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An Investigation of the Various Challenges of OFDM-based Cognitive Radio

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Abstract

Orthogonal frequency division multiplexing wideband modulation scheme is used in Cognitive Radio to transfer the data at high rate and eliminate the inter symbol interference. OFDM also provides various advantages in cognitive radio such as ease in spectrum sensing and provides interoperability to other wireless technologies such as Wi-Fi, 4G, Digital Audio Broadcasting. Beside these pros of OFDM in the cognitive radio, there are number of challenges to implement the OFDM at the physical layer of the Cognitive radio systems. These challenges are reduction in high Peak-to-Average Power Ratio, maintaining synchronization with the primary users in cognitive networks and the size of the cyclic prefix(CP) to reduce the inter symbol interference(ISI) etc. In this paper various major challenges of OFDM implementation in the Cognitive Radio networks are discussed and also how these problems can be resolved are described.

Keywords: Cognitive Radio (CR), Non-Contiguous Orthogonal Frequency Division Multiplexing (NC-OFDM), Primary Users(PU), Inter Symbol Interference (ISI), Secondary Users (SU).

I. INTRODUCTION

The numbers of wireless devices are increasing with emerging wireless technologies. The radio spectrum is becoming gradually more overcrowded. Every wireless need radio channel to communicate with other devices in wireless network. In 2008, according to FCC(federal communication commission) the licensed radio spectrum

are underutilized and unlicensed channel are over utilized[1]. The Cognitive radio technology has potential for handling the shortage of the radio spectrum. In the CR the unlicensed user(cognitive user) can use the licensed channels in opportunistically manner. When the primary channels are free then these free available channel can be utilized by cognitive users(unlicensed users)[2].

OFDM is a wideband multicarrier modulation data transmission technique can be used in Cognitive Radio systems for providing solution to many problems. It handles the problem of slow rate transmission, eliminates the ISI and inter carrierinterference (ICI)[3]. Also, OFDM provides interoperability with other wireless technologies such as Wi-Fi, 4G LTE, WiMax, and Digital Video Broadcasting(DVB) etc. It is impossible to use the consecutive number of subcarriers in the existence of the licensed users(PUs). Therefore, in actual the Non-contiguous OFDM(NC-OFDM) form of OFDM is implemented at the physical layer of Cognitive radio. In this paper, major challenges are discussed which are faced during the implementation of OFDM based Cognitive Radio.

This specialized paper is partitioned into different areas. Section II shows the standard of the OFDM, Section-III depicts the advantages offered by OFDM based CR frameworks. After that the challenges faced by OFDM-based cognitive radio networks are discussed. At last, the paper is concluded.

II. OFDM SYSTEM

OFDM is the mix of both and multiplexing and modulation schemes. It is multicarrier information transmission regulation scheme[4]. A wide transmission capacity transporter is separated into small transfer speed subcarriers which are uncorrelated(orthogonal) to each other to transmit the information in parallel piece streams. The big data block is divide into small data blocks. After that, these small sized information streams are exchanged on the diverse subcarriers parallely [3].

As shown in schematic illustration of fundamental OFDM system, initially the input data symbols are submitted to the serial-to-parallel converter. It creates a complex vector of size N. The vector $Xi=[X_1,X_2,X_{N-1}]^T$, which represents the information in each symbol I is converted in to time domain from frequency domain by passing through Inverse Fast Fourier Transform(IFFT) block. Where, N denotes the number of subcarrier in each OFDM symbol.

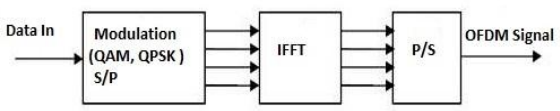

Figure.-1 Basic illustration of OFDM scheme

After performing IFFT transmitted signal is converted from parallel to serial data stream. And, transmitted signal is represented as equation below:

$$x(n) = \frac{1}{\mathrm{N}}\sum_{k=0}^{N-1}\left(X(k)\mathrm{e}^{\frac{j2nk}{N}}\right) \quad \text{, n=0, 1, 2… N-1}$$

