lesser spectrum underutilization due to less number of white spaces(spectrum holes for cognitive users) which fulfills the need of cognitive radio network for enhanced spectral efficiency. The BER range of the order of 0.004065,0.004107,0.004148…is computed at different simulation runs or iterations is also a good indicative measure to prove the lesser spectral leakage in the frequency components while passing through the radio frequency channel environment. Hence, an attempt has been made to get better utilization of the bandwidth.

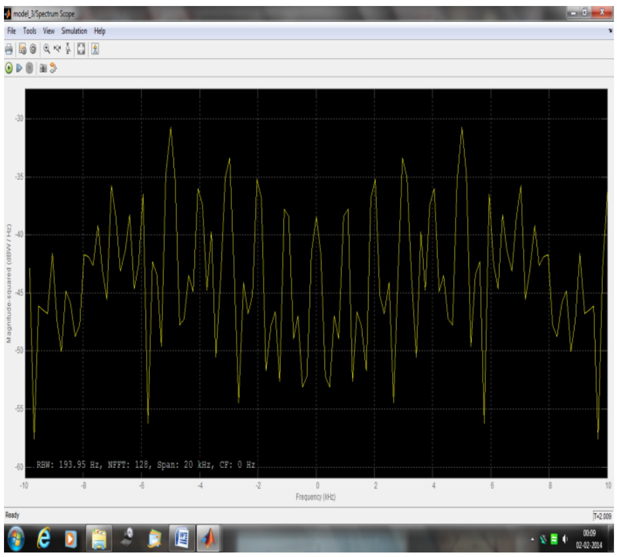

Figure 5: Spectrum scope output.

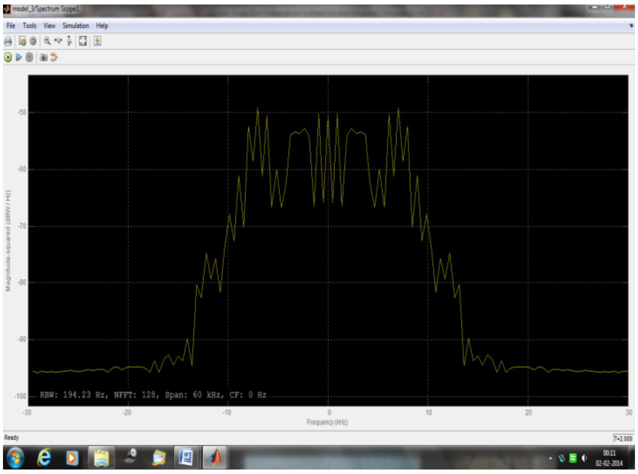

Figure 6: Spectrum scope 1 output.

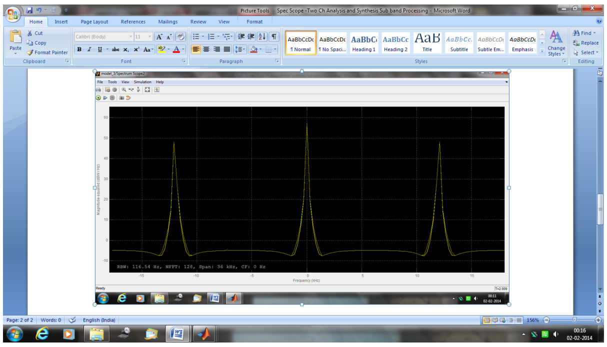

Figure 7: Spectrum scope 2 output.

Graphic output plots of different Primary Users and Secondary Users have been shown below.

Figure 8: Primary user1 input signal.

Figure 9: Primary user 2 input signal.

Figure 10: Primary user 3 input signal.

Figure 11: Primary user 4 input signal.

Figure 12: Primary user 5 input signal.

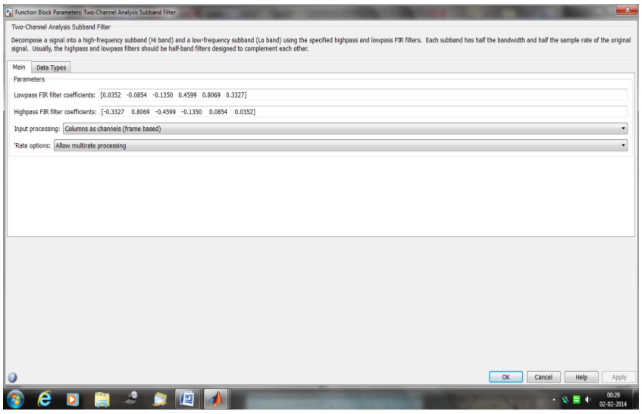

Figure 13: Two channel analysis sub-band filter parameters block.

