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Detection of OFDM Signals Using Pilot Tones and Applications to Spectrum Sensing for Cognitive Radio Systems

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DETECTION OF OFDM SIGNALS USING PILOT TONES

AND APPLICATIONS TO SPECTRUM SENSING FOR

COGNITIVE RADIO SYSTEMS

by

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ABSTRACT

DETECTION OF OFDM SIGNALS USING PILOT TONES AND APPLICATIONS TO SPECTRUM SENSING FOR COGNITIVE RADIO SYSTEMS

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Old Dominion University, 2014
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Nowadays there are an increasing number of wireless devices which support wireless networking and the need for higher data rate communication is increasing rabidly. As more and more systems go wireless, approaching technologies will face spectral crowding and existence of wireless devices will be an important issue. Because of the limited bandwidth availability, accepting the request for higher capacity and data rates is a challenging task, demanding advanced technologies that can offers new methods of using the available radio spectrum. Cognitive radio introduces a key solution to the spectral increasing issue by presenting the opportunistic usage of spectrum that is not heavily occupied by licensed users. It is a latest idea in wireless communications systems which objective to have more adaptive and aware communication devices which can make better use of available natural resources.

Cognitive radio appears to be an attractive solution to the spectral congestion problem by introducing the notion of opportunistic spectrum use. Cognitive radios can operate as a secondary systems on top of existence system which are called primary (or licensed) systems. In this case, secondary (cognitive) users need to detect the unused spectrum in order to be able to access it. Because of its many advantages, orthogonal frequency division multiplexing (OFDM) has been successfully used in

numerous wireless standards and technologies.

It's shown that OFDM will play an important role in realizing the cognitive radio concept as well by providing a proven, scalable, and adaptive technology for air interface. Researches show that OFDM technique is considered as a candidate for cognitive radio systems.

The objective of this dissertation is to explore detecting of OFDM modulated signals using pilot tones information. Specifically we applying Time-Domain Symbol Cross-Correlation (TDSC) method in the confect of actual 4G wireless standards such as WIMAX and LTE. This detection is only based upon the knowledge of pilot structures without knowledge of received signal so that, it can be performed on every portion of the received signal. The approach induces Cross-Correlation between pilots subcarriers and exploits the deterministic and periodic characteristics of pilot mapping in the time frequency domain.

To my family, friends and teachers.

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CHAPTER 1

INTRODUCTION

Wireless communications technology has grown into a major component of the modern society. Nowadays the overall statistics of operators contributing to wireless communications services have exceeded the number of operators contributing to the wired communications services. Over the last two decades there has been substantial research and progress in wireless communications technology. Which it has developed as a successful section of development in the field of telecommunications. The various wireless communications systems existing in the present vary in conditions of data rate of transmission, geographical coverage area, transmission power, and mobility support for users. With developing technologies and with the ever growing number of wireless communications devices, some radio frequency (RF) bands are becoming occasional currently. The RF spectrum is a limited natural resource to permit wireless communication technology between transmitters and receivers. The radio spectrum is divided into bandwidths that are allocated to different services, such as mobile, fixed, broadcast, fixed satellite and mobile satellite services [4]. A fundamental problem facing future wireless communication systems is where to find suitable carrier frequencies and bandwidths to meet the predicted demand of future services. The bar graphs in Figure 1 provide the measured occupancy for each band for New York.

The radio spectrum is globally administered by the International Telecommunication Union (ITU) whereas the use of radio spectrum in each country is nationally

PLM, amateur, others: 30–54 MHz
TV 2-6, RC: 54–88 MHz
Air traffic control, Aero nav: 108–138 MHz
Fixed mobile, amateur, others: 138–174 MHz
TV 7-13: 174–216 MHz
Maritime mobile, amateur, others: 216–225 MHz
Fixed mobile, Aero, others: 225–406 MHz
Amateur, fixed, mobile, radiolocation: 406–470 MHz
TV 14-20: 470–512 MHz
TV 21-36: 512–608 MHz
TV 37-51: 608–698 MHz
TV 52-69: 698–806 MHz
Cell phone and SMR: 806–902 MHz
Unlicensed: 902–928 MHz
Paging, SMS, fixed, BX aux, and FMS: 928–906 MHz
IFF, TACA, GPS, others: 960–1240 MHz
Amateur: 1240–1300 MHz
Aero radar, military: 1300–1400 MHz
Space/satellite, fixed mobile, telemetry: 1400–1525 MHz
Mobile satellite, GPS, meteorological: 1525–1710 MHz
Fixed, fixed mobile: 1710–1850 MHz
PCS, Asyn, Isoc: 1850–1990 MHz
TV aux: 1990–2110 MHz
Common carriers, private, MDS: 2110–2200 MHz
Space operation, fixed: 2200–2300 MHz
Amateur, WCS, DARS: 2300–2360 MHz
Telemetry: 2360–2390 MHz
U-PCS, ISM (unlicensed): 2390–2500 MHz
ITFS, MMDS: 2500–2686 MHz
Surveillance radar: 2686–2900 MHz

0.0%   25.0%   50.0%

Fig. 1: Average Spectrum Occupancy by band in New York [1]

regulated by the corresponding government agencies that have the freedom to make the spectrum available for particular use in their operational area such as The Federal Communications Commission (FCC) in the USA. The Radio Regulations developed by the ITU Radio-communication sector (ITU-R) are a binding treaty governing the use of radio spectrum. The radio spectrum between 9 kHz and 400 GHz is allocated in the Radio Regulations to different services and there is no unallocated spectrum available. Licenses are usually required for operation on certain frequency bands to avoid harmful interference between different networks to affect the user performance.

More information on the utilization of radio frequencies and in particular the spectrum requirements of International Mobile Telecommunications (IMT) systems are given in [5]. Even though the spectrum bands are allocated to certain services, spectrum occupancy measurements, such as [1] and [6], claim that large portions of the allocated frequency bands are only partially occupied leading to inefficient overall spectrum utilization. Only portions of the spectrum band are fully used. Moreover, there are large temporal and spatial variations in the spectrum occupancy. To meet the demand of future services, new novel and more flexible spectrum management schemes need to be developed for the future wireless networks. In addition, the regulatory framework of spectrum management is at a turning point going from strict regulation and licensing into the direction of liberalization.

In contrast, researches show that extensive ranges of the bands are hardly utilized most of the time while other spectrums are deeply used. Nevertheless, those unutilized bands of the spectrum are licensed and therefore cannot be used by handlers other than the license holders. It can be defined as smart wireless technology that is watchful of its nearby situation via detecting and sorts, a scheme that customs its grown knowledge to strategy future activities and adjust to expand the total communication feature and meet handler requirements. One key feature of cognitive radio is its capability to achievement unutilized bands to deliver different methods of communication [2].

Cognitive radio is a new model of scheming wireless communications systems those objectives to improve the use of the RF bands. The attraction behind cognitive radio is the shortage of the available frequency band; improve application, produced by

the developing wireless applications for mobile users. Furthermost of the existing RF spectrum has already been owed to extant wireless systems, nevertheless, plus only slight shares of it can be licensed to new wireless applications. However, researches have presented that some RF spectrums are significantly used by licensed users in specific settings and at specific periods, however that there are also several RF spectrums that are only some used or generally unused [7]. The main key that hints to wasteful usage of the frequency bands is the spectrum licensing structure itself. In old-style RF bands distribution built on the command and control model, wherever the RF bands distribution to licensed operators is not utilized, it cannot be used by unlicensed terminals and uses [8]. Because of this standing and inflexible distribution, settlement wireless systems have to function only on a devoted RF bands, and cannot adjust the communication band adaptation to the moving atmosphere.

1.1 COGNITIVE RADIO SYSTEM

The more populist description of CR as described in [9],cognitive radio is a technology of wireless communications in which a network or a user flexibly changes its transmitting or receiving parameters to achieve more efficient communication performance without interfering with licensed or unlicensed users. A more technical and analytically-oriented definition of CR is offered by [10] that defines a cognitive radio as an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the

incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind,highly reliable communications whenever and wherever needed,efficient utilization of the radio spectrum.

Cognitive radio (CR) schemes are built on the licensed spectrum are not completely used in the some frequencies bands, where the task of spectrum is constant. A CR network dynamically senses spectrum and utilize a spectrum if it does not harm a Primary User (PU) is a licensed user defined as the user which has an exclusive right to a certain spectrum band. In other words, the license holders, means no need to be aware of cognitive users and no additional functionalities or modifications needed. Whereas Secondary User (SU) or (Unlicensed User) Cognitive-radio enabled users Lower priority than PUs [11] [12]. Assumed that the CR scheme will not interrupt the primary network holds license to the spectrum, the CR scheme have to check and frequently detects the bands. If the primary network is sensed in particular spectrum while the CR scheme is using it [10], then the CR scheme have to directly discontinue utilizing the spectrum and sense different spectrum to utilize. Else, the connection of SU and the PU would be significantly disconnected. There are two categories of band detecting in a CR networks:

1. In-band spectrum sensing.

2. Out-of-band spectrum sensing [9].

In the first category of in-band spectrum sensing, in this case CR network detects a band which is already utilize by the CR network, while in out-of-band spectrum

sensing, the CR network detects a spectrum which is has not been utilized by the users. [13] The in-band spectrum sensing type, the CR network has to send no signal over a spectrum during spectrum detecting is in on, since the sent signals could badly disturb the band detacting. The time while the CR network has to send no indication is known as quiet time. This time has to be long sufficient to let maximum detecting exactitude [9], [14]. Nevertheless, the longer the spectrum sensing goes on, the larger:

1. The delay that is experienced by the users (which is critical to real-time traffic users, such as voice over Internet Protocol users)

2. The throughput loss will increase.

To explain the issue that band detecting positions for quality of service (QoS) in CR network, two-stage detecting was studied. Two-stage detecting serially holders two procedures of detecting [15]. First technique is fast sensing, that is typically built on simple energy detection. Second technique is fine sensing, that is built on complicated feature sensing [9]. Usually, fast sensing is completed extremely fast. In two-stage sensing, a CR scheme achieves fast detecting first. Before, on the source of the outcomes of the fast detecting, it picks even to achieve the acceptable detecting [16]. Through using the two stages sensing, the user QoS may be enhanced although keeping great band detecting precision [9]. Nevertheless, specified that the probability that fast sensing will produce a false detection is high, it could regularly be essential to achieve the acceptable detecting.A cognitive network is collected of a great amount of cognitive terminals (CTs) which were spread in a system [17]. In investigate a cognitive network in which the number of band detecting processes that each CT

achieves could be distinguished for each CT centered on the sensing execution of the CT and resolve the issue of enhancing the amount of band detecting processes [18]. To accomplish the wanted detecting performance with respect to the probabilities that band detecting would produce a false detection and a missed detection in the situation of the occurrence of a primary network [19]. This detecting enhancement challenge which distinguishes the amount of band detecting has not yet been studied. In this study for detecting system, if band detecting is achieved, selected CTs will be involved in detecting whereas others are not. When individuals CTs which do not share in band detecting could accept data from a cognitive base station (BS) [20], therefore the achievement of the cognitive network may be maximized with respect to output and delay,to achieve band detecting and communicate together. Thus, through this system, it is likely to:- [21], [22] [23]

- Accomplish the wanted detecting achievement depends on the probabilities of a false detection and a missed detection.

- Maximize the achievement of cognitive network with respect to output and delay.

1.2   SPECTRUM SENSING

Cognitive radio systems normally contain primary users (PU) of the spectrum, who are mandatory licensees, and secondary users (SU) who search for resourcefully use the band when the PU are idle. The introduction of cognitive radios essentially builds better interfering and therefore could damage the quality of service (QoS) of the
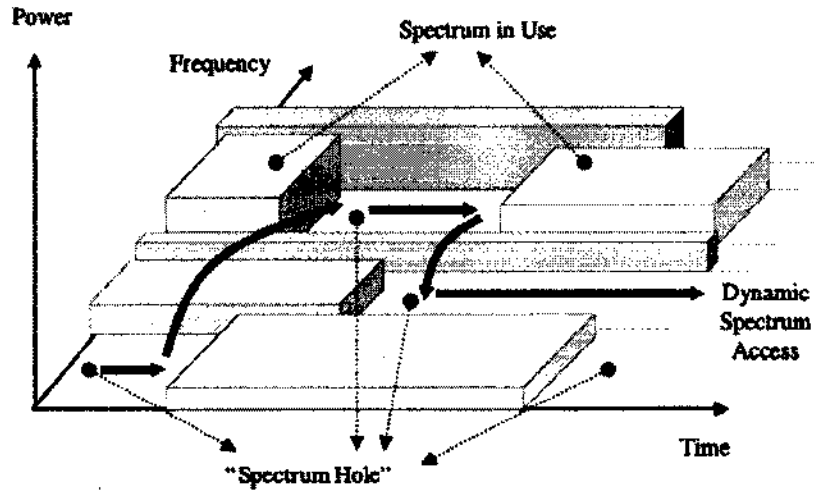
Fig. 2: Spectrum Hole

PU [24], [18]. A key challenge CR systems is the detection of unoccupied frequency intervals, so called spectrum holes, which defined as a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user.

The effect on the PU, for instance in positions of increased interference, necessity to reserve at lowest level. Thus, cognitive radios need to detect the bands to sense if it is used or not and have to can sense very weak PU signals [25], [26]. Therefore, spectrum sensing is one of the most important mechanisms of cognitive radio. The issue of spectrum sensing is to decide if a certain band of the spectrum is used or not. That is, the easiest process required to distinguish among the two hypotheses [27].

$$H_0 : y(n) = w(n). \tag{1}$$

$$H_1 : y(n) = x(n) + w(n). \tag{2}$$

where H_0 noise only, H_1 is signal and noise existing, $x(n)$ represents a PU's signal, $w(n)$ is noise and n represents time.

