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Spectrum-sharing for 5G Wireless Communications based on Cognitive Radio Networks: A Review

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ABSTRACT: Cognitive Radio is a promising way to overcome the spectrum scarcity for wireless communication and improving the spectral efficiency by using the vacant licensed spectrum band. Non-Cooperative communication is a new communication technique which utilizes the help of neighboring nodes to reduce the bit error rate (BER) in a harmful fading environment. The challenging factor is to combine the Non-cooperative communication in cognitive radio to improve the spectral efficiency and to reduce the BER factor of unlicensed user's communication. In this paper, a comparative study of different communication techniques are done by considering Rayleigh fading channel environment and the advantages of non-cooperative communication is analyzed.

KEYWORDS: OFDM System, MIMO-OFDM, Cognitive Radio, Non-Cooperative Communication

I. INTRODUCTION

Wireless communications is a rapidly growing part of the communications field, with the believable to provide high-speed and high-quality information swap between portable devices located anywhere in the world. It has been the topic of study since last two decades the terrific development of wireless communication technology is due to several factors. The demand of wireless connectivity is exponentially increased. Second, the dramatic progress of VISL technology has enabled small-area and low-power implementation of sophisticated signal processing algorithm and coding algorithm. Third, wireless communication standards, like CDMA, GSM, TDMA, make it possible to transmit voice and low volume digital data. Further, third generation of wireless communications can offer users more advanced service that achieves greater capacity through improved spectral efficiency [1].

Potential applications enabled by this technology include multimedia cell phones, smart homes and appliances, automated systems, video teleconferencing and distance learning, and autonomous sensor networks. However, there are two significant technical challenges in supporting these applications first is the phenomenon of fading the time variation of the channel due to small-scale effect of multi-path fading, as well as large-scale effect like pass loss by distance attenuation and shadowing by obstacles. Second, since wireless transmitter and receiver need communicate over air, there is significant interference between them [2]. The intelligent wireless system is called as Cognitive radio (CR) that identifies the spectrum movement in surroundings at each instant. Thus it adapt its parameters such as modulation type, carrier's frequency etc. It has two fundamental purposes they are highly reliable communication whenever and where ever needed and efficient utilization of radio spectrum. Cognitive spectrum sharing was recently studied to allow increasing demands for wireless broadband access which can reduce the problem of under-utilization of licensed spectrum. These techniques can be generally classified into three types: one is interweave, second is underlay and third is overlay [3].

The secondary system can opportunistically access spectrum holes for interweave spectrum sharing. And for the spectrum underlay secondary users (SUs) transmit simultaneously with fundamental (primary) users (PUs) under the constraint that interference caused by the SUs on the PUs must be below a certain threshold. In spectrum overlay SUs actively help primary data transmission in exchange for a spectrum access in time domain, spatial domain or frequency domain [4]. The locations of SUs are usually fixed or limited into a small area without suffering interference from other concurrent transmissions. For more than a decade, Adaptive resource allocations (RA) for the OFDM systems have been studied [5]. As the OFDM-based CR systems are arising, the adaptive Resource Allocation (RA) attracted much attention starting from the broaching. Thus in the case of single SU, Resource Allocation in an OFDM-based CR



system degenerates in to power distribution. The capacity of CR networks can be expanded by using the approach OFDM based CR networks for which different transmit antennas are applied to that approach. Recently, the great attention has been attracted by the combination of MIMO and OFDM [6-7]. The capacity and divergence gain can be increased by using the MIMO in the hybrid pattern channel while the frequency selective channel is converted in to flat fading channels by using the OFDM.

II. OVERVIEW OF OFDM AND MIMO SYSTEM

o OFDM

Orthogonal frequency-division multiplexing (OFDM) is a method of digital modulation in which the data stream is split into N parallel streams of reduced data rate with each of them transmitted on separate subcarriers. In short, it is a kind of multicarrier digital communication method. OFDM has been around for about 40 years and it was first conceived in the 1960s and 1970s during research into minimizing interference among channels near each other in frequency [2]. OFDM has shown up in such disparate places as asymmetric DSL (ADSL) broadband and digital audio and video broadcasts. OFDM is also successfully applied to a wide variety of wireless communication due to its high data rate transmission capability with high bandwidth efficiency and its robustness to multi-path delay[7-8].

