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# A Review Robust Frequency Synchronization in OFDM for MIMO Based Cognitive Radio Systems

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**ABSTRACT: The demand for high data rates in wireless communication systems is increasing as well the demand for new (communication) services. Expanding of existing services or introducing new services needs a portion in the radio spectrum. Mean while the radio spectrum is a scarce resource and is regulated by governmental regulations and policies. In Cognitive Radio systems, spectrum sensing plays a key role to determine the free frequency bands. However, when the primary user signal spectrum exhibits localized fading, PU detection cannot be guaranteed. In addition, as the CR may use the PU faded frequencies, the PU spectrum can be disturbed by a narrow-band interference (NBI) and synchronization algorithms used for the PU carrier frequency offset (CFO) estimation suffer degradations. In this paper, we propose a new scheme that jointly allows the CR-NBI to be detected and the PU-CFOs and the channels to be estimated in an orthogonal frequency division multiple access (OFDMA) system.**

***Keywords:*** Cognitive Radio, narrow-band interference, ofdma,

## I. INTRODUCTION

Cognitive Radio (CR) systems [1] have been proposed as a solution to optimize the spectrum allocation. Among the parameters (power, constellation size, etc.) to be adjusted, they dynamically change the transmission and reception bandwidths by using spectrum sensing to find out which frequency bands are not used. [9] Due to the spectral diversity to allocate the communication resources over different sub channels, [4] the physical layer modulation for CR is usually based on multi carrier modulation, such as filter bank multi carrier (FBMC) and orthogonal frequency-division multiplexing (OFDM). However when CR systems are used, the primary-user (PU) has to be detected. When dealing with multi carrier transmissions, energy detection can be chosen as a spectrum sensing technique [2], [3]. It is optimal if the cognitive devices have no *a priori* information about the PU signal. In case of shadowing or fading, PU detection can no longer be guaranteed. Then the PU signal may be disturbed by an undesirable narrow-band interference (NBI) caused by the CR. This may lead to an inaccurate estimation of the carrier frequency offset (CFO) and hence increases the bit error rate. Therefore, NBI has to be detected and taken into account to deduce the CFO. [6] Concerning NBI detection, Lau *et al.* [4] propose an approach that consists of a repetitive pilot block in the time domain to detect an NBI localized in time. Since the two duplicated parts remain identical after passing through the channel, their subtraction at the receiver provides the contribution of the noise-plus-interference, which is then easily detected. Nevertheless, this method cannot be used in the presence of CFO. Concerning the CFO, their estimation and compensation in OFDM systems are required to maintain the orthogonality between sub carriers. In [5], Morelli *et al.* illustrate various schemes to[2] estimate The impressive evolution of mobile wireless networks and the potential of wireless multimedia communications increases the traffic in the network and the need for accessible radio spectrum[8] The number of new wireless applications increases and some existing applications are expanding. This needs requires regulations and licenses which is the case now a days. Wireless communication networks are regulated by licensing the radio spectrum. Most of the radio spectrum is already licensed and assigned to different commercial and non commercial [3] users who offer different services. Whether the radio spectrum is utilized efficiently is another question. New wireless services like LTE, 4G will restrict the spectrum access even more and will hardly have any room to access the spectrum. Based on these facts, there is a common belief that we are running out of usable radio spectrum. [7] Measurements done by the FCC's spectrum policy task force to measure the actual usage of the spectrum has shown that at any given time and location part of the licensed spectrum is idle and hence not occupied.

This finding of the FCC let us conclude that the spectrum scarcity and crowdedness result from the inefficient use of the spectrum and the spectrum management policy rather than the physical scarcity of idle spectrum. Several factors like the growing demand for new communication services, the demand for high data rates which are required to cope with the different multimedia communications such as data, video and voice packets each having different traffic requirements and the underutilization of the radio spectrum have pushed communication engineers, researchers, economics and regulation [10] institutes to invent new policies and technologies to utilize the radio spectrum more efficiently and pushes the channel capacity to it's limits. Beside this there is a large demand for portable, low power and small devices. Hence power regulation and consumption is an important issue.