CR have to be capable to test the spectrum and measure unrelated channel structures for instance power availability, interference, and noise temperature [28]. Furthermore, the scheme have to be capable to detect different operators signals in the spectrum and similarly detect if they are either licensed or unlicensed users. These capabilities allow CR system to detect unutilized holes in the spectrum and spectral opportunities [13]. However, since for a shared system it is essential not to interfere with other licensed systems consuming the spectrum, other processes should be taken to agreement an interference-free communication between shared terminals. One method is to share the spectrum sensing information between multiple CR devices to reduce or even remove the probability of interference with licensed users [29]. However additional complicated algorithms could be used for spectrum sensing. Whereas the effectiveness of the spectrum sensing and investigating method is significant for a effective application of CR, the release time is very significant. The periodicity of detecting should be little sufficient to agree for spectrum sensing of new spectrum chances then, together, to sense licensed users opening the previously-identified-as unutilized shares of the spectrum [30]. Instead, when spectrum sensing was completed so often, the above of distribution such data will rise dropping the spectrum effectiveness of the entire system not to remark the rise in system difficulty.

In OFDM systems, transformation from time domain to frequency domain is accomplished essentially by using DFT. Therefore, all the points in the time frequency network can be perused deprived of every additional hardware and calculation since of the hardware reprocess of Fast Fourier Transform (FFT) centers. Consuming the time frequency network, the range of holders that are accessible for utilization of spectrum holes can be accepted out consuming easy hypothesis analysis [31]. The DFT outputs can be filtered through time and frequency dimensions to decrease the reservation in detection also [32].

Spectrum Sensing and Awareness

Cognitive radio should be able to scan the spectrum and extent different channel characteristics such as power accessibility, interference, and noise temperature [28]. Furthermore, the system should be capable to recognize different users signals in the spectrum and also recognize if they are either licensed or unlicensed users. These capabilities let cognitive radio system to recognize unused parts of the spectrum and spectral chances. Nevertheless, subsequently for a unlicensed users it is important not to interfere with other licensed systems using the spectrum, other measures should be taken to guarantee an interference-free communication between unlicensed users. [29]. Then, more sophisticated algorithms can be used for sensing the spectrum. Though the efficiency of the spectrum sensing and investigating procedure is important for a effective application of cognitive radio, the processing time can be even more significant. The periodicity of spectrum sensing should be short enough to allow for detection of new spectrum opportunities and, at the same time, to detect licensed

users accessing the previously identified as unused parts of the spectrum. In OFDM systems, conversion from time domain to frequency domain is achieved fundamentally by using DFT. OFDM is a good fit for Cognitive Radio, some of the requirements for cognitive radios and explain how OFDM can achieve these requirements. These requirements presented in table (1).

Cognitive radio requirements	OFDM strength
Spectrum sensing	Inherent FFT operation of OFDM eases spectrum sensing in frequency domain.
Efficient spectrum utilization	Waveform can be easily shaped by simply turning off some subcarriers, where primary users exist.
Adaptation/Scalability	OFDM systems can be adapted to different transmission environments and available resources. Some parameters include: FFT size, subcarrier spacing, CP size, modulation, coding, subcarrier powers.
Advanced antenna techniques	Multiple-Input Multiple-Output (MIMO) techniques are commonly used with OFDM mainly because of the reduced equalizer complexity. OFDM also supports smart antennas.
Interoperability	With WLAN (IEEE 802.11), WMAN (IEEE 802.16). WRAN (IEEE 802.22), WPAN (IEEE 802.15.3a) all using OFDM as their PHY techniques, interoperability becomes easier compared to other technologies.
Multiple accessing and spectral allocation	Support for multiuser access is already inherited in the system design by assigning groups of subcarriers to different users (OFDMA).

Table 1: Cognitive radio requirements

OFDM Concept

For CR to achieve its objective, the Physical Layer (PHY) needs to be highly adjustable and flexible. A special instance of multicarrier transmission identified as Orthogonal Frequency-Division Multiplexing (OFDM) is one of the superlatives commonly used technologies in nowadays wireless communications systems and it

has the potential of satisfying the above-mentioned demands of CR essentially or with insignificant modifications [29]. By separating the spectrum into sub-bands that are modulated with orthogonal subcarriers, OFDM eliminates the requirement for equalizers and therefore diminishes the complication of the receiver. Due of its smart structures, OFDM has been effectively used in several wireless technologies [33]. It is supposed that OFDM will similarly performance in recognizing CR idea by providing a proven, scalable, and adaptive technology for air interface. A basic block diagram of a simple OFDM system is shown in Figure .1.
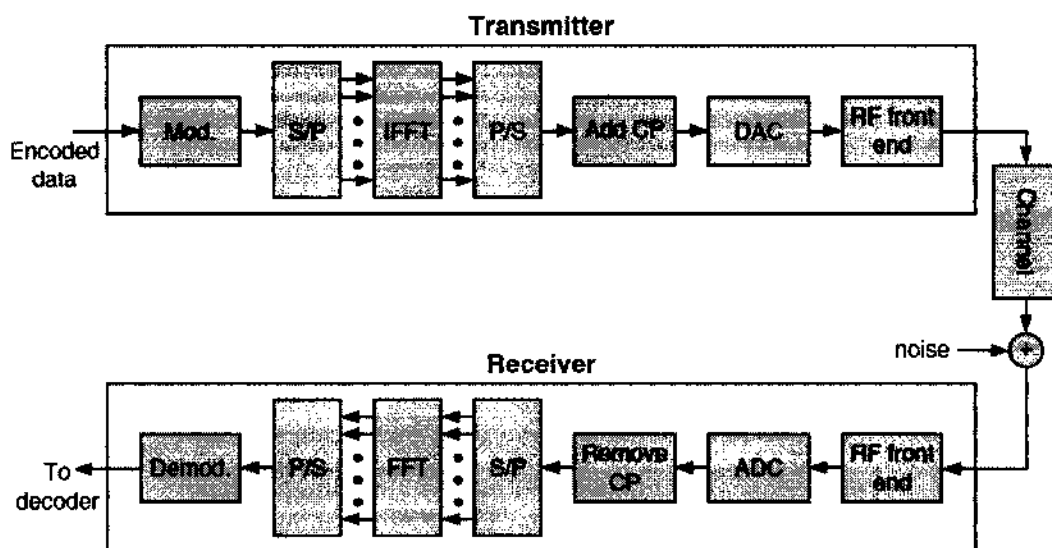
Fig. 3: Block diagram of a generic OFDM transceiver [2]

In a multipath fading channel, because to the frequency choosiness, every subcarrier can has different reduction. The power on some subcarriers may be significantly fewer than the average power due of deep fades. Therefore, the total bit error rate (BER) may possibly be dominated by limited subcarriers with less power levels. To

diminish the dilapidation of scheme performance because to this issue, channel coding could be used prior to the modulation of bits [34]. Channel coding can minimize the BER gradually subject to the code rate, decoder complication, and SNR level between other issues. Inserting is also functional to randomize the rate of bit errors and lead system protection to burst errors. Coded and interleaved data is then drawn to the constellation points to achieve data symbols [32]. This stage is denoted by the modulation block of Figure 3 The serial data symbols are then transformed to parallel data symbols that are fed to the Inverse Discrete Fourier Transform (IDFT) block to achieve the time domain OFDM symbols. Time domain samples can be written as

$$x(n) = IDFTX(k)$$

$$= \sum_{k=0}^{N-1} X(k)e^{j2\pi nk/N} \ 0 \leq n \leq N-1, \tag{3}$$

Cognitive terminals should be capable to openly character the communicated waveform spectrum. It is chosen to switch over signal factors for instance the waveform bandwidth, center frequency, power level, center frequency, and spectrum cover [35]. OFDM systems can offer such flexibility since the unique nature of OFDM signaling. Through stopping a establishing of subcarriers, the spectrum of OFDM waveform can be modified formed to acceptable into the essential spectrum cover. Supposing the bands cover is currently identified to the CR system, selecting the stopped subcarriers is a reasonably easy procedure [7]. The key factors of an OFDM system that can be utilized to figure the waveform spectrum are quantity of subcarriers. Maximizing the number of subcarriers for a steady bandwidth lets the OFDM system to have an enhanced purpose in the frequency domain. Nevertheless, these
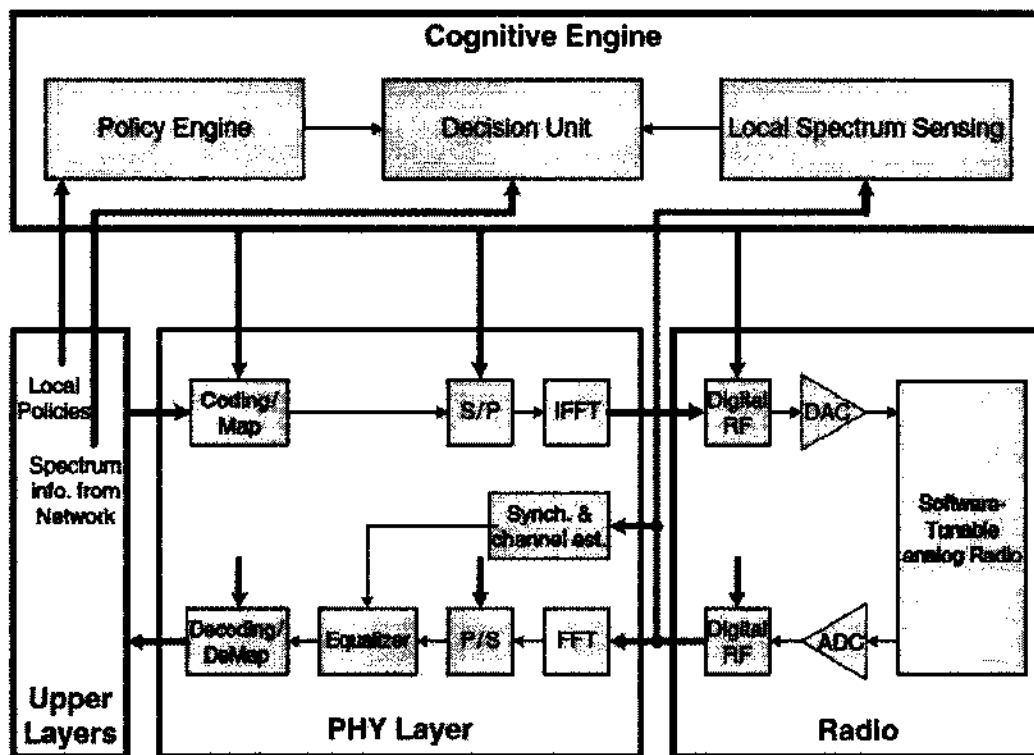
Fig. 4: OFDM-based Cognitive radio system block diagram. All of the layers can interact with the Cognitive engine. OFDM parameters and radio are configured by the Cognitive engine [2]

effects in maximizing the difficulty of the FFT process and therefore aggregate the general scheme complication. Subcarrier power can be utilized to figure the waveform into the chosen mask. Unique aim to give subcarriers unlike powers is to improved suitable into the channel response [36].

Dissertation Contributions

In this dissertation, detection of OFDM signals using pilot tones information is studied and applications to Dissertation Contributionsspectrum sensing in cognitive radio systems are presented. Specifically, the dissertation presents spectrum sensing

based on the Time-Domain Symbol Cross-Correlation (TDSC) of two OFDM symbols. The TDSC uses the parameters that have a nonzero constant term inserted in the TDSC when the two OFDM symbols have similar frequency domain pilot symbols. Therefore, the proposed spectrum sensing method can be applied to WiMAX and LTE systems that assign frequency domain pilot symbols to support in accomplishing synchronization and channel estimate. The dissertation focus is on sensing of WiMAX and LTE signals using pilot tones. This detection is only based upon the knowledge of pilot signals, without knowledge of received signal.

This dissertation deals with a Matlab application currently being developed to simulate WiMAX and LTE transmission in different real channels in order to test pilot sensing, compare them and determine in which channels use is more appropriated. Therefore WiMAX and LTE signals have been generated and detected after crossing a channel. The cyclic prefix (CP) is described and simulated for WiMAX and LTE. The theoretical analytical of the probability of misdetection and probability of false alarm for the spectrum sensors considered in both cases. Different CP ratios are simulated for different real channels (AWGN, Rayleigh, and Ricean).

Dissertation Organization

In Chapter I, we present an over view of cognitive radio systems as we will as works related to study which include spectrum sensing, also a brief outline of OFDM system. The contributions and tentative road map of the dissertation are also presented in this chapter. In Chapter II, we show using pilot tones for spectrum sensing that can be adaptive for spectrum utilization of cognitive radio. In this chapter we

studied the concept of OFDM investigates the guard interval and cyclic extension also explored and studied the OFDM frame. In this chapter we show energy detection techniques, present TDSC, furthermore detection performance in fading channel such as AWGN Rayleigh channel and Rician fading. The theoretical derivations of probability of misdetection and probability of false alarm were presented. In Chapter III, we evaluate OFDM pilot tones for spectrum sensing with applications to mobile WiMAX started the chapter with short introduction about WiMAX. Present the TDSC-Based technique that used for spectrum sensing. Analyzes WiMAX spectrum sensing and present results for WiMAX systems. In Chapter IV, we investigate the spectrum sensing for LTE signal. In Chapter V,we do spectrum sensing comparisons between WiMAX and LTE regarding a spectrum sensing and technical parallels between the LTE and WiMAX. In Chapter VI,in this Chapter, the contributions of this dissertation were concluded and some useful directions for future research are discussed. The Dissertation Organization as described in Table.2.