III. BENEFITS OF OFDM IN COGNITIVE RADIO

- It reduces the Inter Symbol Interference(ISI) by inserting a cyclic prefix code in front of each symbol[3]. When the consecutive symbols overlaps with each other due to delay spread then the ISI occurs in the transmitted signal. By adding cyclic code with each symbol, the effect of delay spread is removed in OFDM transmitted signal and the original symbols are recovered at the receiving end.
- In OFDM-based C, sensing the spectrum job becomes easier because all the values are tracked effortlessly in the frequency and time grid of presently used radio channels[5]. Also, no extra hardware requires reason behind is that FFT cores are reused for sensing purpose.
- OFDM modulation scheme used in various wireless communication technologies[3]. Therefore, it provides interoperability with previous technologies such as Wi-Fi,4G-LTE, Wi-Max etc.
- It is necessary in Cognitive radio to mask those radio bands which are currently being used by PU to stop the interference between the PUs and cognitive users. In OFDM-based CR, shaping the spectrum means deactivating the channels are done very easily by applying proper mask.

IV. CHALLENGES TO IMPLEMENT OFDM IN CR

In this section several major challenges are discussed as following:

1. Minimize the high PAPR

The major drawback of OFDM based system is high value of peak-to-average power ratio. High PAPR occur cause of its nature of implementation[6]. When the numbers of subcarriers are combined orthogonally then the some amplitude values of resultant signal crosses the certain threshold. It causes the ISI and inter channel interference(ICI) in the transmitted signal. It is calculated of transmitted signal by following equation

$$\mathrm{PAPR} = \frac{\mathrm{MAX}\left(x^2(\mathrm{t})\right)}{E\left(x^2(\mathrm{t})\right)}$$

To minimize the high PAPR of the transmitted OFDM signal, various PAPR reduction technique are designed in literature which are categorized into two forms: data distortion and non data distortion PAPR reduction techniques.

Selective mapping, Partial transmit sequence, Coding, Tone Reservation and Tone Injection are the non data distortion techniques[7-9]. All of these technique required side information to decode the OFDM signal at the receiving end. Thus, the side information consumes the extra bandwidth of channel which reduces the spectral efficiency. Whereas, Clipping and Filtering, Peak windowing are the data distortion PAPR reduction techniques which are simple then the non data distortion techniques and does not require side information to decode the transmitted OFDM signal at the receiver[8][10]. These techniques distort the useful information but save the spectral bandwidth. For reducing the high PAPR of transmitted signal is critical aspect of OFDM based CR system because we can't accept any kind interference with PUs. So, selecting an appropriate PAPR reduction technique is big challenge by considering various parameters complexity of technique, data loss and side information.

2. Challenges in sensing the radio Spectrum

It is the most crucial function of Cognitive radio to sense radio spectrum to find out the free licensed channel. Cognitive Radio systems are totally based on this concept for utilizing free licensed channel for providing the solution of spectrum shortage. While scanning the radio channels, various challenges are faced in OFDM-based CR. Some of them are discussed as followings.

i. Hidden Primary User Problem

In many cases presence of primary users are not detected when they are actually present due to severe fading or shadowing experienced by cognitive users during scanning for the PUs[11]. In this situation, the secondary users produce the interference to primary receivers. In OFDM based cognitive radio, it is huge challenges to handle hidden primary user problem due presence of environmental hurdles as well. To tackle this problem co-operative sensing can be used[12].

ii. Detecting Spread Spectrum of PUs

In wireless communication, two core spread spectrum technologies are used for transmission: Frequency Hopping Spread Spectrum(FHSS) and Direct Sequence Spread Spectrum(DSSS)[11]. In DSSS the whole frequency band is used for transmission. So, there is no problem to know which frequency band is accessed by PUs or SUs. But in the case of FHSS, the operational frequencies changes dynamically in order to provide security from unauthorized access of carrying information. The hopping sequence must be known to both sender and receiver for proper communication. It is difficult to detect the spread spectrum signaling of primary users because powers of these signals are very low. To avoid the collision of secondary user to primary user, there must be different hopping sequence. This trouble can conversely be avoided to some extent if the hopping sequence is recognized.

iii. Decision Fusion in Cooperative Sensing

Sensing is performed to find out the available licensed radio bands. In OFDM based CR, the co-operative sensing performed to handle the problem of hidden primary users. In co-operative sensing every cognitive node senses the environment and then information is shared among the cognitive radios to take the decision. It is a challenging job to distribute information among CRs and combine the results from various measurements[13]. On basis of shared information two kinds of decision are taken: soft decision and hard decision[11]. Soft decisions are better in case of the probability of missing opportunity and hard decisions perform well when the cognitive users are large. It has to be done properly that cognitive users don't collide with the primary users.

