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Computer Aided BER Performance Analysis of FBMC Cognitive Radio for Physical Layer Under the Effect of Binary Symmetric Radio Fading Channel

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Abstract The wireless communication has undergone a revolution due to advancements in technology. For each new user or application to be a part of communication network the preliminary requirement is the allocation of frequency spectrum band. This frequency band is a limited resource and it is impossible to expand its boundaries. So the need is to employ intelligent, adaptive and reconfigurable communication systems which can investigate the requiremenmts of the end user and assign the requisite resources in contrast to the traditional communication systems which allocate a fixed amount of resource to the user under adaptive, autonomic and opportunistic cognitive radio environment. Cognitive radio 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 utilised by the secondary users without posing any harmful interference to the primary users. In multi carrier 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 approach for physical layer of cognitive radio under binary symmetric fading channel environment.

Keywords Cognitive radio · Spectrum sensing · FBMC · Channel

1 Introduction

The users need for higher data rates is increasing at a faster rate in the world to fulfill their evergrowing demands for acessing the information anytime, anywhere under pervasive radio

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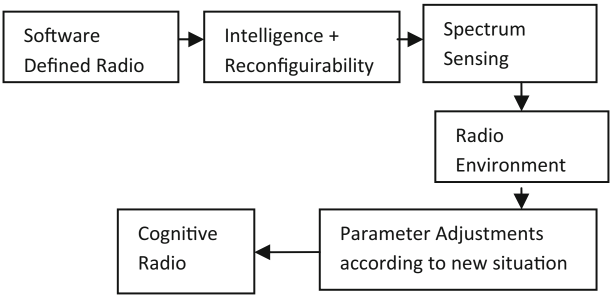

Fig. 1 Development of cognitive radio

environment. The amount of available frequency spectrum is however, limited. Radio spectrum is a important natural scarce resource needed for radio frequency communication. The radio spectrum is omnipresent in the form of invisible waves and is used by innumerable technologies which ultimately affects the most of the aspects of our daily life. The rf 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 defence, 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]. Figure 1 shows the development of cognitive radio technology.

2 Functions 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 [2]. Figure 2 shows the block diagram of cognitive radio operation.

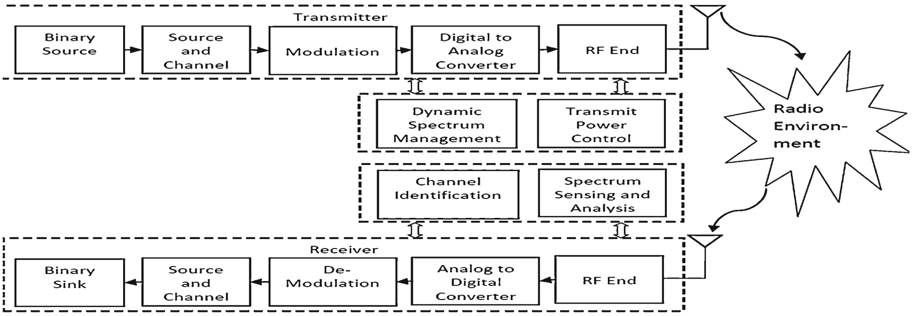

Fig. 2 Block diagram of cognitive radio operation

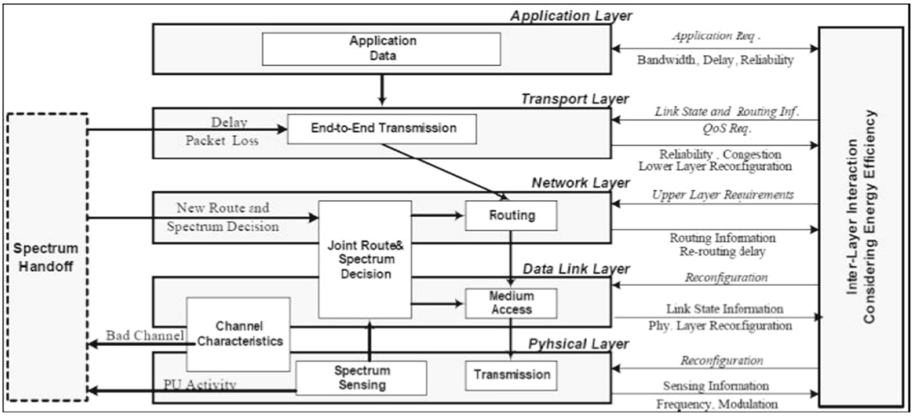

Fig. 3 Interaction between varoius layers of OSI model: communication and dynamic spectrum management