CHAPTER I
Introduction
CHAPTER II
Background
CHAPTER III
Using Pilot Tones And TDSC for Mobile WiMAX
CHAPTER IV
Using Pilot Tones And TDSC for Mobile LTE Spectrum Sensing
CHAPTER V
WiMAX and LTE Parallel Comparison
CHAPTER VI
Conclusion and Future Research

Table 2: Dissertation Organization

CHAPTER 2

BACKGROUND

In this dissertation, just mapping, frame adaptation, pilot and Transmission Parameter Signaling (TPS) signal and OFDM modulation processes are required and are applied in the matlab application. This is because the significant data for detecting the signal is contained in the pilot in other words it's introduced through the frame adaption, so information used in the simulation is random. In order to make it easy the receiver of the signal being transmitted pilot signals are injected. Pilot signals are used at the time of the synchronization and equalization phase, while TPS signals transmits the parameters of the transmitted signal [37]. The reception has to be capable to synchronize, equalize, and decode the signal to gain access to the data seized by the TPS pilots. The signal mapping allows different levels of modulation and different inner code rates to be used to trade bit rate versus ruggedness [38], [39]. OFDM transmission is used. The signal mapping depends on two parameters; the modulation and minimum distance separating two constellation points (α). All data carriers in one OFDM frame are modulated using QPSK, 16-QAM, 64-QAM, non-uniform 16-QAM or non-uniform 64-QAM constellations. The more the QAM number can transmit the more coded data bits it can provide higher quality. The proportions of the constellations depend on a parameter α.

2.1 OFDM SYSTEM

The fundamental feather of OFDM is to split the bandwidth into a number of sub-channels such that those narrow sub-channels able to have flat fading. The basic idea of orthogonal sub-channels makes OFDM have a high spectral efficiency. Cyclic extension is a duplicate of the previous or the forward part of each OFDM symbol [40]. It avoids inter symbol interference (ISI) and inter carrier interference (ICI), and makes the transmitted signal periodic. Mathematical Descriptions of OFDM A frequent time model of OFDM symbol can be supposed that data $X_k(t)$ are modulated by a series of orthogonal sub-carriers [41]. Considering it have N_{sc} sub-carriers:

$$S_n(t) = \sum_{k=0}^{N_{sc}} X_k(t) e^{j(2\pi k_\Delta f t)} \tag{4}$$

Then, it is sampled by a sampling frequency $1/\tau$. The duration of one symbol is T_u that has a connection as

$$T_u = N_{sc}\tau \tag{5}$$

Where N_{sc} samples are generated. When the signal $X_k(t)$ is a stable value over a symbol period it can be rephrased as $X(k)$. The result can be characterized by:

$$S_n(t) = \sum_{k=0}^{N_{sc}} X(k) e^{j(2\pi k_\Delta f n\tau)} \tag{6}$$

Matching the general form of inverse Fourier transform shown in equation (7) with equation (6), if equation (8) then equation (5) and equation (7) are equivalent. Then, IDFT can be used to develop the modulation of an OFDM system:

$$y(n\tau) = \frac{1}{N_{sc}} \sum_{k=0}^{N_{sc}} X(k) e^{j(2\pi k n\tau/N_{sc})} \tag{7}$$

$$\Delta f = \frac{1}{N_{sc}\tau} \tag{8}$$

Cyclic Prefix Insertion
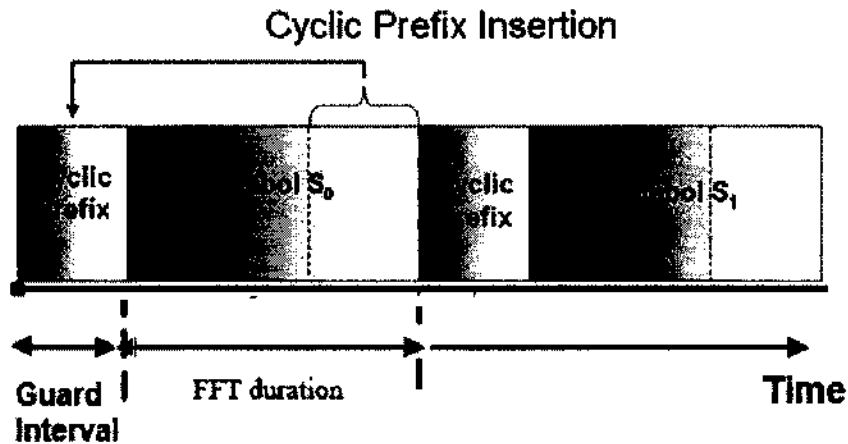
Fig. 5: Cyclic prefix and Guard interval

2.2 GUARD INTERVAL AND CYCLIC EXTENSION

Inter Symbol Interference(ISI) and Inter Channel Interference (ICI) introduced by transmission distortion channel do damage on the orthogonally of sub-carriers in OFDM. A key is to add an empty guard interval (GI) among two following symbols. If the size of GI is longer than the delay spread of channel reply, the next symbol does not interfere with the former one [42], [43]. Nonetheless if symbol edge estimation does not precisely locate the symbol, the unoccupied GI destroys the orthogonally and introduces ICI. In order to avoid this site, an implement is planned to duplicate the last part of an OFDM symbol into the empty GI, which is so titled Cyclic Prefix (CP) as shown in Figure 4. CP creates the sub-carrier signal has essential times, so it can continue the orthogonality [44]. In addition, adding CP to each OFDM symbol creates line convolution be equal to a circular convolution. The lth received OFDM

symbol $r_{l,n}$ and its DFT $R_{l,k}$ is defined as:

$$R_{l,k} = DFT\left\{r_{l,n}\right\} \tag{9}$$

$$= DFT\left\{IDFT\left\{D_{l,k}\right\} \otimes h_{l,n}\right\}$$

$$= DFT\left\{IDFT\left\{D_{l,k}\right\}\right\} DFT\left\{h_{l,n}\right\}$$

$$= D_{l,k} \cdot H_{l,k}$$

Since the attitude of circular convolution, the transmitted data $D_{l,k}$ can be recovered by the estimation of response of channel.

$$\widehat{D}_{l,k} = \frac{R_{l,n}}{\widehat{H}_{l,k}} \tag{10}$$

Where k is the sub-carrier index, n is the sample index in time domain, $h_{l,n}$ is the channel impulse response and $H_{l,k}$ is the channel frequency response.

2.3 OFDM FRAME STRUCTURE

The OFDM system is specified for bandwidth channel spacing. A flexible guard interval is stated to allow optimum tradeoff between network topology and frequency efficiency [45]. This will enable the system to support different network configurations, such as large area Single Frequency Network (SFN) and single transmitter [46]. Two modes of operation are defined, a 2K mode and an 8K mode.

- The 2k mode has wider sub-carriers spacing, so it can be used against the distortion caused by Doppler spread. It is suitable for single transmitter operation and for small SFN networks with limited transmitter distances.

- The 8k mode has longer symbol duration, so it is adapted for long distance transmission. It can be used both for single transmitter operation and for small and large SFN networks.

The OFDM transmitted signal is organized in frames. One super-frame is constituted by four frames. Each frame consists of 68 OFDM symbols and has duration of T_F. Each symbol is constituted by a set of K carriers and transmitted with duration T_S. Depending on the mode, $K = 6.817$ carriers (8k mode) or $K = 1.705$ carriers (2k mode). The symbol is composed of two parts, a suitable part with duration T_U and a guard interval with duration Δ. The guard interval contains in a cyclic extension of the suitable part, T_U, and is injected before it. Four values of guard intervals are used 1/4, 1/8, 1/16 and 1/32. The symbols in an OFDM frame are numbered from 0 to 67. All symbols contain data and reference information [47], [48]. In accumulation to the transmitted data an OFDM frame contains:

- Continual pilot carriers.

- Scattered pilot cells.

- TPS carriers.

The pilots are used for frame synchronization, frequency synchronization, time synchronization, channel estimation, transmission mode identification and can also be used to follow the phase noise. The carriers are indexed by $K \in [K_{min}; K_{max}]$ and determined by $K_{min} = 0$ and $K_{max} = 1.704$ in 2K mode and $K_{max} = 6.816$ in 8K mode respectively. The spacing between adjacent carriers is $1/T_u$ while the spacing between

carriers K_{min} and K_{max} is determined by $\frac{K-1}{T_u}$. The values for the several time-related parameters are given in multiples of the elementary period T. The emitted signal $S(t)$ is described by the following expression:

$$S(t) = Re\left\{ e^{2\pi f_c t} \sum_{m} \sum_{l=0}^{67} \sum_{k=k_{min}}^{k_{max}} C_{m,l,k} \cdot \varphi_{m,l,k}(t) \right\} \qquad (11)$$

$$\varphi_{m,l,k}(t) = \left\{ \begin{array}{cc} e^{2\pi \frac{k'}{T_u}(t-\Delta-l.T_s-68.m.T_s)} & (l+68.m).T_s \leq t \leq (l+68.m+1).T_s \\ \\ 0 & else \end{array} \right\} \qquad (12)$$

Where K is the carrier number, l is the OFDM symbol number, m is the transmission frame number, k is the number of transmitted carriers, T_s is the symbol duration, T_u is the inverse of the carrier spacing, Δ is the duration of the guard interval, f_c is the central frequency of the RF signal, K' is the carrier index accomplished to the center frequency, $K' = K - \frac{k_{max}+k_{min}}{2}$, $C_{m,0,k}$ is the complex symbol for carrier k of the Data symbol number 1 in frame number $C_{m,0,k}$ is the complex symbol for carrier k of the Data symbol number 2 in frame number m and $C_{m,67,k}$ is the complex symbol for carrier k of the Data symbol number 68 in frame number m [49].

2.4 OFDM IN MULTIPATH FADING CHANNELS

In wireless communications, fading is deviation of the attenuation affecting a signal over certain propagation media. The fading may vary with time, geographical position or radio frequency, and is often modeled as a random process [50]. A fading channel is a communication channel comprising fading. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, or due to

shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading [51]. Fading Parameters: Model the behavior of the channel. This channel can be Rayleigh, Rician or AWGN.

- AWGN and Fading Channel

The AWGN channel is the simplest channel model used in most communication systems. The thermal noise in the receivers can be characterized as an additive white Gaussian process. Although there are other factors inducing channel noise, such as antenna temperature, receiver filter, and multipath fading [52], only multipath fading will be studied in this chapter. Channel fading is generally categorized into large-scale and small-scale fadings, which often occur simultaneously. Large-scale fading results from shadowing terrain contours such as hills, forests, or buildings, relative to the distance between transmitter and receiver. Small-scale fading, also known as Rayleigh fading, is not determined by the distance in communication. The small-scale fading is manifest in two ways: the signal spreading and the time variation [53].

- Rayleigh and Fading Channel

A Rayleigh model is widely used to model wireless multipath fading channels in practice. Rayleigh model is frequently used to describe a wireless channel with AWGN but without Light of Sign (LOS), where the power gain is subject to a random Rayleigh distribution [54].

- Rician and Fading Channel

The model behind Rician fading is similar to that for Rayleigh fading, except that in Rician fading a strong dominant component is present. This dominant component

can for instance be the line-of-sight wave [55]. Refined Rician models also consider that,the dominant wave can be a phasor sum of two or more dominant signals, e.g. the line-of-sight, plus a ground reflection. This combined signal is then mostly treated as a deterministic (fully predictable) process, and that,the dominant wave can also be subject to shadow attenuation. This is a popular assumption in the modeling of satellite channels. Besides the dominant component, the mobile antenna receives a large number of reflected and scattered waves [56].

- OFDM In Multipath Slowly Fading Channel

The insertion of CP reduces the spectral efficiency [57]. Without necessary CP, two difficulties increase when the OFDM signal is transmitted over multipath slowly fading channel. One issue is that the time dispersion of the channel terminates the orthogonality between subcarriers and causes intercarrier interference (ICI). Additionally, a system may send the OFDM signal in sequence so that the time dispersion of the channel causes interblock interference (IBI) between successive OFDM blocks [58].

2.5 SENSING OFDM SIGNALS

Energy Detection

As an instance of a very basic sensing technique, we clarify the well-known energy detector, which known as the radiometer [59]. Simply the energy detector measures the energy received throughout a finite time interval and compares it to a programmed threshold. It should be explained that the energy detector works well for many cases, however it may not be the best. To develop this detector, suppose that the signal to

be sensed does not have any known configuration that could be used, and model it through a zero-mean circularly symmetric complex Gaussian [60]

$$\Lambda(y) = \frac{\|y\|^2}{\sigma^2} = \frac{\sum_{i=1}^{LN} |y_i|^2}{\sigma^2} \geq \eta \tag{13}$$

The functioning implication of (6) is to compare the energy of the received signal in contradiction of a threshold; because of the (6) is called the energy detector. Its performance is well known,can be expressed as

$$P_D = Pr(\Lambda(y) \geq \eta H_1) = 1 - F_{X_{2ML}^2}\left(\frac{2\eta}{\sigma^2 + y^2}\right)$$

$$= 1 - F_{X_{2ML}^2}\left(\frac{F_{X_{2ML}^2}(1 - P_{PF})}{1 + \frac{y^2}{\sigma^2}}\right) \tag{14}$$

Clearly, P_D is a function of P_{FA}, NL and the $SNR \equiv \gamma^2/\sigma^2$ Note that for a fixed P_{FA}, P_D as $NL \longrightarrow \infty$ at any SNR. At any SNR. That is,ideally any duo (P_D, P_{FA}) can be accomplished if detecting can be done for an randomly long time. But this is normally not the case in practice. It has been claimed that for some models, and if the probability density functions under both hypotheses are well known, energy detection accomplishes adjacent to the optimum detector [26], [61]. For instance, it was shown in [26] that the achievement of the energy detector is asymptotically same, at low SNR, to that of the optimum detector when the signal is modulated with a zero-mean finite signal constellation, supposing that the symbols are independent of each other and that all probability distributions are well known. A equivalent result was shown mathematically in [61] for the sensing of an OFDM signal. These productions clutch if all probability density functions, counting that of the noise, are well known. Compare, if for example the noise variance is unidentified, the energy

detector cannot be used due knowledge of σ^2 is required to set the threshold. If an incorrect estimated value of σ^2 is used in (6) then the resulting detector may perform rather wrong.