iv. Handling PUEA Security Issue

Primary user emulation attack(PUEA) is the major security problem of CRNs. When a secondary user(cognitive user) pretends as primary user, is known as primary user emulation attack. It is done by secondary users to take advantage of licensed channels and not giving opportunity to the cognitive users to use the free licensed channels. The chances of PUEA are reasonable due to the Cognitive Radio is very dynamic[14]. This security problem also occurs in OFDM based cognitive radio. To stop the PUE attacks, a strong transmitter authentication approach have to design with the purpose of discrimination between the genuine present primary signal transmitters and cognitive signal transmitters. The main technical challenge in sensing from the perspective of security is to stop the PUE attack. A public key encryption phenomenon was used to handle this attack, in which the primary user encrypts own identity by its private key[15]. The secondary users receive the signature then decrypts with public key and verify that signature by various base stations to know it is valid primary user or not. It prevents to the unauthorized user to create a valid signature. But, it makes the communication process so complex.

3. Trade-off between size of Cyclic Prefix and Spectral Efficiency

For reducing the Inter Symbol Interference in OFDM based CR systems, the cyclic prefix(CP) code is inserted at the beginning of each OFDM symbol[16]. Delay occurs in the OFDM signal cause of multipath propagation transmission. This occurrence of delays overlaps the values of consecutive symbols, is known as inter symbol interference. Therefore, the size of CP must be equal to or greater than the delay spread for eliminating the ISI. To recover the original symbol values, size of CP is taken one fourth of the symbol size. It is advantage of OFDM that it reduce the ISI but for reducing ISI, redundancy bits(CP or guard bits) are needed to add. These extra bits consume the channel bandwidth which reduces the spectrum efficiency. So, size of cyclic prefix should be enough which can eliminate the effect of ISI and while keeping bandwidth loss at minimum is a challenging task in OFDM based CR

systems.

4. Synchronization

OFDM based Cognitive radio is very responsive to time and frequency. It is necessary to synchronize the clock and set of subcarrier between transmitter and receiver for avoiding narrow band interference(NBI) in multi user cognitive radio networks[11][16]. If the numbers of subcarriers are not matched between the communicating transmitters and receivers then there might be loss of or data can be intermixed with other subcarriers. In OFDM based CR, both primary and secondary users transfer the data concurrently. So, there must be different subcarriers to each different user and maintaining orthogonality between the subcarriers for avoiding the interference among the subcarriers.

5. Designing Effective Pruning Algorithm

Pruning means to deactivate those channels which are currently being occupied by PUs. It is essentialfor preventing interference between primary and secondary user's communication. Pruning algorithms are integrated with dynamic sensing function of Cognitive Radio[17]. Based on the sensing decision, the subcarriers which are not available for secondary user(cognitive user) are turned off. Therefore, a dynamic fast pruning algorithm is required of having optimum efficiency to reduce the interference of secondary user with primary user.

6. Signaling Transmission Parameters

In NC-OFDM, the subcarriers are deactivated which are occupied by primary users to avoid the collision between secondary user and primary user. Non-contiguous orthogonal frequency division multiplexing system easily change its waveform by deactivation some subcarriers with the purpose of make use of the available free licensed channels. But, the receiver must be known about the subcarriers which are turned off and which are available to use. Other parameters such as FFT size, cyclic prefix size are required to transmit to the receiver for intended transmission. And, these parameters consume extra bandwidth which reduces the spectral efficiency. A technique was designed to reduce the burden of transmission of these signaling parameters[17]. Thus, the transmission of these parameters must be done carefully as to prevent obstruction to the PUs whereas keeping the bandwidth loss at minimum.

CONCLUSION

The orthogonal frequency division multiplexing is most suitable wideband wireless modulation scheme to solve the various problems of wireless communication technologies. Similarly in Cognitive Radio, OFDM provides several features such as

ease in spectrum sensing, eliminates the effect of multipath fading(Inter Symbol and Inter Channel Interference), transmit data at higher rate. Even though, there are numbers of challenges to deploy the OFDM based Cognitive Radio which are discussed in this paper. These challenges can be managed by designing a proper OFDM based Cognitive Radio system of having proper hardware configuration and software specifications with efficient proposed techniques.

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