The OSI model of CR is presented below in Fig. 3. A binary symmetric channel (or BSC) is a common communications channel model used in coding theory and information theory. In this model, a transmitter wishes to send a bit (a zero or a one), and the receiver receives a bit. It is assumed that the bit is *usually* transmitted correctly, but that it will be “flipped” with a small probability (the “crossover probability”). This channel is used frequently in information theory because it is one of the simplest channels to analyze. The channel model we have used is the binary symmetric channel (BSC) which takes a binary input and with probability $p < 1 = 2$ switches it. This is a good model for deep space communications but not so good for hard drives or for terrestrial communications where errors come in bursts [3].

3 Role of Digital Filter Banks for Next Generation Multi Carrier Communication Systems

Multirate DSP is required in digital systems where more than one sampling rate is required. The applicability of multirate signal processing approach is in the areas of Communication Systems, Speech & Audio Processing systems, Antenna & Radar Systems. Advanced technique on multirate 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 multirate application, Less sensitivity to filter coefficient length [4,5].

4 Related Work: Signal Processing Perspectives in Cognitive Radio

Laddomada [6] presented a multirate 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. Hamid et al. [7] 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. Farhang-Boroujeny and Yuen, presents 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 paper also reviews the recent novel developments in the design of FBMC systems that are tuned to cope with fast fading wireless channels [8]. Moret and Tonello [9], address the efficient realization of a filtered multitone (FMT) modulation system. The paper analyzes 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. Ju et al. [10], 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. Ma et al. [11] 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. Zhang et al. [12], 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. Amini and Farhang-Boroujeny [13], develop 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. Stitz et al. [14], presents 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 scenarios. TeroIhalainen [15], 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. Rosenbaun et al. [16], introduced an approach for synthesizing modulated maximally decimated FIR FBs using the FRM technique. Each of the analysis and synthesis FBs was realised 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. Feldbauer et al. [17] described that in single rate systems, only one sampling rate is used whereas in multirate systems the sampling rate gets changed at least once. The paper deals with the realization and analysis of multirate systems. Abo Zahhad [18], provided an overview of basic concepts, current state and future directions of uniform and non uniform multirate 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.

5 Problem Formulation

Large parts of assigned spectrum is underutilized while the increasing number of wireless multimedia applications lead to spectrum scarcity. Cognitive radio is an option to utilize non used parts of the spectrum that actually are assigned to primary services. The benefits of cognitive radio are clear in the emergency situations. The current emergency services rely much on the public networks. This is not reliable in public networks where the public networks get overloaded. The major limitation of emergency network needs a lot of radio resources. The idea of applying cognitive radio to the emergency network is to alleviate this spectrum shortage problem by dynamically accessing free spectrum resources. Cognitive Radio is able to work in different frequency bands and various wireless channels and supports multimedia services such as voice, data and video. A reconfigurable radio architecture is proposed to enable the evolution from the traditional software defined radio to cognitive radio. So cognitive radio network architecture devices detect the local oscillator (LO) leakage and communicate the channel usage to cognitive radios. The performance of existing and proposed architectures assuming passive primary receivers can be compared. So detecting primary receivers for cognitive radio applications has been the main motivation that prompts to choose this problem statement. 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 Binary Symmetric 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.

6 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 users data over a respective frequency band. 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 variation in power versus frequency allocation output plots.

7 Simulation Study of FBMC Cognitive Radio: Matlab Implementation

Simulink based FBMC-CR Model using Binary Symmetric channel with FIR Decimation & Interpolation Multi rate Filters has been developed and implemented as a CR system design.