Time Domain Symbol Cross Correlation (TDSC) Method

Under the assumption that a packet-based OFDM transmission system. The nth sample of the mth OFDM symbol can be represented as the inverse Discrete Fourier Transform (IDFT)of the complex data vector$d_{m,0}..dm, N-1$

$$x_m[n] = \sum_{k=0}^{N-1} d_{m,k} e^{j2\pi kn/N} \tag{15}$$

where$0 \le n \le N-1$ and N symbolizes the number of sub-carriers or equivalently the length of the DFT. A cyclic prefix of length N_g is added to give the mth transmitted OFDM symbol $x_m = [x_{m,N-Ng}, ..., x_{m,N-1}, x_{m,0,}, x_{m,N-1}$. A preamble sequence is introduced at each frame of data before transmission. Here we describe the wireless communication system under consideration that , the length of the Cyclic Prefix (CP), is longer than the length of the time invariant channel, the sample of the OFDM symbol can be written as

$$x_l[n] = e^{j(2\pi f_\Delta n/N + \theta_l)} \cdot \frac{1}{N} \sum_{k=0}^{N-1} H[k] X_l[k] e^{j2\pi kn/N} + w_l[n] \tag{16}$$

$$\Theta_l = (2\pi f_\Delta lM/N + \theta_0)$$

The phase Θ_l is the initial phase of the lth OFDM symbol,Δf is the carrier frequency offset normalized to the subcarrier spacing, $M = N + L$ is the length of an OFDM symbol, $X_l[k]$ is the data symbols at the k th subcarrier of the lth OFDM symbol,

$H[k]$ is the complex channel gain of the kth subcarrier, $w_l[n]$ is a sample of a complex additive white Gaussian noise (AWGN) process,assumed to be a circularly symmetric complex Gaussian random variable, variance of σ_w^2/N. Furthermost of the current standards that accept OFDM modulation [6] [62] [10] assign pilot symbols in the frequency domain and these pilot symbols are called pilot tones. Suppose $\mathbf{P}_a, a = 0, 1, ... A - 1$,represent the sets of all possible pilot tone positions for the transmitted OFDM symbols. Let that $\mathbf{P}_a$ is the set of pilot tone positions of the hth OFDM symbol and $X_l[k] = \mathbf{P}_a[k]$ for $k \in \mathbf{P}_a$. Now, it should recognized that the pilot symbols $\mathbf{P}_a[k]$ are predefined and have the same amplitude. For most situations,is a static constant and in some settings they change sign. Assume that the lth and m^{th} OFDM symbols have the same pilot tone positions and expressed as

$$R(l,m) = \frac{1}{N} \sum_{n=0}^{N-1} x_l[n] x_m^*[n] \tag{17}$$

That is the Time-Domain Symbol Cross-Correlation (TDSC) function of two OFDM symbols. After straight forward calculations and approximations the Eq(10) can be written as

$$R(l,m) \cong e(l-m) \cdot \frac{\rho^2}{N^2} \sum_{k \in \mathbf{P}_a} |H[k]|^2 + \frac{1}{N} \sum_{k=0}^{N-1} w_l[n] w_m^*[n]. \tag{18}$$

$R(l,m)$ consists of a constant term and a noise term. Probability of Misdetection P_{MD} is the probability that the secondary user decides that a primary user is not present in a certain channel whereas essentially the primary wireless system does present that network. The probability distribution assigns for H_0 and H_1 of TDSC spectrum sensing algorithms is circularly symmetric complex Gaussian, where $\sigma_{H_0}^2$ and $\sigma_{H_1}^2$ are the variances of the distributions of H_0 and H_1 respectively and $\mu_{H_0}^2$

is the mean of the distribution of the H_1. Rayleigh distribution has been used for hypothesis H_0, $|T_{NP}|$. Probability of false alarm P_{FA} that the secondary user decides that a primary user is accrue in a certain channel whereas the primary wireless system does not consuming that channel,According to [63],the matching threshold γ is given by

$$\gamma = \sqrt{-\sigma_{H_0}^2 \ln P_{FA}}. \tag{19}$$

For sake of simplicity it's been used a single-path channel, the probability of misdetection P_{MD} is expressed as

$$P_{MD} = 1 - Q_{x_2'^2(\lambda)}\left(\frac{\gamma^2}{\sigma_{H_1}^2}\right). \tag{20}$$

Where the function $Q_{x_2'^2(\lambda)}(x)$ is the right-tail probability of the non-central Chi-Squared distribution with two degrees of freedom.

2.6 CHAPTER SUMMARY

Cognitive radio is a promising effort for resolving the spectrum limited issue. On the other hand, OFDM system is used in many wireless systems and verified as a consistent and operative transmission technique. OFDM can be used for recognizing CR concept because of its abilities that are discussed in this chapter. By employing OFDM transmission in cognitive radio systems; adaptive, aware and flexible systems that can function with current technologies can be realized.

CHAPTER 3

USING PILOT TONES AND TDSC FOR MOBILE WIMAX SPECTRUM SENSING

3.1 INTRODUCTION

Wireless communication systems have become ubiquitous and affordable, and their evolution is prompting new wireless services and applications. Current fourth generation (4G) networks and emerging wireless systems aim toward providing a multitude of applications and services beyond those delivered by established third generation (3G) cellular and wireless local area networks (WLANs).

At the physical layer of 4G systems the modulation schemes are based on Orthogonal Frequency Division Multiplexing (OFDM) which has many attractive features such as the ability to transmit over non-contiguous frequency bands, simplicity of implementation, and scalability. OFDM-based schemes are currently being used in the WiMAX/IEEE 802.16 and 3GPP/LTE standards, as well as in the established IEEE 802.11 standard for wireless local area networks (WLAN) [64]. We note that, while the spectrum assigned to WiMAX systems is not the same throughout the world, the WiMAX standard specifies three licensed bands for use (2.3 GHz, 2.5 GHz and 3.5 GHz) in a determined effort for calibration and cost efficiency [65]. We also note that, channel estimation in OFDM systems is accomplished either by inserting pilot symbols in all subcarriers, or by using pilot tones for all OFDM symbols.

To optimize spectrum utilization in future generations of wireless systems, cognitive radios (CR) are expected to allow secondary access to licensed spectrum by unlicensed devices subject to strict constraints. Specifically, if a CR operator senses the presence of licensed user in a specific spectrum band, it may not use that band and has to seek alternative unused bands. To detect the use of the spectrum by licensed systems a spectrum sensing procedure must be applied, and in this chapter we study spectrum sensing for OFDM systems by using an algorithm based on the Time-Domain Symbol Cross-correlation (TDSC) of two OFDM symbols [66]. The TDSC algorithm is based on the observation that the cross-correlation of two OFDM symbols in time domain has a non-zero component if the two symbols correspond to pilot tones, and the studied spectrum sensing technique is applicable to any OFDM scheme that shares frequency-domain pilot symbols for synchronization and frequency estimation [67,68].

3.2 PILOT INFORMATION IN WIMAX SIGNALS

The WiMAX network model is aimed to provide an IP outgoing framework with scalable data capacity, open access to new applications and services, improving QoS and mobility. The IEEE 802.16 standards explain the configuration of the Physical and Link Layer setups that ensue among mobile stations (MSs) and base stations (BSs).
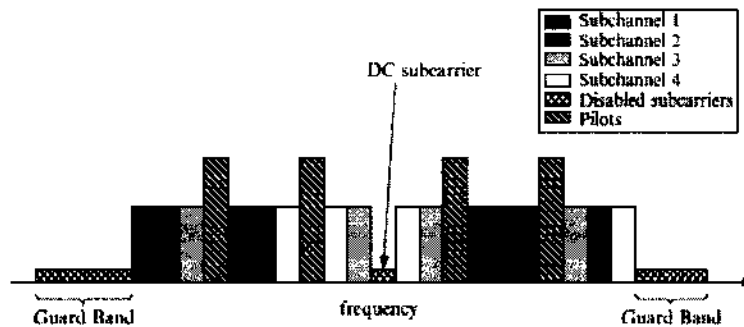
Fig. 6: OFDM signal structure used in WiMAX

3.3 TIME-DOMAIN SYMBOL CROSS-CORRELATION OF OFDM SIGNALS

Let the n-th sample of the l-th OFDM symbol be expressed as [63]

$$x_l[n] = e^{j(2\pi f \Delta n/N + \theta_l)} \cdot \frac{1}{N} \sum_{k=0}^{N-1} H[k]X_l[k]e^{j2\pi kn/N}$$

$$+w_l[n] \qquad (21)$$

where: Δf is the carrier frequency offset normalized to the subcarrier spacing, θ is the initial phase of the l-th OFDM symbol, $M = N + L$ is the length of an OFDM symbol, and N is the number of subcarriers, $X_l[k]$ are the data symbols at the k-th subcarrier of the l-th OFDM symbol. The complex channel gain of the k-th subcarrier is denoted by $H[k]$, $w_l[n]$ is a sample of a complex additive white Gaussian noise (AWGN) process assumed to be a circularly symmetric complex Gaussian random variable with variance of σ_w^2/N. Under the assumption that pilot tones P_a were set of pilot tone locations of the l-th OFDM symbol, the TDSC as defined in equation (10). Where it is assumed that the l-th and m-th OFDM symbols have the same pilot

tone positions. After calculations that are omitted due to space constraints but can be found in [63] we get that the TDSC.

3.4 THE TDSC-BASED TECHNIQUE FOR WIMAX SIGNAL SENSING

According to [63], $v = l - m$ represents the index difference of two OFDM symbols. Since the symbol index difference equal to v that have the same pilot tone situations. Additional denotation $C(v)$ is the accrued TDSC function

$$C(v) = \frac{1}{S_v} \sum_{v=m-l} R(l,m) = e(v)\frac{\rho^2}{N^2} \cdot \frac{1}{A} \sum_{a=0}^{A-1} \sum_{k \in P_a} |H[k]|^2$$
$$+ \frac{1}{N} \sum_{v=m-l} \sum_{k=0}^{N-1} w_l[n]w_m^*[n], \tag{22}$$

where S_v is the number of $R(l,m)$ that are accrued and supplemented. Note that S_v is designated to be an integer compound of A. It is clear from (15) the mean of $C(v)$ is unaffected. Nevertheless, the variance of the second term which is noise term in $C(v)$ is contrariwise related to S_v. Thus, even though the accumulated number of $R(l,m)$, S_v is increased, the noise term in $C(v)$ will decreased. As a result, it could be achieved spectrum sensing in scenarios with significantly low SNR. According to [63] $C(v)$

$$C(v) = e(v)\Lambda + \zeta(v), \tag{23}$$

where

$$\Lambda = \frac{\rho^2}{N^2} \cdot \frac{1}{A} \sum_{a=0}^{A-1} \sum_{k \in P_a} |H[k]|^2 \tag{24}$$

is the average received signal power in the pilot tone positions divided by N^2 and $\zeta(v)$ is a circularly symmetric complex Gaussian random variable.

The possible decisions for binary hypotheses testing are:

$$H_0 : C(v) = \zeta(v)$$

$$H_1 : C(v) = e(v)\Lambda + \zeta(v), \tag{25}$$

where H_0 corresponds to noise only while H_1 to signal and noise existing. The likelihood ratio function is

$$L(\mathbf{C}) = \frac{p(\mathbf{C}; H_1)}{p(\mathbf{C}; H_0)}. \tag{26}$$

Following some calculations, the decision statistic for the Neyman-Pearson (NP) test [69] is equivalent to

$$T_{NP} = |C(v)|, \tag{27}$$

and determines the probabilities of misdetection and false alarm for TDSC-based spectrum sensing.

The probability of misdetection P_{MD} corresponds to the situation when the unlicensed (secondary) user decides that a licensed (primary) user is not present in a certain channel when in fact the primary wireless system is present, while the probability of false alarm P_{FA} corresponds to the case when the secondary user decides that a primary user is present in a given channel when actually the primary wireless system is not active.

The probability distribution corresponding to the H_0 and H_1 hypotheses for the TDSC spectrum sensing technique is circularly symmetric complex Gaussian, where $\sigma_{H_0}^2$ and $\sigma_{H_1}^2$ are the variances of the distributions of H_0 and H_1 respectively and $\mu_{H_0}^2$ is the mean of the distribution of the H_1. We note that a Rayleigh distribution has been used for $|T_{NP}|$ in hypothesis H_0.

According to [63] the decision threshold γ as given in equation (19). For sake of simplicity it's been used a single-path channel, the probability of misdetection P_{MD} as expressed in (20).