Joseph Mitola from KTH Sweden had a brilliant idea in 2000 introducing the concept of Adaptive communication techniques. His concept called Cognitive Radio utilizes the spectrum in an opportunistic manner and makes it possible to use the gaps in the

## II. MIMO CHANNEL MODEL

With the increasing demand for data rate and reliability in Wireless communications and devices, several issues become very important like bandwidth efficiency, quality of service and radio coverage. Because the radio spectrum is almost fully occupied, hence time and frequency domains are also fully occupied. [12] The space domain can deal with these limitations. Exploring the spatial domain can be done in several manners and is called spatial diversity. In this thesis we explore the spatial diversity by having multiple transmitters and multiple receivers. The challenges we face when we apply MIMO with OFDM are explained in ch. 5 where implementing MIMO in OFDM is explored and proper solutions are provided. When having multiple transmit and receive antennas, the signal (data) is transmitted through a number of different independent paths in a multi path fading environment. Hence different replicas of the transmitted signal are received. During propagation through the wireless channel the received signal will undergo different (independent) channel fades providing spatial diversity. Signals obtained form different diversity channels have to be combined at the receiver to detect the transmitted symbol. [14] In a uniform scattering environment, half wavelength _ 2 spacing is sufficient to obtain independent fading. Without loss of generality, in this paper we put our attention to a 2x2 MIMO system.

The channel model is based on the wide sense stationary uncorrelated scattering (WSSUS) model. Each of the channel links uses the WSSUS model. We assume that the channel fading statistics remain constant over short periods of time or small spatial distances (the channel is aimed constant during at least one OFDM symbol) and the different sub channels are uncorrelated. This model has the following channel impulse response We employ the MIMO [11] concept in our simulation platform because it has been proven that MIMO can achieve a major breakthrough in providing reliable wireless communication links. This reliability is in the context of the channel estimation in our case. With the MIMO concept we improve the bit rate and BER of the overall system. MIMO is capable of this improvement, because of the property of multiple transmission multiple reception. This property is a form of spatial diversity. This diversity is the most effective technique to accomplish reliable communication over the wireless channel and combating with fading, because it provides the receiver with multiple copies of the transmitted signal. Those multiple copies are independently faded. If at least one copy of the transmitted signal is received correctly, we will have the transmitted signal back. This property improves the BER significantly (low BER) as shown in ch 6. Beside this, MIMO increases the channel capacity also, which means more throughput. There are different ways to exploit multiple antennas at both sides of the communication channel. [13] To improve the transmission reliability, the transmit antennas should be used such that transmit diversity is achieved. The transmission rate is comparable to the one obtained in SISO. To improve the transmission rate, independent signals are transmitted from the different transmit antennas. i.e. there is no correlation between the transmitted signals from the different antennas

### *A. Cognitive radio*

Cognitive radio employs spectrum sensing to facilitate coexistence of different communication systems over a same frequency band. A peculiar feature of this technology is the possible presence of interference within the signal bandwidth, which considerably complicates the synchronization task. This paper investigates the problem of carrier frequency estimation in an orthogonal frequency-division multiplexing (OFDM)-based cognitive radio system that operates in the presence of narrowband interference (NBI). Synchronization algorithms devised for conventional OFDM transmissions are expected to suffer from significant performance degradation when the received signal is plagued by NBI.

To overcome this difficulty, we propose a novel scheme in which the carrier frequency offset (CFO) and interference power on each sub carrier are jointly estimated through maximum likelihood (ML) methods.