The basic principle of OFDM is to split a high data rate streams into a number of lower data rate streams and then transmitter these streams in parallel using several orthogonal sub-carriers (parallel transmission). Due to this parallel transmission, the symbol duration increases thus decreases the relative amount of dispersion in time caused by multipath delay spread. OFDM can be seen as either a modulation technique or a multiplexing technique.

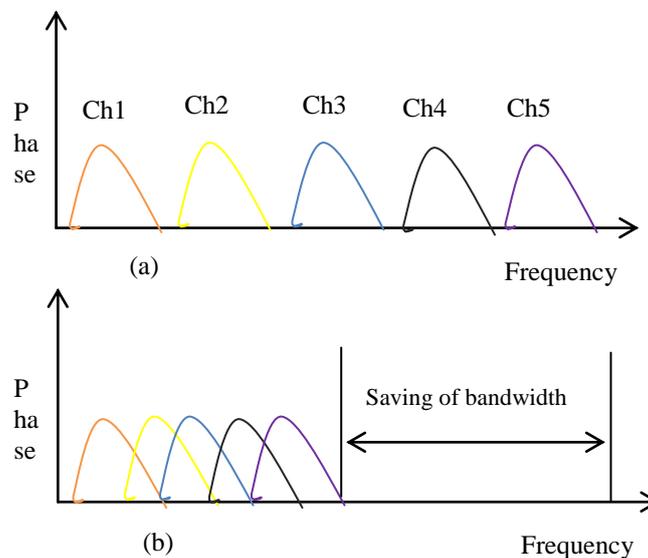


Figure 1: Comparison between conventional FDM(a) and OFDM (b)

o MIMO

MIMO has been developed for many years for wireless systems. One of the earliest MIMO to wireless communications applications came in mid-1980 with the breakthrough developments by Jack Winters and Jack Saltz of Bell Laboratories [9]. They tried to send data from multiple users on the same frequency/time channel using multiple antennas both at the transmitter and receiver. Since then, several academics and engineers have made significant contributions in the field of MIMO. Now MIMO technology has aroused interest because of its possible applications in digital television, wireless local area networks, metropolitan area networks and mobile communication. Comparing to the Single-input-single-output (SISO) system MIMO provides enhanced system performance under the same transmission conditions. First, MIMO system greatly increases the channel capacity, which is in proportional to the total number of transmitter and receiver arrays. Second, MIMO system provides the advantage of spatial variety: each one transmitting signal is detected by the whole detector array, which not only improved system robustness and reliability, but also reduces the impact of ISI (inter symbol interference) and the channel fading since each signal determination is based on N detected results. In other words, spatial diversity offers N independent replicas of transmitted signal. Third, the Array gain is also increased, which means SNR gain achieved by focusing energy in desired direction is increased.



○ MIMO-OFDM

OFDM reduces BER performance and ISI with using multiplexing and modulation techniques to get higher data rate over wireless channels, the use of multiple antennas at both ends of the wireless link provide better performance. The MIMO technique does not require any extra transmission power and bandwidth. Therefore, the promising way to increase the spectral efficiency of a system, the combination of MIMO and OFDM is used over fading channels [10-11].