3.5   SIMULATIONS AND NUMERICAL RESULTS FOR WIMAX SYSTEMS

In this section we present simulation results corresponding to application of the TDSC technique for sensing of WiMAX OFDM signals. The physical layer parameters of the WiMAX system considered in the simulations are: the FFT size $M = 1024$, the signals are simulated with 5 MHz double-sided bandwidth, for a mobile WiMAX signal with $T_{cp} = 1/8$ and $1/4$. The system employs 16-QAM digital modulation and unit variance of the signal constellation is used to modulate the data subcarriers. The pilot subcarriers in mobile WiMAX are modulated according to the IEEE 802.16e standard [70]. The number of symbols in the uplink subframes is 35 and downlink subframes is 12, and the RTG duration is 60 μs while the TTG duration equals 107.225 μs [71]. The roll-off factor for the transmitter window of the OFDM signal was set to a maximum value of 0.1 in order for the post-fix not to exceed the predefined cyclic prefix. The sampling frequency is chosen to be 8.4 MHz, the signal is affected by a phase offset φ uniformly distributed in $[-\pi, \pi]$, and by a carrier frequency offset 0.5. The pilot symbol on subcarrier is generated as $8(0.5 - w_k)/3$ where is a value taken from a pseudorandom binary sequence that is different for each OFDM symbol [72]. At the receiver, a filter is used to eliminate the out-of-band noise an the SNR is determined at the output of this filter. The SNR was set from -23 dB to -14 dB, the

Fig. 7: Misdetection performance for the TDSC method with $P_{FA} = 0.01$, CP length $= 1/4$ and sensing time $= 50$ ms

probability of false alarm P_{FA} is set to be 0.01, and the decision threshold is found based on equation (3.7). The TDSC spectrum sensing method was tested for the parameters of WiMAX defined in [71]. The simulation environments considered are AWGN, multipath Rayleigh and Ricean fading channels, ITU-R normal and vehicular A fading channels. The maximum delay spreads for the ITU-R normal is 410 ns and for vehicular fading channels is 2.51 μs [73]. The maximum Doppler frequency for the ITU-R pedestrian channel model is set to 7.28 Hz and for the vehicular A fading channel model is 145.69 Hz.
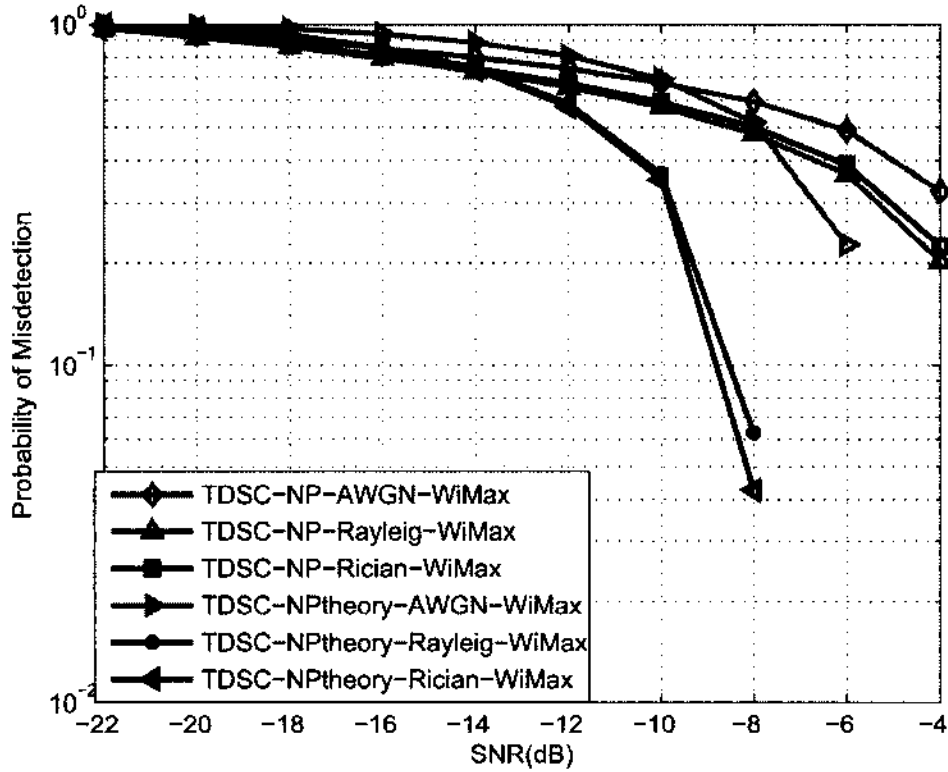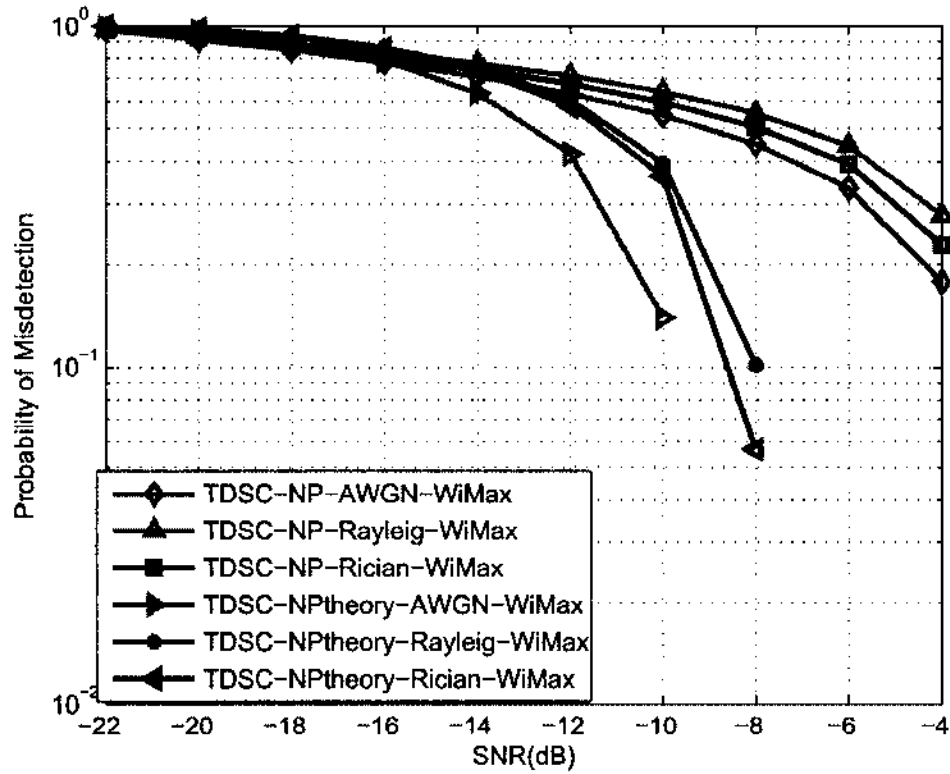
Fig. 8: Misdetection performance for the TDSC method with $P_{FA} = 0.01$, CP length = 1/8 and sensing time = 50 ms

The misdetection performance for sensing time of 50 ms and CP ratios equal to [1/4, 1/8] is shown in Figures 5 and 6 for from where one can observe that it does not reduce much whereas the sensing performance under the multipath channel Rayleigh has a slight change.

Fig 8 there is a significant variation are observed in the curves after crossing an AWGN channel, a Rayleigh channel or a Rician channel. The three curves show a different behavior in terms of probability of misdetection. Figure 8 plots a family of ROC curves for TDSC method for different levels of SNR, a CP ratio of 1/4 and
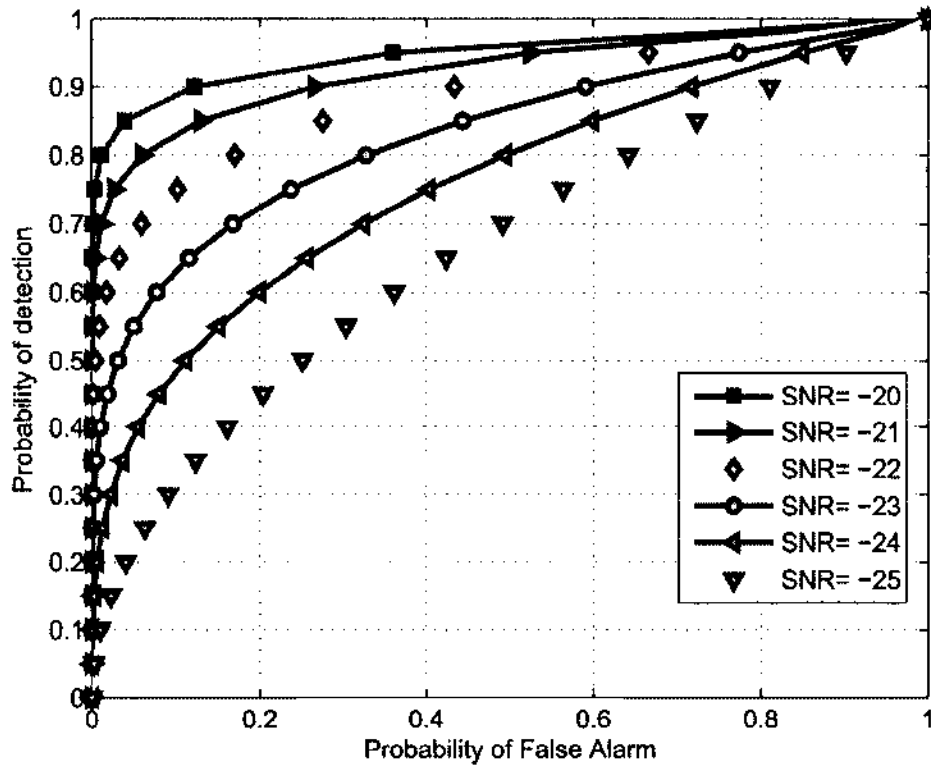
Fig. 9: ROC curves for TDSC method for different SNR, CP length = 1/4

multipath AWGN. As it can be seen at a glance, the behavior of the TDSC detector has a good performance, at a 0.9 of probability of detection is reached for a SNR of −20 dB. This SNR value can be considered as a good result. For over, a 0.7 of probability of detection is reached for a SNR of −22 dB. If you look in terms of probability of detection there exist a clear difference between P_{FA}= 0.01 and P_{FA}= 0.1.

3.6 CHAPTER SUMMARY

In this chapter we study the performance of spectrum sensing algorithm based on Time-Domain Symbol Cross-Correlation (TDSC) method applied to WiMAX systems. The method provides a good performance at low SNRs. The performance of the TDSC method for detecting WiMAX signals is illustrated with numerical results obtained from computer simulations using Matlab software , which show good performance at low SNR in AWGN, Rayleigh, and Ricean channel scenarios. From this results, conclusions can be drawn regarding the probability of misdetection performance evaluation of WiMAX Communication system over AWGN channel and fading (Rayleigh and Rician) channels as following. The performance of AWGN channel is the best of all channels as it has the lowest probability of misdetection for CP ratio of 1/4 and 1/8. The theoretical performance of Rayleigh fading channel is the worst of all channels for CP ratio 1/8 as probability of detection of this channel has been much affected by noise however for simulation performance they were almost identical. The theoretical performance of Rician fading channel when CP ratio is 1/8 is worse than that of AWGN channel and better than that of Rayleigh fading channel.

CHAPTER 4

USING PILOT TONES AND TDSC FOR MOBILE LTE SPECTRUM SENSING

4.1 INTRODUCTION

LTE is the main standard for the fourth generation (4G) of wireless communication systems that are capable of supporting broadband applications at data rates of up to 100 Mbps in the downlink and 50 Mbps in the uplink with a bandwidth of up to 20 MHz [74], [75].

At the physical layer LTE uses OFDM which has emerged as a preferred radio access scheme due to its many attractive features among which we note simplicity of implementation and scalability [64]. OFDM is also used in other wireless standards such as IEEE 802.11 for wireless local area networks (WLAN) and IEEE 802.15 for short distance and personal area networks (WPAN) [76] as well as in the current digital television standards [77]. In addition, OFDM has been proposed for use in future generations of wireless systems that will be using cognitive radio technology, which is expected to allow secondary access to licensed spectrum by unlicensed devices subject to strict constraints [2].

In anticipation of significant increases in mobile data traffic in upcoming years and to enable more efficient use of the frequency spectrum, recent studies have looked at the use of LTE systems in heterogeneous networks that include the licensed LTE

frequencies as well as unlicensed frequencies such as the WLAN bands or the TV white spaces [78, 79].

To detect the presence of active transmissions for general OFDM-based systems the use of a spectrum sensing method based on the TDSC of OFDM symbols has been proposed recently [63]. The TDSC method is applicable to OFDM systems where pilot information is included on specific frequencies and takes advantage of the properties that the cumulative correlation of distinct symbols displayes due to the periodic nature of the pilot information. In this chapter we present application of the TDSC method to detection of LTE signals and we illustrate its performance with numerical results obtained from simulations.

4.2 PILOT INFORMATION IN LTE SIGNALS

Currently, most of the LTE systems operating on the global market use Frequency Division Duplex (FDD) to implement the downlink (DL) and uplink (UL) channels between a provider base station and a mobile subscriber. Thus, two distinct frequency bands are used for communication between the mobile subscriber terminal and the base station.

To understand the periodic nature of the pilot information present in LTE signals we start by outlining the frame structure for the LTE standard. This is divided into 20 individual slots, each with duration of 0.5 ms as shown in Figure 10 for the FDD DL channel, and each slot contains $N_{\text{symb}}^{\text{DL}}$ OFDM symbols. The actual number of symbols depends on the length of the cyclic prefix (CP) and the useful symbol duration parameters of the OFDM signal [74, 75].
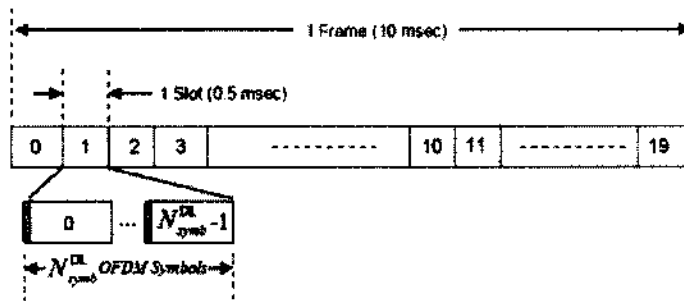
Fig. 10: FDD DL frame structure in the LTE systems [3].
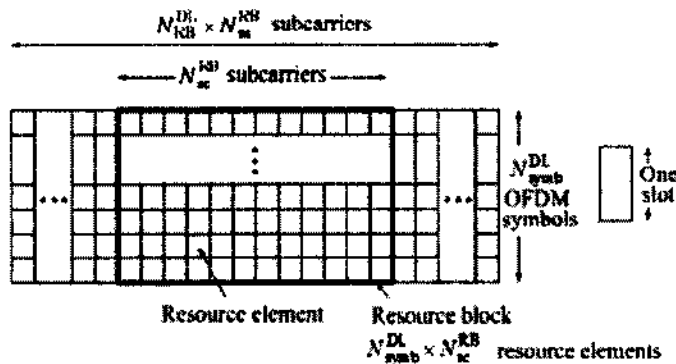
Fig. 11: Slot structure and resource grid in the FDD DL frame [3]

Each slot within an LTE frame is represented as a two dimensional grid as shown in Figure 11, and consists of $N_{\text{symb}}^{\text{DL}}$ OFDM symbols in time domain and $N = N_{\text{RB}}^{\text{DL}} N_{\text{sc}}^{\text{RB}}$ subcarriers in frequency domain[1], with $N_{\text{RB}}^{\text{DL}}$ as the number of resource blocks and $N_{\text{sc}}^{\text{RB}}$ as the number of subcarriers in a resource block. We note that a resource block is defined by a set of $N_{\text{symb}}^{\text{DL}}$ consecutive OFDM symbols in time domain and $N_{\text{sc}}^{\text{RB}}$ consecutive subcarriers in frequency domain. $N_{\text{sc}}^{\text{RB}} = 12$ and 24 for the LTE signals having subcarrier spacing $\Delta f = 15$ kHz and 7.5 kHz, respectively. The resource grid