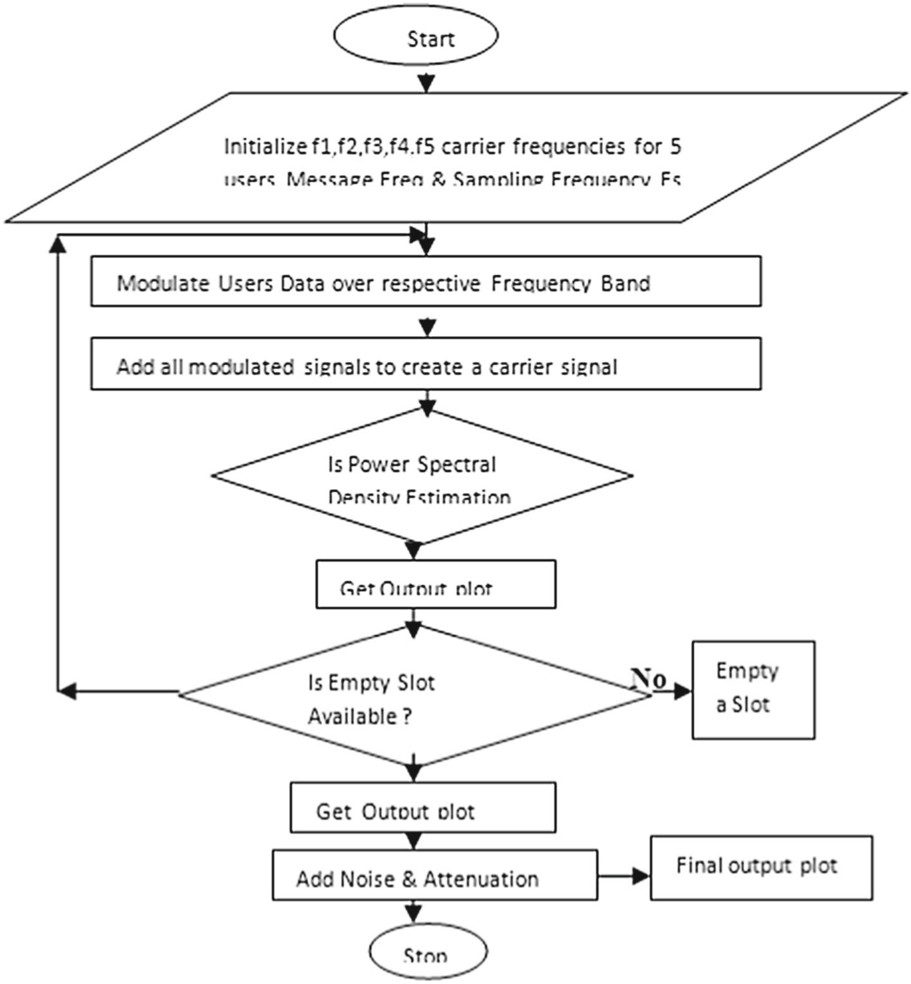

Fig. 4 Simulation flow chart

Effect of various parameters given in the blocks of this simulink model has been studied which is helpful for achieving results as per Simulation testbed (Figs. 4, 5).

In this Simulink model, the data bits are randomly generated to represent the random input signal. The model has been worked out for varying frequencies of input data and it performs equally well over entire specified range of frequencies of input data. This model takes into account three parameters as user defined namely Input data frequency, observation time and output available. The other important input parameters of interest are bits per frame, computation time and carrier frequency. The sine signal as a carrier is chosen for simulation purposes. DSBSCAM is used as a modulation scheme to modulate the binary data. A set of five new carrier frequencies is prepared and product modulator blocks are used for point to point multiplication between modulated signal and carrier. Then frequency content of the signals is observed with the help of different scope displays meant for primary users. Practically, BER increases with increases with increase in Bandwidth. He output is then made to pass