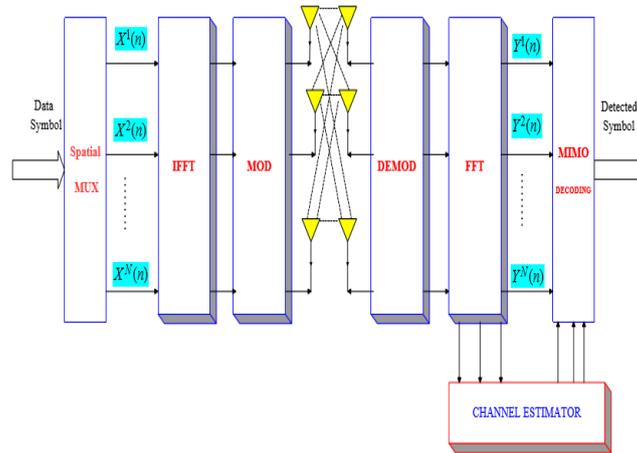


Figure 2: MIMO-OFDM system model

The received signal at j^{th} antenna can be expressed as

$$R_j[n, k] = \sum H_{ij}[n, k] X_i[n, k] + W[n, k] \tag{Eq. 1}$$

Where H is the channel matrix, X is the input signal and W is noise with zero mean and variance. Also $b_i[n, k]$ represents the data block i^{th} transmit antenna, n^{th} time slot and k^{th} sub channel index of OFDM. Here i and j denoted the transmitting antennas index and receiving antenna index respectively.

The MIMO-OFDM system model [4] with NR receives antennas and NT transmits antennas can be given as:

$$\begin{bmatrix} Z_1 \\ Z_2 \\ \dots \\ Z_N \end{bmatrix} = \begin{bmatrix} H_{1,1} & H_{1,2} & \dots & H_{1,NT} \\ H_{2,1} & H_{2,2} & \dots & H_{2,NT} \\ \dots & \dots & \dots & \dots \\ H_{N,R-1} & H_{NR,2} & \dots & H_{NR,NT} \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \\ \dots \\ A_{NT} \end{bmatrix} + \begin{bmatrix} M_1 \\ M_2 \\ \dots \\ M_{NT} \end{bmatrix} \tag{Eq. 2}$$

III. SPECTRUM SENSING

A major challenge in cognitive radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and quit the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary users. This technique is called spectrum sensing. Spectrum sensing and estimation is the first step to implement Cognitive Radio system [5]. We can categorize spectrum sensing techniques into direct method, which is considered as frequency domain approach, where the estimation is carried out directly from signal and indirect method, which is known as time domain approach, where the estimation is performed using autocorrelation of the signal. Another way of categorizing the spectrum sensing and estimation methods is by making group into model based parametric method and period gram based nonparametric method.

a. Primary transmitter detection: In this case, the detection of primary users is performed based on the received signal at CR users. This approach includes matched filter (MF) based detection, energy based detection, covariance based detection, waveform based detection, cyclostationary based detection, radio identification based detection and random Hough Transform based detection.

b. Cooperative and collaborative detection: In this approach, the primary signals for spectrum opportunities are detected



reliably by interacting or cooperating with other users, and the method can be implemented as either centralized access to spectrum coordinated by a spectrum server or distributed approach implied by the spectrum load smoothing algorithm or external detection.

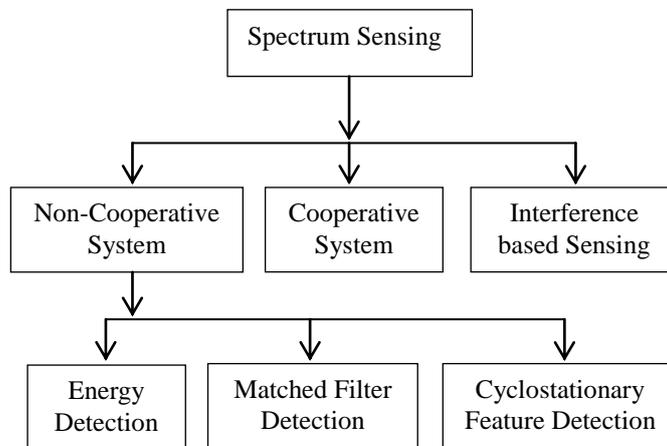


Figure 3: Classification of spectrum sensing techniques

Figure 3 shows the detailed classification of spectrum Sensing techniques. They are broadly classified into three main types, transmitter detection or non-cooperative sensing, cooperative sensing and interference based sensing. Transmitter detection technique is further classified into energy detection, matched filter detection and cyclostationary feature detection [12].

Non-cooperative Spectrum Sensing

Since it is difficult to sense the status of the primary receiver, so to detect the primary user transmission it is necessary to detect the signals sent by the primary transmitter. This kind of spectrum sensing is also called primary transmitter detection.