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[1]N represents the number of subcarriers in an OFDM symbol.
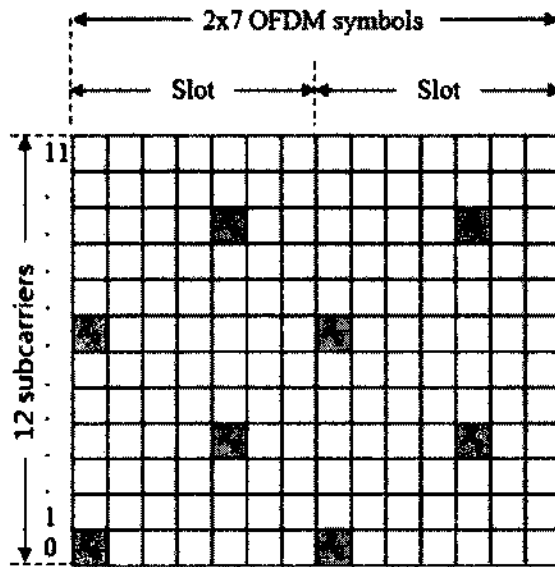
Fig. 12: Resource element mapping of pilot information in LTE signals [3]

is further partitioned as shown in Figure 11 into resource elements, which are the smallest entities of the grid. A resource block consists of $N_{\text{symb}}^{\text{DL}} \times N_{\text{sc}}^{\text{RB}}$ resource elements, and the pilot information – referred to as reference signals (RS) in the LTE standard – is embedded in the resource blocks of the transmission frame for channel estimation, synchronization, and cell search/acquisition purposes [74, 75] as illustrated in Figure 12. An RS is assigned to each cell of the network and acts as a cell identifier. Therefore, the RS repeats each downlink frame. The RSs are interspersed over the resource elements, usually transmitted on some of the subcarriers of one or two non-consecutive symbols in each slot. Figure 12 illustrates the distribution of the cell-specific RS for long CP over one resource block and two consecutive slots ($N_{\text{symb}}^{\text{DL}} = 7$ OFDM symbols per slot and $N_{\text{sc}}^{\text{RB}} = 12$ subcarriers per resource block): the cell-specific RS is transmitted on the first and seventh subcarriers of the first

OFDM symbol and on the fourth and tenth subcarriers of the fourth OFDM symbol in each slot.

We note that the UL slot structure is similar to the DL slot structure, with differences mainly due to simplifications of reference symbols, robustness, and physical UL channel multiplexing. A detailed description of the UL slot structure is omitted due to space constraints.

4.3 THE TDSC-BASED TECHNIQUE FOR LTE SIGNAL SENSING

As its name suggests, the TDSC method for spectrum sensing is based on taking the cross-correlation in time domain for two distinct OFDM symbols with similar patterns for their corresponding pilot tones, that is in [63].the TDSC as defined in equation (10). where it is assumed that the ℓ-th and m-th OFDM symbols have the same pilot tone positions. The expression of the n-th sample of the ℓ-th OFDM symbol as was written in (9) where:

- f_Δ is the carrier frequency offset normalized to the subcarrier spacing;

- θ is the initial phase of the ℓ-th OFDM symbol;

- $M = N + L$ is the length of an OFDM symbol, with and N is the number of OFDM subcarriers;

- $X_\ell[k]$ are the data symbols at the k-th subcarrier of the ℓ-th OFDM symbol;

- $H[k]$ is the complex channel gain of the k-th subcarrier;

- $w_\ell[n]$ is a sample of a complex additive white Gaussian noise (AWGN) process assumed to be a circularly symmetric complex Gaussian random variable with variance of σ_w^2/N.

With these notations, the TDSC expression (9) can be rewritten as in (11) where the first summation is taken only over the set of indices $\mathbf{P}_{\hat{a}}$ corresponding to the pilot tone locations for the considered OFDM symbols ℓ and m. We note that the TDSC expression (11) does not depend on the actual positions ℓ and m of the two OFDM symbols considered, but rather depends only on their corresponding index difference $v = \ell - m$, which implies that no timing information is needed to use it to define a test statistic for spectrum sensing.

The test statistic used for spectrum sensing consists of the accumulated TDSC function over multiple pairs of OFDM symbols with the same pilot tone positions corresponding to equal index difference v as defined in (15). where S_v is the number of $R(\ell,m)$ terms being accumulated taken to be some integer A [63]. Plugging in the TDSC expression (15) the test statistic expression can be written as in (16). The term in equation (17) represents the deterministic component of the test statistic and is the average received signal power in the pilot tone positions divided by N^2. This term determines the average value of the test statistic $C(v)$ and is is independent on the number of accumulated TDSC terms. The term in equation (17) represents the random component of the test statistic and is a circularly symmetric complex Gaussian random variable with zero mean and variance [63]

$$\sigma_\zeta^2 = \frac{\sigma_w^4}{S_v M N^2}. \tag{28}$$

Since this term is inversely related to the number S_v of accumulated TDSC terms, its variance will decrease as S_v increases, enabling spectrum sensing at very low SNRs [63].

The binary hypothises testing problem for detecting active LTE transmissions is formally stated as:

$$H_0 : C(v) = \zeta(v)$$

$$H_1 : C(v) = e(v)\Lambda + \zeta(v), \tag{29}$$

where H_0 corresponds to no active LTE transmission since only the noise term is present, while H_1 corresponds to the presence of an LTE transmission for which the test statistic contains both noise and active signal power coming from the pilot information. The test statistic $C(v)$ has a circularly symmetric complex Gaussian probability distribution with variance σ_ζ^2 and mean $\mu_{H_0} = 0$ in the case of hypothesis H_0, respectively $\mu_{H_1} = e(v)\Lambda$ in the case of hypothesis H_1. The probabilities of misdetection and false alarm are defined as:

- The probability of misdetection P_{MD} corresponds to no LTE transmission detected when hypothesis H_1 is true.

- The probability of false alarm P_{FA} corresponds to identifying an LTE transmission when hypothesis H_0 is true.

Following the Neyman-Pearson approach [69] the solution to the binary hypothesis testing problem (29) is obtained by threshold comparison as

$$|C(v)| \underset{H_0}{\overset{H_1}{\gtrless}} \gamma. \tag{30}$$

The decision threshold γ is obtained by setting a desired value for the probability of false alarm as [63]:

$$\gamma = \sqrt{-\sigma_\zeta^2 \ln P_{FA}}. \tag{31}$$

With the threshold given by equation (31) the probability of misdetection P_{MD} for a single-path channel is given by

$$P_{MD} = 1 - Q_{x_2'^2(\lambda)}\left(\frac{\gamma^2}{\sigma_{H_1}^2}\right), \tag{32}$$

where the function $Q_{x_2'^2(\lambda)}(x)$ corresponds to the right-tail of the non-central Chi-Squared distribution with two degrees of freedom and $\lambda = [e(v)\Lambda]^2/\sigma_\zeta^2$. We note that the expression for the probability of false alarm in (32) is only a lower bound in the case of multipath channels since then the TDSC expression (15) will contain additional samples due to inter-symbol interference occurring because of lack of channel information and timing. Theoretical expression for probability of misdetection in (12) for Chi-Squared distribution can be expressed as:

$$f_x(x) = \left\{ cx^{n/2-1}exp\left(-\frac{1}{2}x\right) \right.$$

if $x \in R_X$ (33)

$f_x(x) = 0$ Otherwise. where c is a constant

$$c = \frac{1}{2^{n/2}\Gamma(n/2)}$$

and $\Gamma()$ is the Gamma funcation.

4.4 SIMULATIONS AND NUMERICAL RESULTS FOR LTE SYSTEMS

In this section we present numerical results obtained from simulation, matlab is used to simulate to illustrate the performance of the proposed TDSC-based technique for detecting LTE signals.

The OFDM parameters corresponding to the physical layer of the LTE system considered in the simulations are:

- FFT size is $N = 2048$ corresponding to a mobile LTE signal with 20 MHz bandwidth.

- Cyclic prefix (CP) ratios considered are 1/4 and 1/8.

- The digital modulation scheme employed is QPSK with unit variance of the signal constellation.

- The pilot information is added according to the LTE standard specifications as outlined in Section 4.2.

- Using Matlab built-in functions,have generated AWGN, Rayleigh and Rician channels respectively.

Figure 13 plots a family of Receiver Operating Characteristic (ROC) curves corresponding to the TDSC method for SNR values ranging from -20 dB to -25 dB, for a CP ratio of 1/4 and AWGN channel. As it can be observed, the TDSC detector has a good performance with a probability of detection of 0.9 reached for SNR equal to -20 dB and 0.7 for -22 dB.
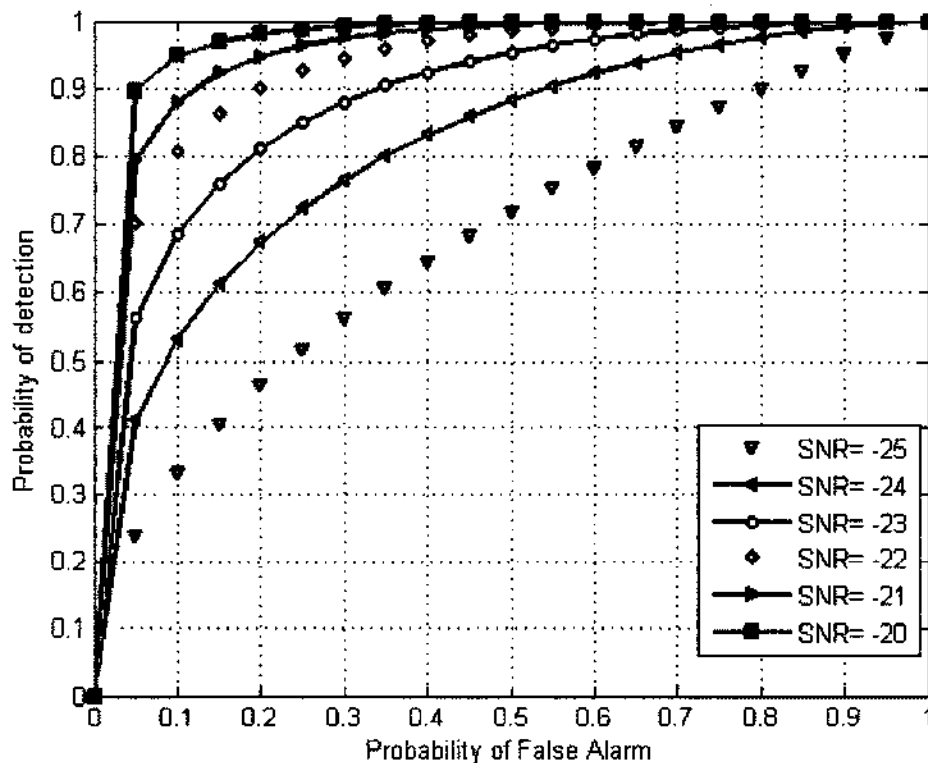
Fig. 13: ROC curves for TDSC method for cyclic prefix equal to 1/4

The ROC in Figure 13 also shows that there is a clear difference in the probability of detection for $P_{FA} = 0.01$ and $P_{FA} = 0.1$.

The performance of the TDSC method in terms of the probability of misdetection was also evaluated for a probability of false alarm set to $P_{FA} = 0.01$, SNR between -22 dB and -4 dB, and for CP ratios equal to $[1/4, 1/8]$, in AWGN, Rayleigh, and Rician channel scenarios for sensing time of 50 ms corresponding to a set of 5 LTE frames. The corresponding plots are shown in Figures 14 and 15, from where one can notice that changing the CP does not affect the AWGN performance, but it affects the performance in Rayleigh and Rician scenarios.From figures 14 and 15 we
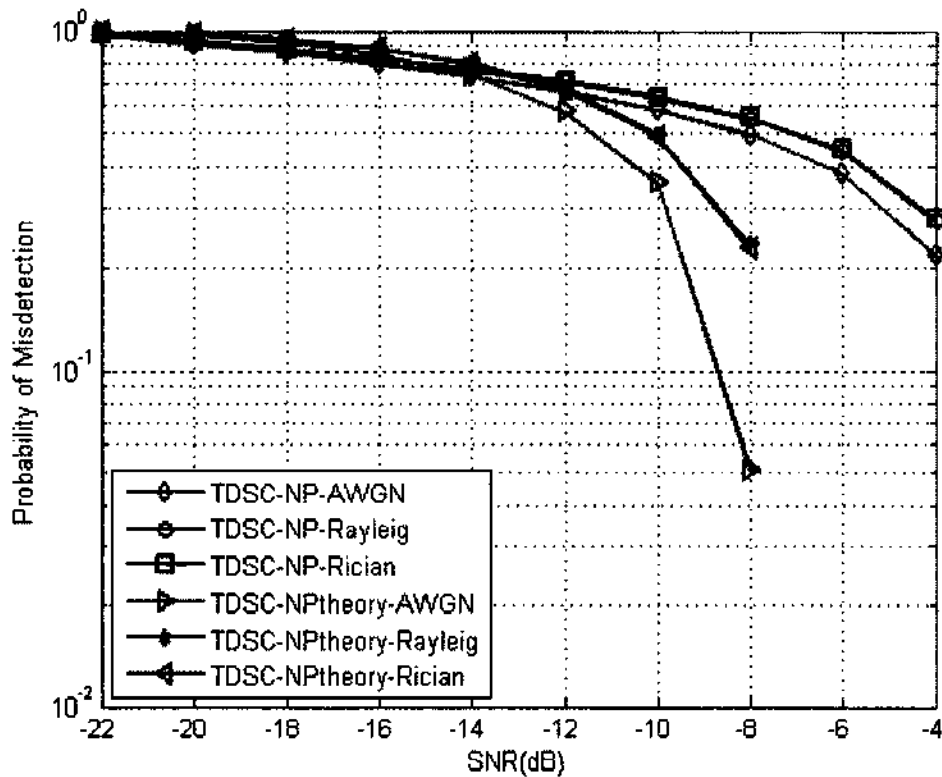
Fig. 14: Probability of misdetection for the TDSC method with $P_{FA} = 0.01$ and CP length $= 1/4$