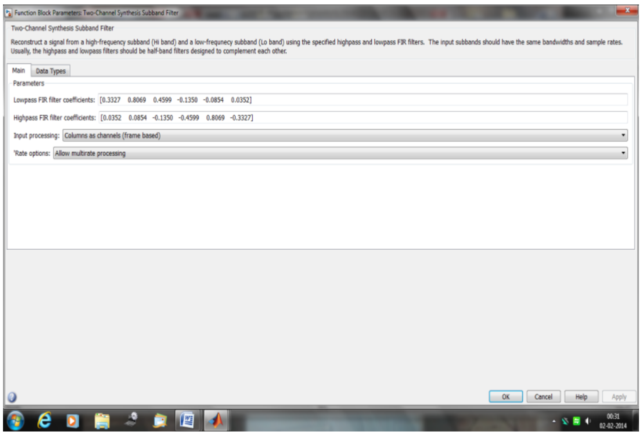

Figure 14: Two channel synthesis sub-band filter parameters block.

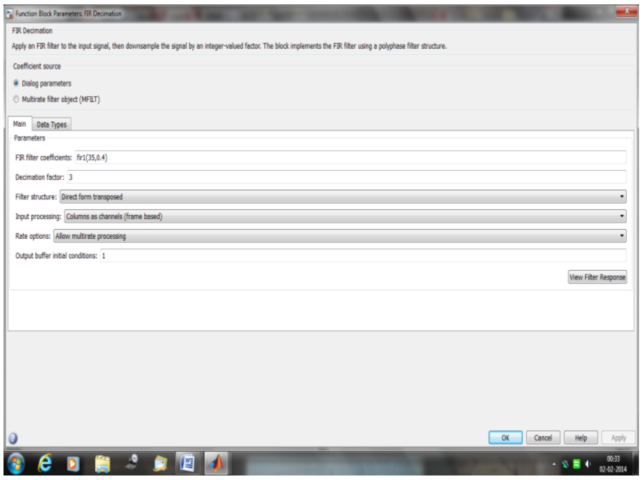

Figure 15: FIR Decimation: function blocks parameters.

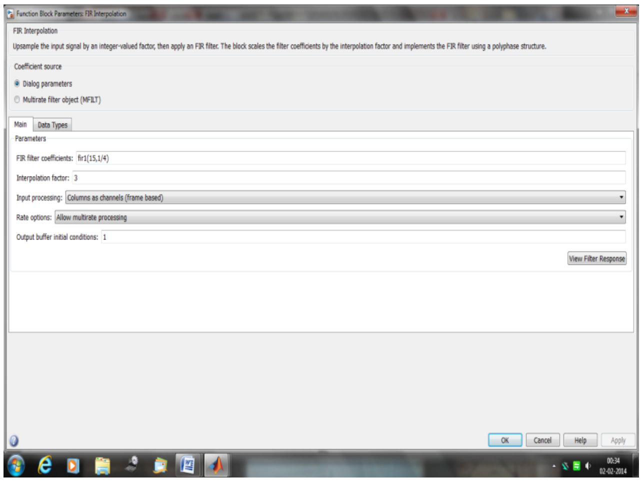

Figure 16: FIR Interpolation: function blocks parameters.

The BER computed in this Simulink model is of order of 0.004*10-3

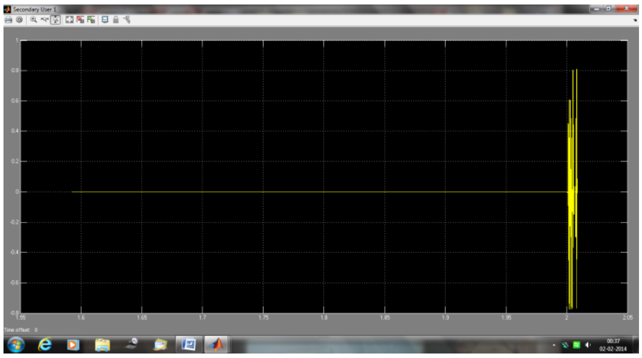

Figure 17: Secondary user 1 output.