Energy Detection

If CR users have no information about the primary signals then energy detection can be used for spectrum sensing. ED is optimal detector if noise power is known to the CR user [2]. Energy detection is very simple and easy to implement. It is the most popular spectrum sensing technique. In energy detection, the presence of the signal is detected by measuring the signal over an observation time.

Advantages: Simple and fewer complexes than other techniques No prior knowledge of the primary signal required Easy to implement

Disadvantages: High sensing time required to achieve the desired probability of detection Using ED, it is not easy to distinguish Primary Signal from noise signal Detection performance is limited by noise uncertainty Spread spectrum signals cannot be detected by ED.

Matched Filter

Detection In matched filter detection SNR of the received signal is maximized. The CR user needs to have the prior knowledge of the primary signal transmitted by the primary user. This is the basic requirement for the matched filter detection. Matched filter operation defines a correlation in which unknown signal is convolved with the filter whose impulse response is the mirror and time shifted versions of a reference signal [6].

Advantages: It needs less detection time. When information of the primary user signal is known to the CR user then Matched Filter Detector is optimal detector in stationary Gaussian noise [3].

Disadvantages: It needs priori knowledge of the received signal. High Complexity.

Cyclostationary Feature Detection

The modulated signals are generally cyclostationary in nature and this kind of feature of these signals can be used in



this technique to detect the signal. A cyclostationary signals have the statistical properties that vary periodically with time [7]. This periodicity is used to identify the presence or absence of primary users. Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation, which is not found in stationary noise [8].

Advantages: Robust to noise uncertainties and better performance in low SNR regions. Capable of distinguishing the CR transmissions from various types of PU signals. No synchronization required Improves the overall CR throughput
 Disadvantages: Highly complex method Long sensing time

IV. METHODOLOGY

The circuit will be implementations in MATLAB 2013b software, with the main parameters described below. We generated a random binary signal generate in a serial manner. To analyze a signal in the time domain, we apply IFFT (Inverse Fast Fourier Transform) and convert it from parallel to serial OFDM signal to add a cyclic prefix (CP), which helps avoids interference between OFDM symbols.

This signal is then feed through an Additive White Gaussian Noise (AWGN) channel. At the receiver end, the CP is removed and the signal converted from serial to parallel to get the original, with FFT applied to each symbol for analysis in the frequency domain. After demodulation, the signal is cross correlated with that of a time-shifted local oscillator.

Finally, the received signal is compared to a threshold value (Λ) following the SNR or determines whether the signal is absent or present; if the received signal is greater than the threshold value, there will be detection, otherwise not:

$$S(t) = n(t) \quad H_0$$

$$S(t) = \{h*P(t) + n(t)\} \quad H_1$$

where $S(t)$ is the secondary user, $P(t)$ the primary user’s transmitted signal, $n(t)$ is AWGN, h the amplitude gain of the channel, H_0 = there’s no primary user, and H_1 = primary user is present.