can see that, AWGN channel has lower probability of misdetection than Raleigh and Rician fading channel.The simulation model built for this work, demonstrates that AWGN channel has better probability of misdetection performance than Rayleigh and Rician fading channels. Results reveal that the simulated part achieves excellent performance, matching that of theoretical part.
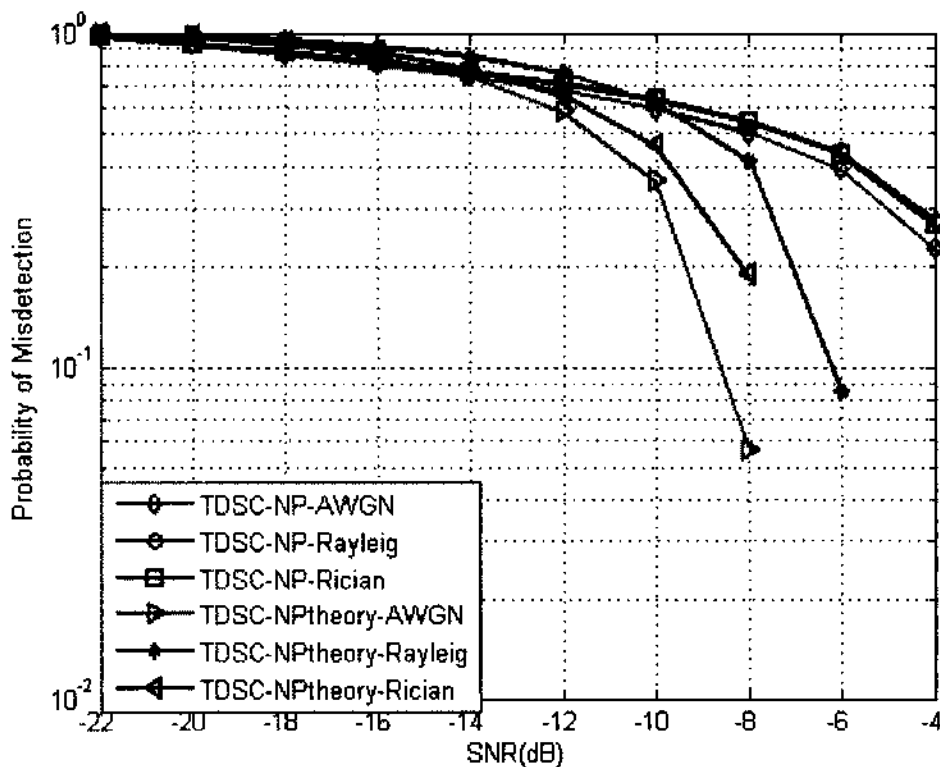
Fig. 15: Probability of misdetection for the TDSC method with $P_{FA} = 0.01$ and CP length $= 1/8$

4.5 CHAPTER SUMMARY

In this chapter we presented the use of OFDM pilot tone information for detecting active LTE signals using the TDSC method for spectrum sensing. According to the LTE standard specifications, such information is embedded in in LTE signals periodically on specific OFDM subcarriers for synchronization and channel estimation, and is also useful for detecting active LTE signals by using a cross-correlation approach. Specifically, the TDSC technique considered in the chapter takes advantage of the fact that the mean of the cumulative correlation of distinct symbols with the same

pilot tone positions is constant while its variance changes, which enables detection of LTE transmissions in low SNR environments. The performance of the TDSC method for detecting LTE signals is illustrated with numerical results obtained from computer simulations using Matlab software , which show good performance at low SNR in AWGN, Rayleigh, and Ricean channel scenarios. From this results, conclusions can be drawn regarding the probability of misdetection performance evaluation of LTE Communication system over AWGN channel and fading (Rayleigh and Rician) channels as following . The performance of AWGN channel is the best of all channels as it has the lowest probability of misdetection for CP ratio of 1/4 and 1/8. The theoretical performance of Rayleigh fading channel is the worst of all channels for CP ratio 1/8 as probability of detection of this channel has been much affected by noise however for simulation performance they were almost identical . The theoretical performance of Rician fading channel when CP ratio is 1/8 is worse than that of AWGN channel and better than that of Rayleigh fading channel.

CHAPTER 5

WIMAX AND LTE COMPARISON

5.1 INTRODUCTION

In this chapter, since both (WiMAX and LTE)use OFDMA in the DL with higher order modulation and coding Peak performance is similar for same modulation and code rate. Both support FDD and TDD with channel BWs up to 20 MHz. Both support higher order MIMO antenna solutions. Both offer reduced latency [80]. Then in this dissertation both systems can be tested regards their spectrum sensing to see if there is differences and to verify their sensing behavior.

5.2 FEATURES OF LTE/WIMAX

Equally WiMAX and LTE are all-IP, all packet technology with a packet network central. This sorts them greatest for burst data traffic with decent VoIP support. Equally use OFDMA technology that is a formula of FDM where the sub-carriers are made orthogonal to each other [81]. This allows compressing more sub-carriers in the spectrum provided giving increase to higher spectral efficiency. The small sub-carrier split-up results in big symbol size [82]. This supports modifying ISI (Inter-Symbol Interference) and diminishes the necessity for complex adaptive equalization required in single carriers wide-band systems. OFDM is robust against frequency selective burst errors and narrow band interference. In OFDMA, the connection is arranged in both time and frequency by taking many connections sharing multiple carriers while

this sharing can be revised periodically to maximize performance [83]. Some of the other features associated with LTE and WiMAX are the following features [84]:

Sub-channelization and permutation: In the assigned spectrum, some subcarriers are utilized for data whereas some others are utilized as guard bands and pilots. Data carriers and pilots are arbitrarily selected to dissimilar sub-channels periodically. Meaning, the channels are hopping. This is comparable to hopping in Wifi [?]. Nevertheless, just one channel is hopping in WiFi, however in these, all the sub-channels in the spectrum. These results in interfering and giving increase to less error corrections and give back system capacity [82]. Subcarriers are subdivided into clusters and only some of these clusters can be utilized in any cell. This is so-called partial use of sub- carriers (PUSC). PUSC reduces neighboring cells interfering thus expanding performance. Another is the usage of fractional frequency reuse (FFR) [85]. In FFR terminals in the cell nearby to cell center usage all the frequencies whereas those near the cell boundary use frequencies dissimilar to those used near boundaries of bordering cells in order to decrease inter-cell interference.

Equally LTE and WiMAX use a version of OFDMA called scalable OFDMA (SOFDMA). In this system, at any time the bandwidth allotted to facility provider modifications, the number of subcarriers also. Therefore, the Doppler Effect on performance is kept the same for mobile users [86]. Both LTE and WiMAX use AMC (adaptive modulation and coding) for link adaptation. In this system, the connection that is currently using modulation can be reorganized, to a more robust modulation on every occasion the users signal is fading, on other words. The user is moving away from base station thus struggling with less SNR

5.3 TECHNICAL DIFFERENCES

There are many of technical parallels between the LTE and WiMAX in architecture and objectives. LTE and WiMAX were using OFDMA with flat-IP architecture and both are expected to meet or even exceed IMT-Advanced requirements with parallel supporting technologies [87]. However, an amount of technical differences exist. Some of these differences with mobile WiMAX (WiMAX 1.0) compared to LTE and WiMAX 2.0 compared to LTE-Advanced are the following:

Duplex mode

Both LTE and WiMAX provide for both TDD and FDD. However, FDD was the focus of all telecom corporations and continuous throughout the different generations. TD-LTE is gaining reputation as movement path of the synchronous CDMA. WiMAX, otherwise, TDD focus on throughout. Upcoming WiMAX implementation LTE will most likely head to TD-LTE [88].

Spectrum

LTE use Licensed IMT-2000 Bands at bands like 700, 900, 1800, 2100, and 2600 MHz while WiMAX is Licensed unlicensed, at 2.3, 2.5, 3.5 and 5.8 GHz. Therefore LTE is generally available at desired low frequency band that provides it coverage advantage. This improved its chances to function as public wide area network [89]. With WiMAX legend to LTE some operators started trying LTE in some of the WiMAX bands they already identifiable.

Intercarrier spacing

LTE uses a typical 15 KHz intercarrier spacing while WiMAX uses 10.94 KHz. The larger intercarrier spacing the upper the protection against Doppler spread. LTE can rule mobility speeds up to 350 Km/hr whereas WiMAX can support speeds of the order of 120 Km/hr [90].

Access technology

LTE access technology for its downlink (OFDMA) is different to its uplink. In the uplink Single Carrier FDMA (SC-FDMA) is used. SC-FDMA reduces Peak-to-Average-Power-Ratio (PAPR) by 3 - 5 dB giving rise to uplink enhancements that can be used to expand coverage or throughputs of cell borders users [82]. WiMAX uses SOFDMA for uplink and downlink. In reality, the main problem in spreading GSM TDMA and wideband CDMA to broadband schemes is enlarged receiver complication with multipath received signal. The key benefit of OFDM, as is for SC-FDMA, is its robustness against multipath signal propagation that sorts it appropriate for broadband systems [91]. Paralleling 4G WiMAX and LTE from other features are covered in the literature as well [92]. compares LTE and WiMAX when utilized in companies setting from two features security and integration into corporations IT network. Both WiMAX and LTE can be presented and installed by the corporations as the next generation of mobile establishments network and WiMAX can meet concerns security naturally because of the WiMAX verification protocols. In general, it can be determined that LTE design seems to be more specially regarding mobility,

data throughputs and capacity [86]. Nevertheless, these features, though significant may not be the only issues that influence the approval of one technology compared to the other.

Other Differences and Factors

Alongside the technological constrains other regional, operator and controlling factors and constraints, principal to the preference of LTE over WiMAX or vice versa. WiMAX preceded LTE in appearance and organization. WiMAX is a TDD technology which does not need balancing spectrum with flexibility in sharing the time frame between the uplink and the downlink [92]. This made it appear more appropriate for data as the viable wireless alternative to wired DSL. This makes these systems more costly in terms of spectrum and equipment. But, the summary of TD-LTE, a TDD version of LTE with single band for its operation wipes out one core advantage of WiMAX over LTE

The set of IEEE standards, on which WiMAX issues are based, are modular separate standards offering high performance. The 4G form of WiMAX have no sustenance for legacy 3GPP devices that means no handovers. On the other hand, 3GPP delivered a clear progression path towards LTE standards. Hence, operators worldwide who have already arranged their networks based on 3GPP standards discover it a good commercial case with easy improvement and with option that they reuse their already possessed matching spectrum of abandoned technologies of 2G or so for the more efficient LTE. [93] Table (3) provides a comparison of 3GPP track that led to LTE and IEEE 802.16 track that led to current WiMAX.

Characteristic	3GGP Track	IEEE 802.16 Track
All IP vs Circuit Switched	Started Circuit switched, moved to half IP (2.5/3 G) and finally All IP (LTE)	All IP from the beginning
Architecture	Centric architecture, gradually moving to flat architecture	Flat architecture from the beginning
Mobility	Started voice centric gradually moved to data centric	Started as data centric gradually serving voice
Mode of operation	FDD is the main mode with increased interest in TDD recently	TDD mode mainly
Access Technology	Different access technologies like TDM/FDM and Spread Spectrum before heading to OFDMA in LTE	OFDMA was considered at early stages by IEEE 802.16 standards
Spectrum	Lower licensed bands	Higher licensed and unlicensed bands
Target	Targeted wide coverage and ubiquitous service	Targeted spotty dedicated coverage. Failed to provide ubiquitous coverage later on

Table 3: Comparison of 3GPP(LTE) and IEEE 802.16 (WiMAX).

5.4 SIMULATION AND DISCUSSION

This chapter presents our simulation results along with underlying assumptions. In order to illustrate the accuracy of the method for evolution the performance of spectrum sensing, extensive simulations were performed with the following set up: The SNR was set from -23 dB to -14 dB, the probability of false alarm P_{FA} set to be 0.01. Then the threshold is found based on the equation (10). The pilot pattern assemblies of WiMAX OFDM were tested using TDSC spectrum sensing the parameters of WiMAX defined in [94]. OFDM WiMAX physical layer parameters

are chosen for simulations: FFT-size and M equal to 1024, the signals are simulated with 5 MHz double-sided bandwidth, the mobile WiMAX signal T_{cp} equals 1/4 and 1/8. This supports a transmission of QAM with 16 points and unit variance of the signal constellation is used to modulate the data subcarriers. The pilot subcarriers in mobile WiMAX are modulated giving to the IEEE 802.16e standard [95]. The number of symbols in the uplink subframes is 35 and downlink subframes is 12, and the RTG duration is 60s while the TTG duration equals 107.225s [73]. Rolloff factor of the transmitter window of the OFDM was set of maximum value of 0.1 in order for the post-fix not to exceed the predefined cyclic prefix. The sampling frequency is modulated to 8.4 MHz, as well as the signal is magnified by a phase offset ' uniformly distributed in the carrier frequency offset 0.5. The simulation environments considered are the AWGN, multipath Rayleigh fading, and multipath Ricean fading channels, and ITU-R normal and vehicular A fading channels are considered. The maximum delay spreads for the ITU-R normal is 410 ns and vehicular A fading channels is 2.51s [19]. The maximum Doppler frequency for the ITU-R pedestrian is set 7.28 Hz, 145.69 Hz whereas the vehicular A fading channels is set 145.69 Hz. At the receive-station, a filter is used to eliminate the out-of-band noise; also the SNR is modulated at the output of this filter. The performing with respect to P_{MD} and the thresholds used with the TDSC spectrum sensing tests equivalent to a P_{FA} equal to 0.01 and with a sensing time of 50 ms. The CP ratios are set [1/4; 1/8]. Figure 15, 16 shows the sensing performance under the multipath channel (AWGN and Ricean) condition does not reduce much whereas the sensing performance under the multipath channel Rayleigh the sensing presentations of TDSC-NP method and

Fig. 16: Performance Comparison of the TDSC-NP-WiMAX and LTE methods and the reference value for $P_{FA} = 0.01$, CP length $= 1/4$

channel environments, we choose a CP ratio of 1/4 and multipath AWGN.