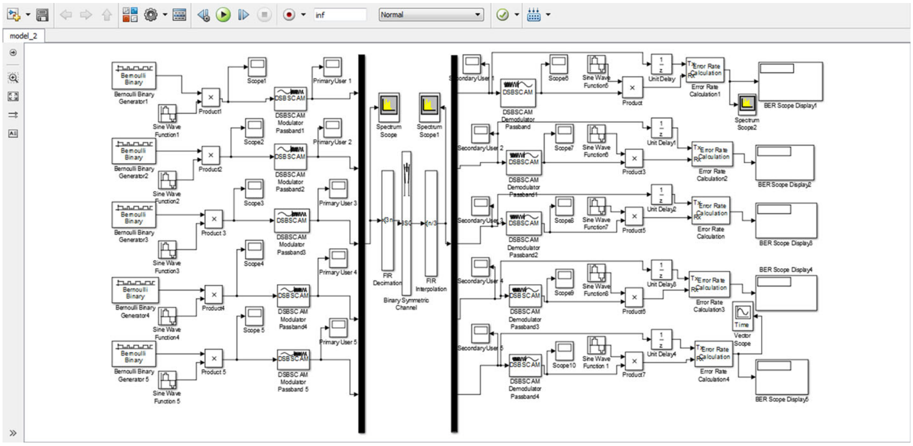

Fig. 5 FBMC-CR simulink model for physical layer under BSC prior to run

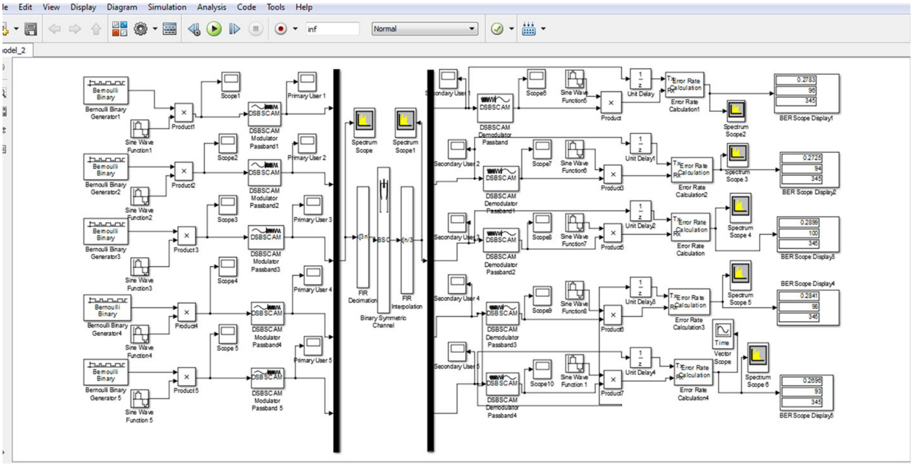

Fig. 6 Simulink model in running mode

through MUX and DemUX. In between is a FIR Decimation and FIR Interpolation Filter with Binary Symmetric channel environment. Then the five carrier frequencies used at transmitter are made available at receiver side as well. Ultimately the demodulated arrays are clubbed together to generate the received bit sequence as shown in right side of the simulink model in Fig. 6. The various blocks from the Matlab Simulink Library have been used for making the above Simulink Model for FBMC CR using multirate filters before and after Binary Symmetric channel. A Code for the proposed study on Cognitive radio has been generated in Matlab R2013a version.

8 Results and Discussion

The simulation parameters for FBMC transmission performance scheme are number of sub-carriers, N = 1,024, Number of used subcarriers, Nu-482 with cyclic prefix absent and Over-