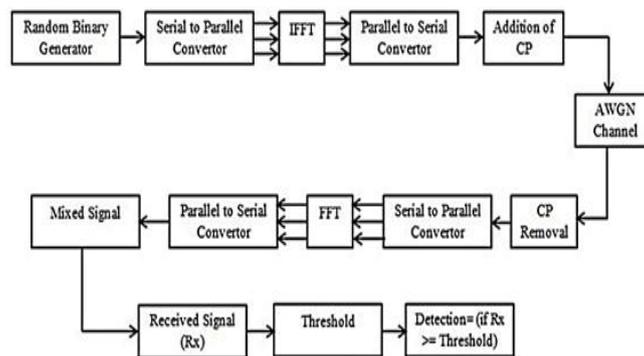


Figure 4: MIMO-OFDM System using Matched Filter Detection Technique

V. CONCLUSION

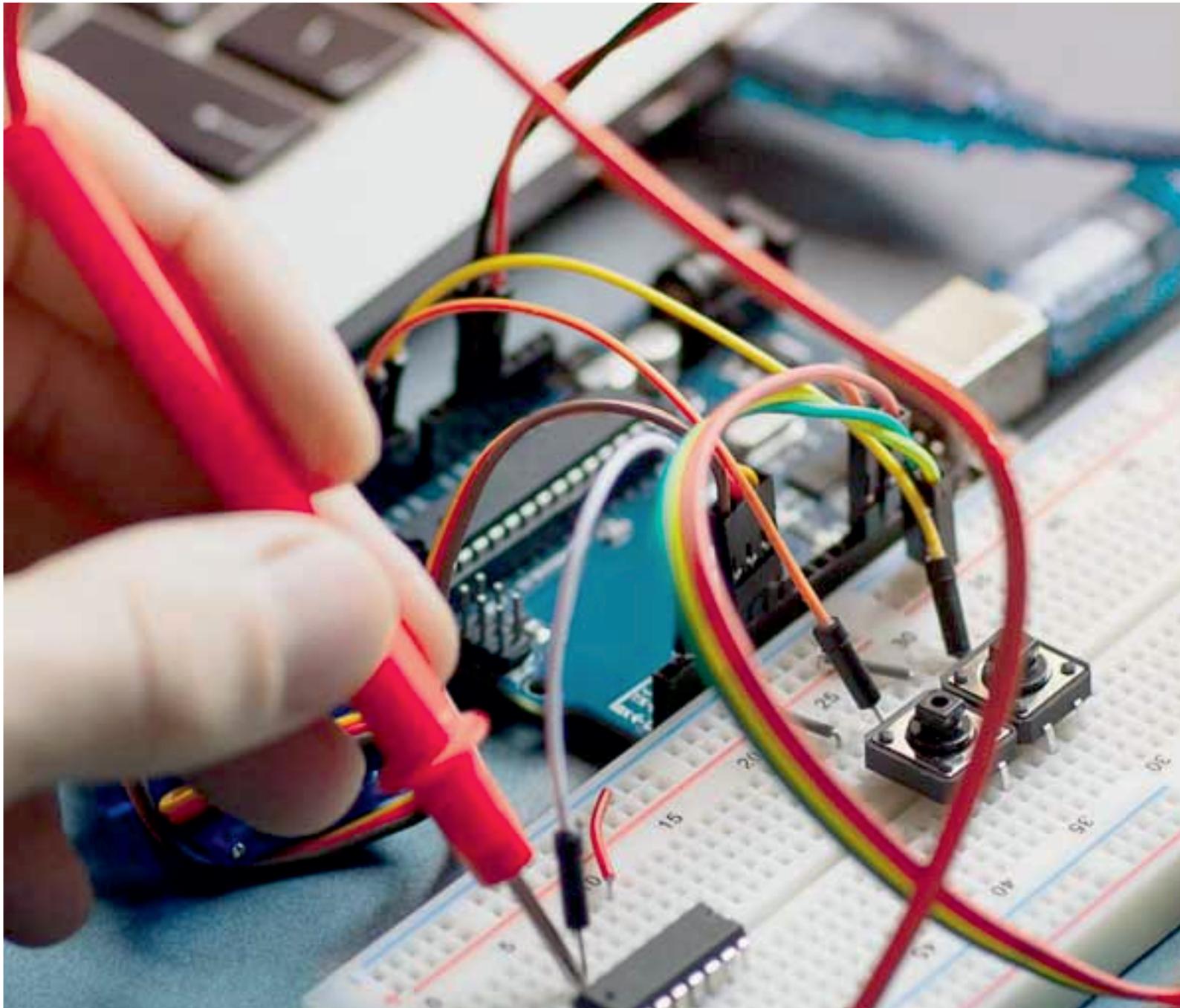
A matched filter, also known as optimal linear filter, is aspectrum-sensing method that detects the free portion of theprimary user’s spectrum and allocates it to secondary users. Itderives from cross-correlating an unknown signal with knownones to detect the unknown signal’s presence based on its SNR.In matched-filter detection, the dynamic threshold is usedto improve the spectrum-sensing efficiency and provide betterperformance in cases of lower SNR.

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