In doing so we exploit two pilot blocks. The first one is composed of several repeated parts in the time-domain and provides a CFO estimate which may be affected by a certain residual ambiguity. 802 According to recent studies, most of the licensed radio spectrum is severely underutilized in both the time and spatial domain [1]. Spectrum efficiency can be significantly increased by sharing the available frequency band between licensed primary users (PU) and a group of unlicensed secondary users or cognitive radios (CRs). By observing the spectrum of interest, CRs are able to detect the unused portions (spectrum holes) and adapt radio operation to dynamically changing environment without introducing harmful interference to the PU. In order to regulate [15] opportunistic spectrum utilization, IEEE 802.22 working group puts efforts in standardization of wireless regional wireless networks (WRAN) providing broadband access in UHF/VHF TV bands between 54 and 862 MHz [2]. The standard also leaves opportunity that spectrum utilization methods can be extended within any regulatory regime. Due to its flexibility in allocating resources among CRs, OFDM was shown as a promising candidate for physical (PHY) layer in WRAN standard. OFDM is a multi carrier modulation scheme that provides strong robustness against intersymbol interference (ISI) by dividing the broadband channel into many narrowband sub channels modulated on different sub carriers in such a way that attenuation across each sub channel stays flat. By leaving a set of sub channels unused, OFDM provides a flexible spectral shape that fills spectral gaps without interfering with the PU .11g WLAN system in the presence of a Bluetooth interferer.

*B. Spectrum sensing*

Assume that $N$ detected free sub carriers used for cognitive transmission are divided into $Q$ blocks where the $q$-th block contains $Nq$ sub carriers such that $=N$. Each block corresponds to any one channel of the primary user or one primary user. [16] This is also a case when the cognitive radio system operates in the licensed frequency bands of the narrowband system such that the licensed bands from several primary users have to be used in an exact order to achieve high data rate. [19] Let the ordered sub carrier index be named from 1 to $N$.

Denote $\mathbf{ix}q$ be denoted as the $1 \times Nq$ vector that contains the sub carrier indexes in the $q$-th block. Considering an example of above, if the second block contains the eighth, ninth, tenth, eleventh sub carriers, one has $N2 = 4$ and $\mathbf{ix}2 = [8\ 9\ 10\ 11]$. Denote the probability $Pq(H0)$ as the a priori probability that the $q$-th block is vacant and where $H0$ represents the hypothesis that the licensed block is free. Also, denote that the probability $Pq(H1)$ as the a priori probability that the $q$-th block is occupied and where $H1$ represents the hypothesis that the licensed user block is busy. As mentioned before, each block of the radio transmission corresponds to the same channel of one primary user or one narrowband primary user out of several primary users. Therefore, it is assumed that the sub carriers in the same block have the same availability. The values of $Pq(H0)$ and $Pq(H1)$ depends on how busy the primary traffic in the $q$-th block is. In the first part of the secondary frame period, the spectrum sensing is performed. The sensing accuracy depends on two important measures: the probability of detection and the probability of false alarm. The probability of detection gives the probability that a licensed band is busy and hence is detected busy. The probability of the false alarm gives the probability that the licensed user band is free while it is detected busy. In this paper, we focus on the effect of the sensing errors on the performance of the OFDM-based cognitive radio transmission, and assumed that the $= Pq\{H1|H1\}$ denotes the probability of detection and the $= Pq\{H1|H0\}$ denotes the probability of false alarm in the spectrum sensing for the $q$-th block The OFDM data transmission in the data transmission period of the secondary frame period is based on the sensing result from the primary frame period. The data transmission in the secondary frame period will only proceed when the licensed band is free and it is detected free or when the licensed band is busy but it is detected free. The first case happens with probability.

The difference between interference generated as microphone test signal and as the complex sinusoid. The complex sinusoid is perfectly stable over OFDM symbol duration and as such provides higher autocorrelation peaks resulting in lower probability of correct frame synchronization in comparison to the PMSE test signal. As the complex sinusoid can model PMSE interference quite reliably, it can be used to assess the influence of the single tone normalized frequency on the probability of correct synchronization. For this test CFO was set to $\nu = 0$. According to the frequency of the interfering signal has high impact on the probability of synchronization error [17].