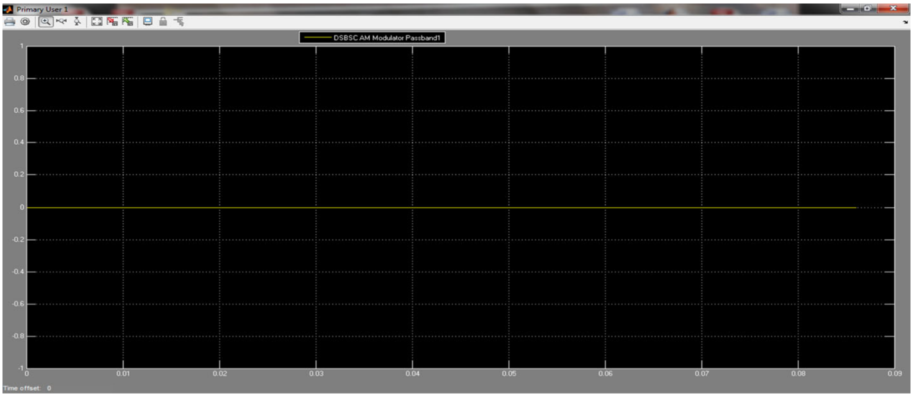

Fig. 7 Primary user 1 input signal

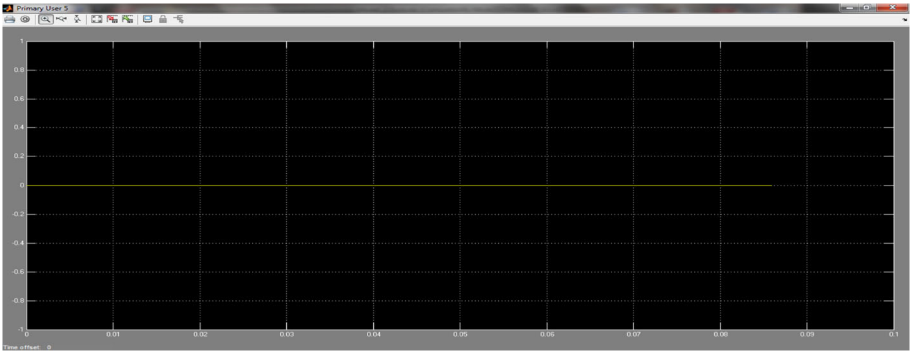

Fig. 8 Primary user 5 input signal

sampling factor K = 4 (only for FBMC), Subcarrier spacing = 15 kHz, Modulation of 64 QAM and with convolutional coding rate 1/2 with interleaving as applicable. With FBMC as the advanced Multicarrier technique, the performance evaluation has been done with the aid of different primary user input signals and different spectrum scope displays. The effect of multipath fading in this cognitive radio scenario using FBMC under Binary symmetric radio fading channel is clearly reflected form the various measurement and Interpretation results shown in Figs. 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19. Figure 9 shows that the Magnitude Squared (dBW/Hz) of −50 (peak magnitude) varies to −75 (dBW/Hz) over a frequency range from −10 to +10 Khz. In Fig. 10 with frequency range of −6 to +6 khz, the peak magnitude varies from 15–20 dBW/Hz to as low as −50 to −55 dBW/Hz. In Fig. 11 the spectrum signal magnitude varies from +20 dbW/Hz to as low as −45 dBW/Hz over a frequency range of −6 to +6 kHz. Figures 14 and 15 show the Amplitude versus time/frequency axis representation of the spectrum scope signal at the output level varying from 0.35 dBW/Hz to beyond 0 dBW/Hz along negative y axis. Figures 16 and 17 show the Exponential rise and fall in the buffered FFT spectrum scope outputs. The simulation model is run over several iterations 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

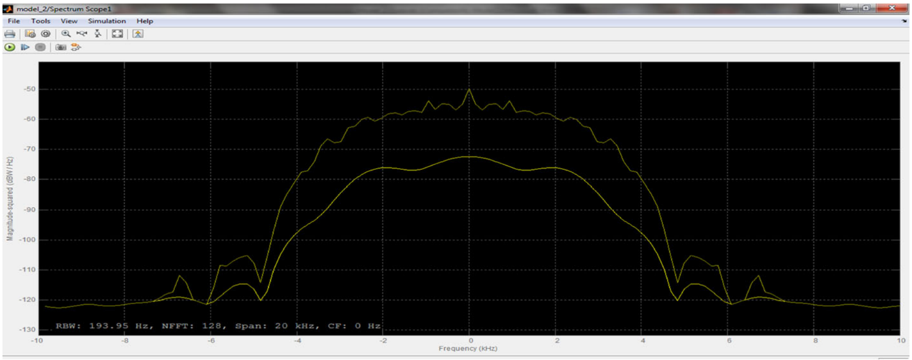

Fig. 9 Spectrum scope 1 output display

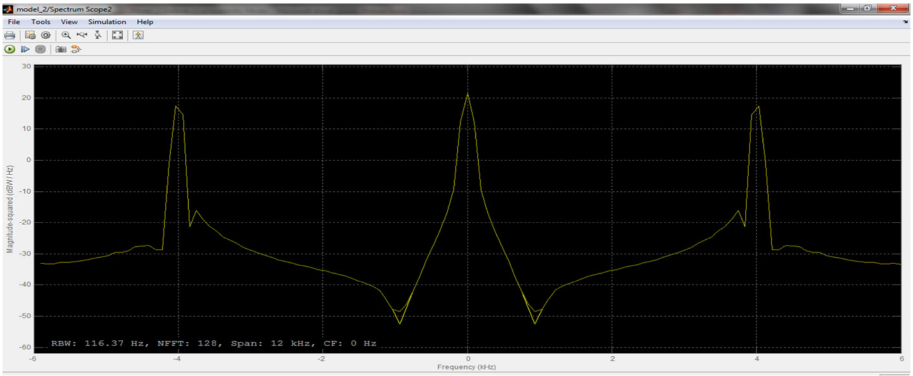

Fig. 10 Spectrum scope 2 output

are passed through DSBSC AM Modulator Passband whose output is further made to pass through Multiplexer and Demultiplexer. Now in between MUx and De-Mux there is a cognitive radio environment composing AWGN channel with pre and post processing devices in form of FIR Decimation and FIR Interpolation Filters. The output Spectra of these multirate filters used is analysed 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 is computed for showing the effect of attenuation and other technical parameters set in the various simulink parameter blocks on Secondary users. Also the time-amplitude vector scope output is visualized at the end with fifth secondary user in the simulink model. Hence, the spectrum analysis process optimizes the power of transmission for a secondary opportunistic user so that the quality of service for primary network users is maintained and overall spectrum usage is augmented to the extent as far as possible. The cognitive radio technology proposes to increase the spectrum usage by doing Dynamic Allocation of the unused spectrum in changing environments. So, taking BER Performance as a Metric is a step for maintaining the variable data rates in cognitive radio.