Figure (15) presents the performance of WiMAX and LTE using subcarrier TDSC-NP schemes for various channels. It is clear from the simulation outperforms the Rayleigh and Rician channels conditions gives better performance then AWGN in both WiMAX and LTE, also in this case WiMAX gets a slight better response then LTE . Figure (16) presents the $P_{M}D$ performance of TDSC system in AWGN Rayleigh
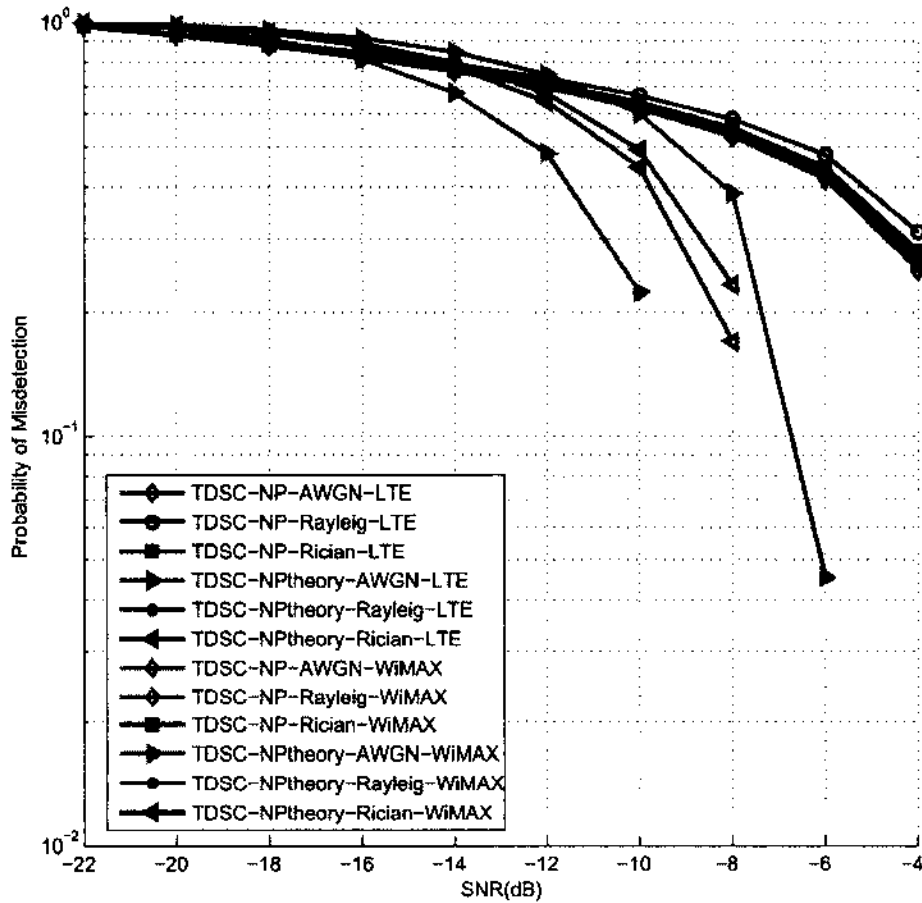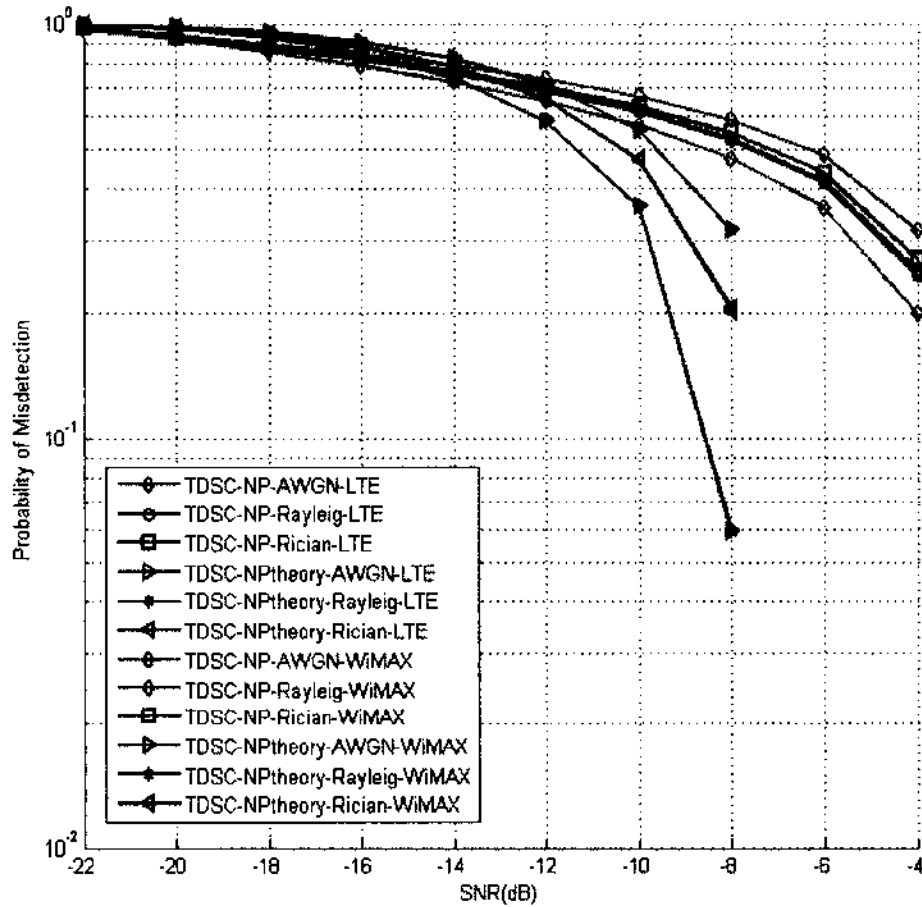
Fig. 17: Performance Comparison of the TDSC-NP-WiMAX and LTE methods and the reference value for $P_{FA} = 0.01$, CP length $= 1/8$

and Rician channels using CP length 1/8 for WiMAX and LTE. In case of AWGN channel for both techniques, we see that simulation and theory have almost similar performance whereas for Rayleigh channel the two performances have different PMD performance. We can also observe that the behavior of AWGN Rayleigh and Rician channels are quite similar in case of WiMAX and LTE.

In addition, it is clearly shown that the performance of SNR gives approximately
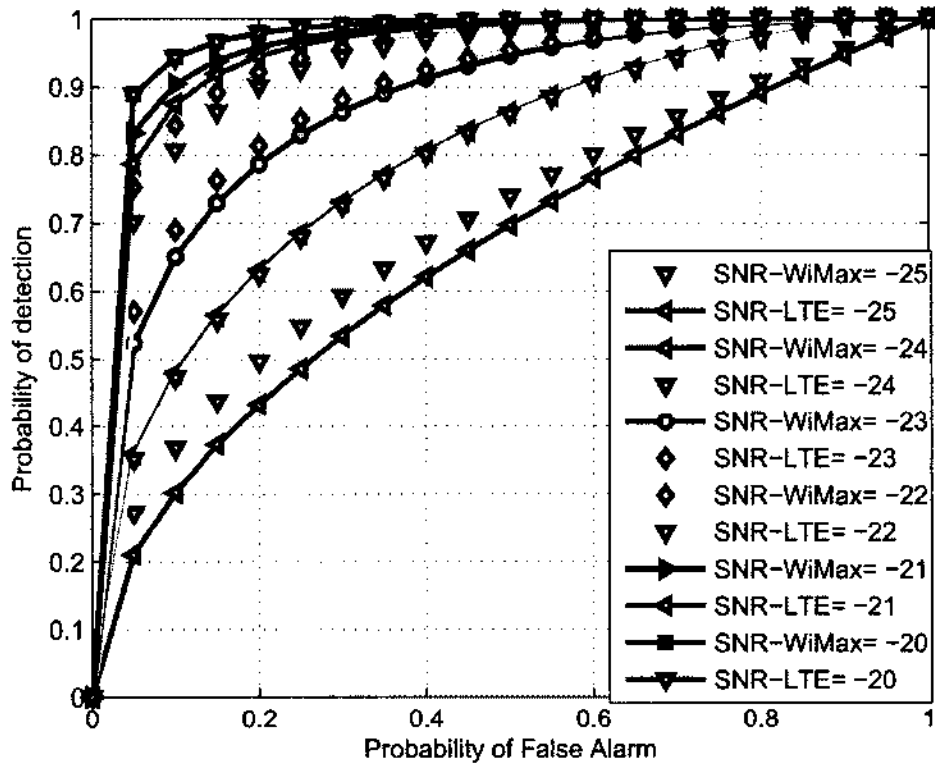
Fig. 18: WiMax and LTE ROC curves for TDSC method for cyclic prefix equal to 1/4

similar SNR curves for simulation and theoretical. This is due to the inherent characteristic of AWGN channel.

Figure (17) shows simulation of ROC curves for TDSC method for cyclic prefix equal to 1/4 OFDM system using WiMAX and LTE techniques. The graph shows that the LTE technique of OFDMA system is identical with WiMAX technique.

5.5 CHAPTER SUMMARY

In this chapter we consider the performance of spectrum sensing algorithm based on Time-Domain Symbol Cross-Correlation TDSC-NP method and applied to WiMAX systems.Also exploring futuer investigation to a performance of spectrum sensing algorithm based on TDSC method applied to WiMAX and LET systems and the spectrum sensing comparisons between WiMAX and LTE. The TDSC-NP method provides a good performance at low SNRs for both systems. TDSC-NP based method is simulated for CP ratios of 1/4,1/8. The sensing performance was under the multipath channel of AWGN,Rayleigh and Ricean. Since Both (WiMAX and LTE) use OFDMA in the DL with higher order modulation and coding Peak performance is similar for same modulation and code rate.Both support FDD and TDD with channel BWs up to 20 MHz. Both support higher order MIMO antenna solutions. Both offer reduced latency [80]. Then the simulations results as exposed in results shows the both systems have similar sensing behavior.

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CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH

In this chapter, the contributions of this dissertation are briefly summarized and some useful directions for future research are outlined.

6.1 CONCLUSIONS

Cognitive radio is an exciting and promising effort for solving the spectrum crowding problem. On the other hand, OFDM technique is used in many wireless systems and proven as a reliable and effective transmission method. OFDM can be used for realizing cognitive radio concept because of its inherent capabilities that are discussed in this dissertation. By employing OFDM transmission in cognitive radio systems; adaptive, aware and flexible systems that can interoperate with current technologies can be realized. The adoption of OFDM in cognitive radios arises in two ways:

- Current wireless technologies change to have more and more cognitive features.

- Improved systems developed that has full cognitive features.

In either case, OFDM will be the dominant physical layer technology for cognitive radio. WiMAX and LTE use OFDM as mechanism multiple media access. As a result of this they achieve high transfer rates and decrease of the influence of multipath. OFDM is a scheme of that let to multiplex different data flows for different users, using for that the OFDM subchannels. That is why, one of the technologies that are

getting a fair amount of interest lately in both academia and industry are WiMAX and LTE.

In this contribution, It has been analyzed a performance of spectrum sensing algorithm based on Time-Domain Symbol Cross-Correlation (TDSC) method applied to WiMAX and LTE systems. In both cases, the method provides a promising results at low SNRs [96], [97]. This detection is only based upon the knowledge of pilot structures without knowledge received signal so that, it can be performed on every portion of the received signal. The approach induces cross-correlation between pilots subcarriers and exploits the deterministic and periodic characteristics of pilot mapping in the time frequency domain.

6.2 FUTURE RESEARCH

Both WiMAX and LTE are standards used for current 4G wireless system. Both WiMAX and LTE appear to have similar goals for enabling worldwide wireless data network connectivity for cell phones, laptops and other computing devices. Nevertheless WiMAX had the priority advantage over LTE in passing to light much of the themes currently implemented such as the flat architecture, all IP network and TDD structure. LTE on the other hand, motivated from all circuit switched of 2G, complete half packetized of 2.5G and 3G and lastly to all IP in LTE and LTE-Advanced. The aim of telecoms corporations from the start was big client base, public networks and wide coverage whereas WiMAX ruled to serve vertical segments demanding broadband. This, collected with the formerly discussed factors, made WiMAX people understand that the network of WiMAX as a separate technology cannot last to

compete with LTE stream and its attractive. WiMAX setting had to set strategies to continue. One of which is to match and participate with LTE rather than remain matching it.

This dissertation presents a promising results of TDSC method which can be implemented successfully in the design future LTE and WiMAX standards using Single-input Single-output. Since Multiple-Input Multiple-Output OFDM (MIMO-OFDM) techniques have been already adopted in LTE and WiMAX standards to achieve very high data rates. In these standards, high mobility users, moving at very high speed need to be supported. Accurate channel state information is required for reliable signal detection at the receiver. Pilot symbols are inserted among sub-carriers before transmission to accurately detection the wireless channel. In a high mobility environment, the wireless channel is time-variant and frequency-selective causing the symbol transmission to be impaired by the Doppler spread. In addition, the channel changes significantly within one OFDM symbol. As a consequence, the Standard channel detection methods cannot be used in LTE and WiMAX to support high mobility users. The contributions of this dissertation may be extended by proposing a novel pilot-aided iterative receiver, based on pilot symbols and iterative estimate of data symbols. The channel is estimated by TDSC method for MIMO-OFDM techniques.

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APPENDIX A

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- Ahmed Temtam, Dimitrie C. Popescu, and Otilia Popescu. "Using OFDM pilot tone information to detect active 4G LTE transmissions." *In Communications (COMM), 2014 10th International Conference on, pp. 1-4. IEEE, 2014.*

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