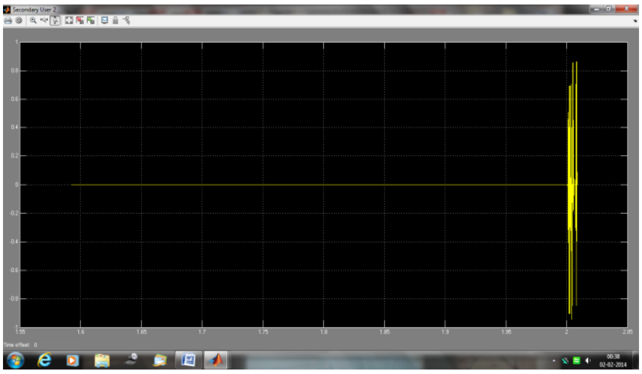

Figure 18: Secondary user 2 output.

Figure 19: Secondary user 3 output.

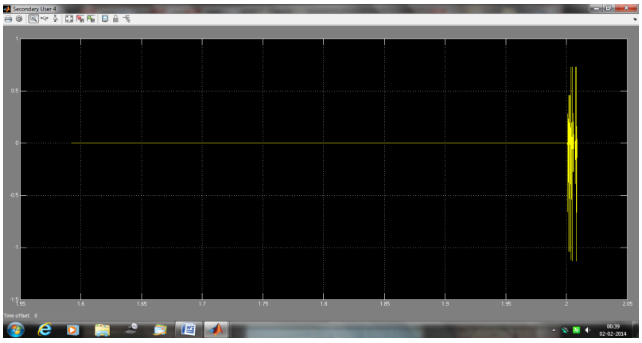

Figure 20: Secondary user 4 outputs.

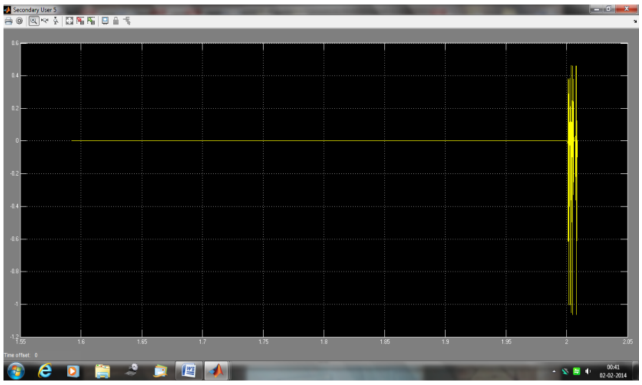

Figure 21: Secondary user 5 output.

Impact of Study

The expected outcome of proposed research will be helpful in detecting interference at primary receiver and speed and reliability of detection in Cognitive cycle of CR system. The Spread Spectrum Detection in terms of Power and with wide frequency range hidden in the noise can be done. The hidden node problem due to the multipath fading in the propagation between primary transmitter and sensing receiver can be studied by applying learning and intelligence approach. The most of the CR will have to autonomously work in multiservice, multi technology and multiuser environment and it has to adapt the different parameters under different conditions. Vertical and Horizontal sharing of radio spectrum will be possible to some extent with efficient spectrum space opportunities, spectrum mobility and transmission power control. The CR must be capable of spectrum sensing and operating over wide radio spectrum range, emulate many radio technologies and different modulation schemes which cause various hardware challenges. The present study will be useful for optimum selection of hardware components which will minimize circuit complexity and cost and less chances of interference. OFDM based CR network performance will improve with the application of multi-rate signal processing in multicarrier wireless communication. Better Radio Resource Management is possible. The problem of Congestion in ISM bands which adversely affects the quality of communication will be reduced by CR networks based on Dynamic Spectrum Access.

Future Directions

As Cognitive radio technology is an important innovation for the future of communications and likely to be a part of the new wireless standards, becoming almost a necessity for situations with large traffic and interoperability concerns. Moreover CR is devised to be used with telecommunications or computer network related disciplines but there are inadequate facilities to provide robustness and effective security. To overcome this, existing technologies will increase the complexity and new types of attack are possible. Therefore, innovative ideas are required to provide security to Cognitive Radio Networks and make them robust against crucial attacks, especially the attacks inherent to the Cognitive Radio functionality. So to make Cognitive Radio systems trustworthy, dependable and efficient, a comprehensive energy efficient mechanism is required to identify, remove or mitigate the attacks at any phases of the Cognitive Cycle.

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