Buffered-FFT Scope Outputs at three different Instants in a FBMC-CR Simulink model for Physical Layer under BSC (Binary Symmetric) Radio Fading Channel are observed .

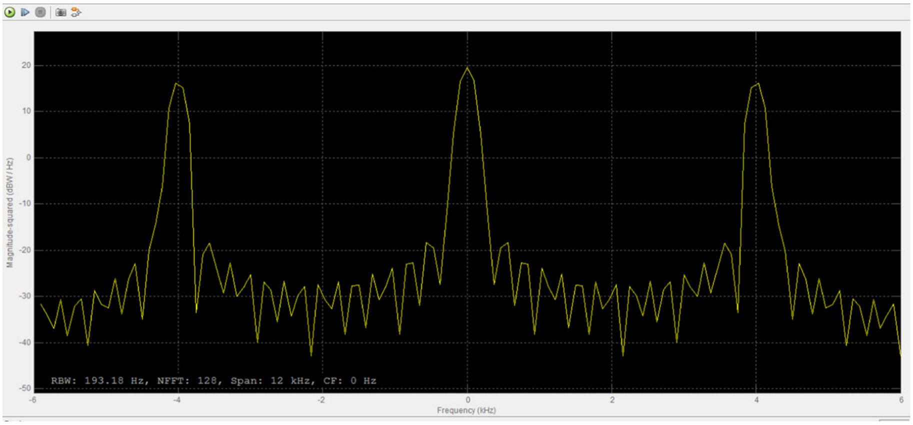

Fig. 11 Spectrum scope 3 output

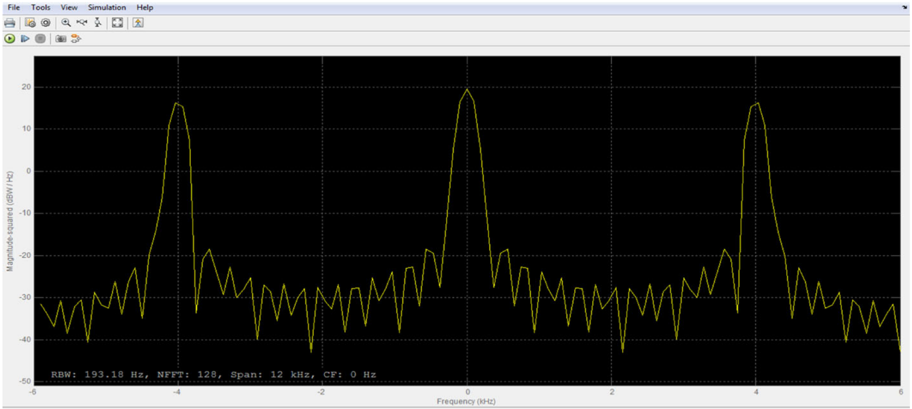

Fig. 12 Spectrum scope 6 output plot

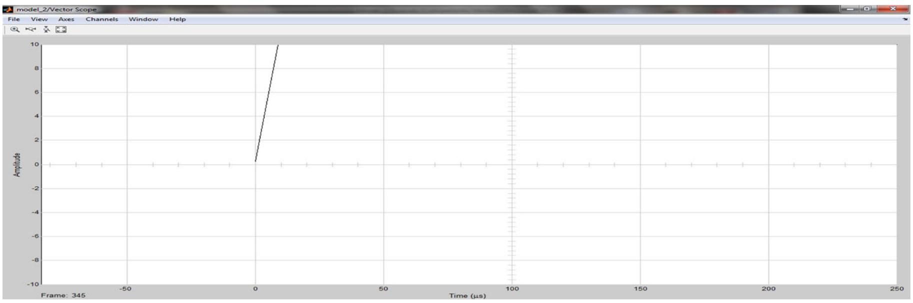

Fig. 13 Amplitude-time vector scope display

9 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

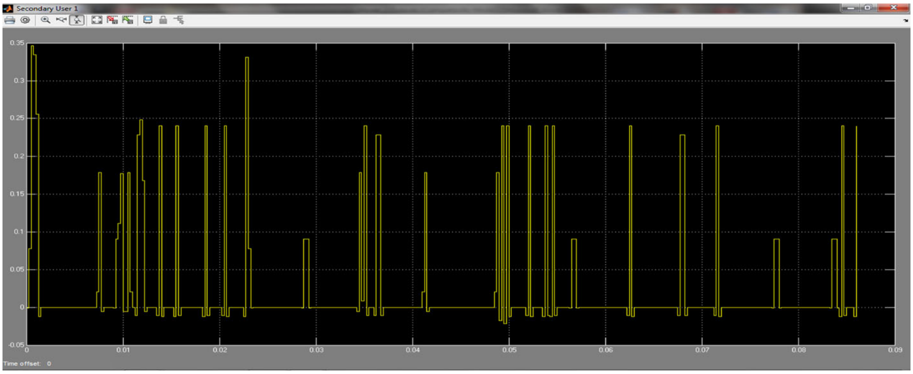

