Orthogonal Frequency-Division Multiplexing over Cognitive Radio Technology

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Abstract

In recent years with the explosive growth of applications over wireless networks, the solicitation for radio spectral has been increased significantly. The issue in spectrum scarcity is not related to the physical shortage of the spectrum, but underutilizing of it. Recently, Federal communication Commission (FCC) proposed the notion of secondary spectrum access by cognitive radio (CR) to improve spectrum utilization. CR is a wireless communication technology which can changes its transmission parameters according to interaction with the environment in which it operates.

The process of transmitting several different signals via a single carrier is known as multiplexing. Orthogonal Frequency-Division Multiplexing (OFDM) is known as the most appropriate technique for multiplexing process. OFDM is the most competent multiplexing technology for cognitive radio because of its unique characteristics such as: the receiving etiquette, spectrum shaping, and flexibility. In this paper, we discuss the various aspects of applying OFDM over CR technology.

I. Introduction

In the previous decades “Multi–Tone Modulation” was more popular. In multi–tone modulation, a frequency was split into several subcarriers. Somehow, multi–tone modulation had some advantages such as: (1) parallel transmission of data which results in quick data transmission, and (2) fault tolerance: if for any reason, some of the subcarriers have been failed, it does not result in losing of the whole data.

Orthogonal Frequency–Division Multiplexing (OFDM) technology was conceived in the 1960s and 1970s while the research issue of minimization of interference among nearby channels in frequency was in consideration [1]. As a definition, OFDM is a digital modulation technique in which a signal is divided into many narrow–band channels at various frequencies. The way of signal modulation / demodulation differentiates pure FDM from OFDM. OFDM’s objective is to minimize the interference among the channels which carry the data stream. The orthogonality is the key advantage of OFDM compare to multi–tone modulation [4]. In OFDM, each two subcarriers work in orthogonal fashion [5]. As it has been shown in figure 1, 50% of the bandwidth can be saved by using of OFDM technique.

Figure 1, FDM vs. OFDM
In cognitive radio [2], users utilize spectrum bands in an opportunistic manner. Secondary Users (SU) are able to sense the band and utilize it when there is no active Primary Users (PU). The portion of the spectrum band which is not utilized by a PU is known as White-Space. The technique of detecting white-spaces is known as Spectrum Sensing. Other than spectrum sensing, SUs must have some functionalities such as: (1) spectrum management: the ability to choose the best available channel, (2) spectrum sharing: to share the detected channel with some other SUs, (3) spectrum mobility: to vacate the spectrum at the time of appearance of PU without any harmful interference.

Two main characteristics of a CR are: (1) Cognitive Capability: the ability to sense the unused spectrum at any time and location and (2) Re-configurability: the ability to send and receive at different frequency band.

II. OFDM over Cognitive Radio

Receiving etiquette, flexibility, adaptability, and spectrum shaping in OFDM, made it as the most appropriate transmission technology for CR [3, 6]. Spectrum sensing, spectrum shaping, adapting to the environment, multiple accessing and spectral allocation and interoperability are the requirements of CR. In the next sections, we will investigate how these requirements can be satisfied by OFDM technique.

a. Spectrum Sensing:
Spectrum sensing is white-space detecting and spectrum sharing without any harmful interference to other users. Reliable spectrum sensing is one of the most crucial aspects for the successful deployment of CR. In OFDM technologies, equalizing from time-domain to frequency-domain is done via Fast Fourier Transform (FFT) algorithm. The output of the FFT algorithm determines the presence of the PU. The orthogonality characteristic of OFDM allows for efficient implementation of modulation /demodulation via FFT on the receiver, and on the sender it is done by inverse FFT. The computational time for FFT or inverse-FFT should be less than the time for each symbol, which can be calculated as follow:

\[ \text{MIPS} = \frac{\text{CC}}{T_s} \times 1.3 \times 10^{-6} \]

Where MIPS is “Million of Instructions per second”, CC is Computation Complexity, is computation time for each symbol, FFT enables OFDM technology to satisfy the hardware requirements as well. Moreover, it decreases the limitations of spectrum sensing protocols because the receiver already used the FFT algorithm for signal equalization into frequency-domain.

b. Spectrum Shaping
CR has the ability to shape its signal spectrum to have minimum possible interference to PUs. To do that, flexible and adaptable physical layer is required. OFDM has the potential of fulfilling this issue for CR by dividing the spectrum into sub-bands that are modulated with subcarriers in an orthogonality fashion. In a nutshell, spectrums in OFDM technology can be shaped easier in compare to other signaling technologies. An instance of spectrum sensing and shaping in an OFDM–based CR is depicted in figure 2.

c. Adaptation to the Environment
Adaptability is one of the most important requirements of cognitive radio [8, 9, 10]. By modulating of the collected data, CR obtains knowledge about the primary network and its
constraints to occupy a licensed spectrum band without any harmful interference to PUs. CR is able to adapt its spectrum shape to the others communications tools. Further, it can select the most appropriate channel for its transmission. OFDM suggests a worthy range of flexibility to extend parameters for adaptability and compatibility. An OFDM-based CR can adapt the level of modulation, coding and sender power of each subcarrier to satisfy SU’s requirements. This allotment is applied in order to achieve different goals such as improvement of the system performance, decreasing of the Bit Error Rate (BER), and avoiding interference to the PU. In order to avoid Inter–Symbol Interference (ISI), the delay spread of the channel must be smaller than the Cyclic Prefix (CP) duration of the OFDM symbol. Therefore the maximum allowable delay spread should be equal to the CP duration. The CP is used as Guard Interval (GI) by duplicating of a part of the symbol as illustrated in figure 3.

![Figure 3](image)

Figure 3, duplicating of Guard Interval to the symbol

According to the estimation of channel parameters, OFDM–based CR can change the length of CP to keep the signal without ISI and to have maximum system output. Similarly, an OFDM–based system can change its subcarrier interval in order to decrease Inter–Carrier Interference (ICI) by Peak–to–Average–Power–Ratio (PAPR).

d. Multiple Access and Spectral Allocation

Available resources should be accessible for all CR users in the range. To achieve it, OFDM supports some technologies such as: (1) Frequency–Division Multiple Accessing (FDMA), (2) Time–Division Multiple Accessing (TDMA), and (3) Carrier–Sense Multiple Accessing (CSMA). And also, Code Division Multiple Accessing (CDMA) can be utilized together with OFDM. OFDMA is a special instance of FDMA in which, subcarriers are categorized in some groups and each one is assigned to a different task. The subcarriers are used either randomly or multiplex. Hence, OFDMA is flexible without adding any new complex hardware which makes it as an appropriate candidate for CR. Subcarriers allotment can be adjusted based on available spectrum band.

e. Interoperability

OFDM is used in short–range or long–range communications. So, an OFDM–based CR can communicate with other OFDM–based systems as well. However, to do it successfully, the system must recognize all the standards, signal encoding requirements for frequency subcarriers, frame structure, coding type and the rate. Further, RF circuitry of the CR must have adequate flexibility to adjust various signal bands and intermediate frequencies. As a result, CR should be made based on the Software Defined Radio (SDR) to provide the requirements with high flexibility.

III. Conclusion

CR is an emerging technology that provides some solutions to the spectrum crowding issue. On the other hand, OFDM is employed in many wireless applications and it is known as an effective transmission technique due to its reliability and adaptability. OFDM can be utilized for CR because of its unique capabilities. This paper discussed in detail the inherent capabilities of OFDM for CR. It can be concluded that, CR systems with OFDM obtain considerable advantages such as adaptability, awareness and flexibility.
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References