Fig. 14 Secondary user 1 output signal display

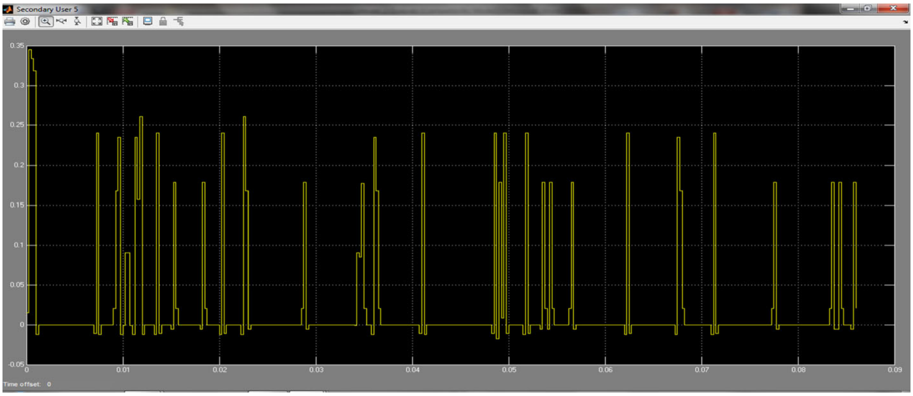

Fig. 15 Secondary user 5 output display

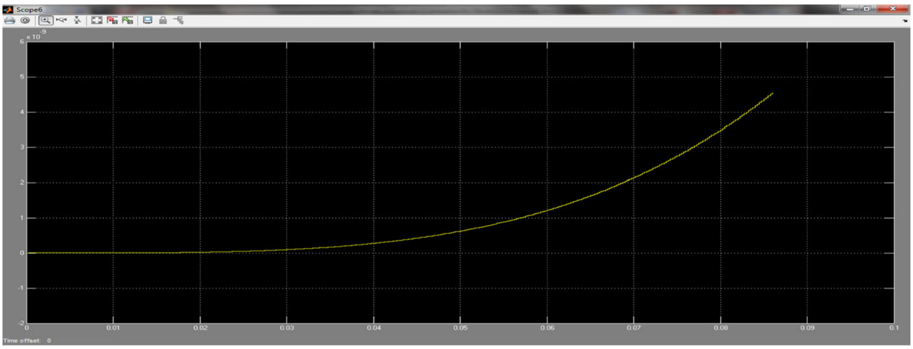

Fig. 16 Buffered-FFT scope 6 output

two instants prior to decimation and after interpolation show the more places of spectrum that are prone to underutilization. Different spectrum scopes show the quick side lobe tail decay occuring with only some peaks, hence 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. A set of five readings of BER

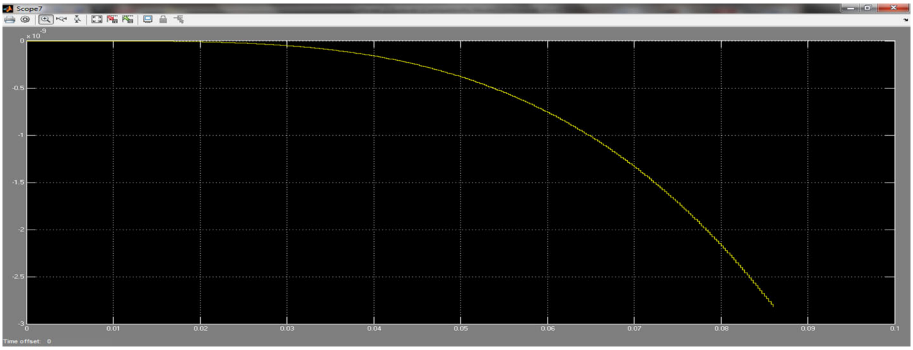

Fig. 17 Buffered-FFT scope 7 output

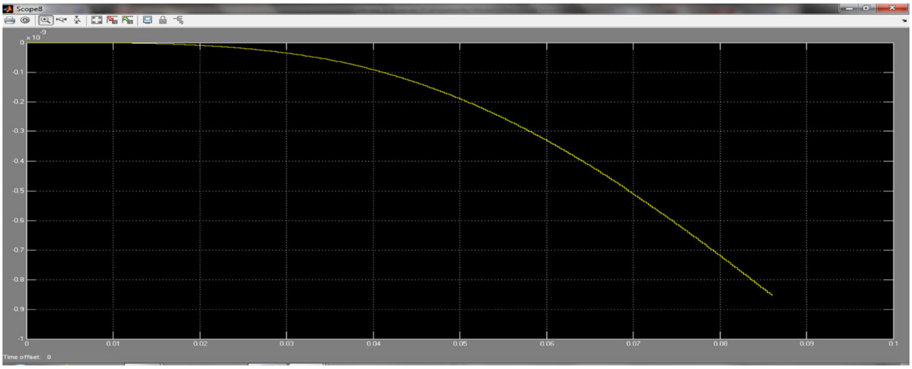

Fig. 18 Buffered-FFT scope 8 output

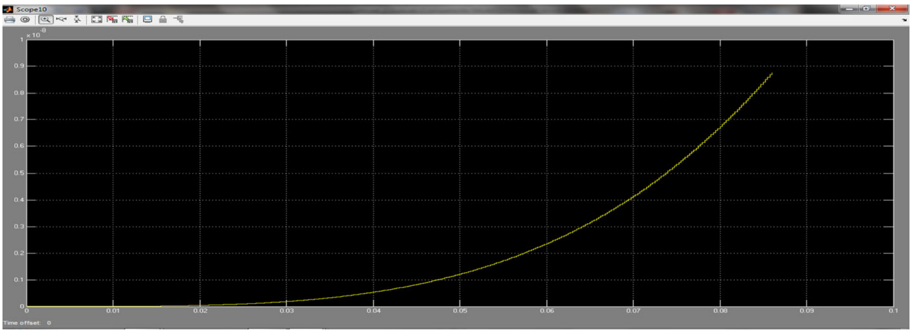

Fig. 19 Buffered-FFT scope 10 output

of order of 0.2783, 0.2725, 0.2899, 0.2841, 0.2696 has been taken.The BER = 0.2788 has been computed with the aid of simulink model 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. The Performance analysis of FBMC Spectrum Sensing technique under BSC fading channel environment clearly shows that far than better results are achieved for certain SNR values but beyond the threshold value, the results vary drastically. In the nutshell, this article describes that the technical challenges have to be met while the concept of implementation of spectrum pooling is the prime driving force or innovative strategy for the enhancement of spectrum efficiency although different mobile radio channels in Matlab have their different fading effects which can be studied through Monte Carlo Simulation Analysis.

10 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 multirate 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. The study has its impact on design and development of cognitive radio system under ubiquitous pervasive environment [19–30]. Apart from the study of Spectrum sensing using FBMC cognitive radio in physical layer, the performance analysis can be extended further to Media Access Control Layer, wherein sensing the unused signal in interference temperature is the most crucial step.

11 Benefits and Features of Spectrum Sensing Cognitive radio Enhancement

ProtoMAC (MAC Layer Protocol) monitors the changes in network management statistics, optimizing throughput with simultaneous increase in capacity, thereby ensuring negligible interference with other users. This software based technology will work with a wide range of existing cost effective radios. Moreover, with its applications in Chipset (ASIC) or transceiver DSP (low level software implementation), one can work in IEEE 802.11 Standard. From Technology Commercialization point of view, the applicability of FBMC cognitive radio under Binary Symmetric Radio fading Channel is equally useable in wireless broadband for commercial and military purposes including rural broadband data, video and telephone services as well.

12 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 are 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. All current opportunistic spectrum access techniques for cognitive radio work at the physical layer using methods such as energy detection, cyclostationary signal detection, multi-resolution spectrum sensing etc.The data packets of primary system are used to identify and exploit the transmission opportunities for the secondary system. This technology allows for much higher power communication as compared to Ultra Wide Band communication technologies.

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