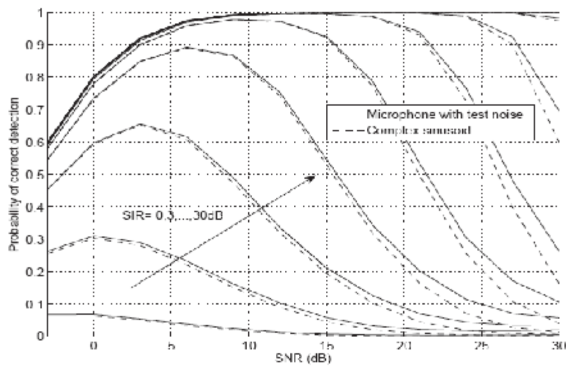


**Fig. 1.** Probability of correct frame synchronization estimated over 100000 random frames for two interference models: complex sinusoid and microphone model modulated with noise.

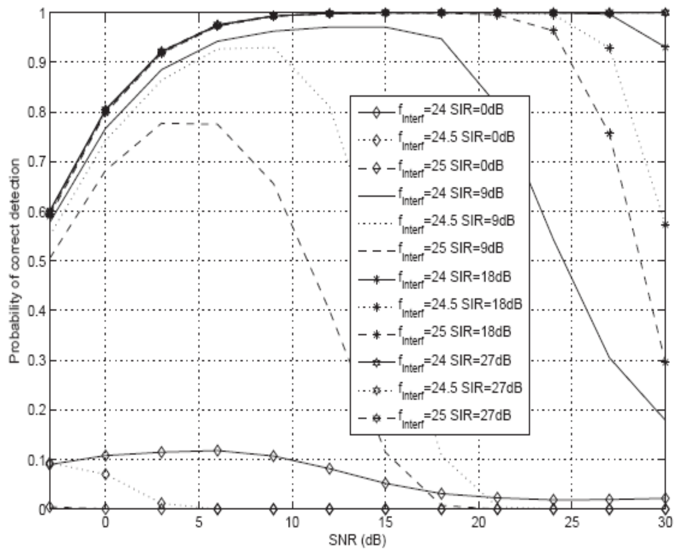


**Fig. 2.** Probability of correct frame synchronization estimated over 100000 random frames for three complex sinusoid frequencies: 24, 24.5 and 25. Zero CFO was assumed.

For the SIR of 9dB, the probability of correct synchronization equal to 0.5 is obtained for SNR of 10.8dB, 14.75dB and 24.55dB for complex sinusoid of normalized frequency 25, 24.5 and 24,respectively. The preamble used in NC-OFDM system utilizes only even sub carriers and the interference on even sub carrier does not deteriorate the timing metric so much. It can be treated as an additional sub carrier. The strongest degradation is observed when the interference occupies an uneven sub carrier. The peak of the timing metric is degraded at optimal correlation index, i.e. correlation index for which autocorrelation windows in (6) is perfectly aligned with two halves of received preamble. In no-interference, nonoise case maximum of timing metric is observed at optimal correlation index. For the simulated system correlation index equals 561. The effect of complex sinusoid carrier frequency can be observed in the resulting timinig-metric values too mean timing metric (solid line) is shown in no-noise, no interference environment. Region, in which 68% of all samples appear is found between the dashed lines. The maximum of the timing metric is achieved for the correlation index value equal to 561. The other three subplots of Fig. are presented for SIR of 0dB. In all of them timing metric achieves the maximum value of 1 (with very small variance) for the correlation indices characteristic for the time before the frame start. It is possible that the maximum of timing metric is [18] found in this region, and the false frame synchronization occurs. For the interference frequency of 24, the mean timing metric at optimal correlation index is close to 0.8.

As the variance of timing metric at optimal correlation index is quite high, correct frame synchronization is possible. As the interference frequency is closer to the odd frequency 25, the mean timing metric at optimal correlation index decreases strongly. The probability of correct frame synchronization decreases,

## III. CONCLUSIONS

The effect of sensing errors on the average BER performances of the OFDM-based cognitive radio transmission has been evaluated by deriving their analysis expressions as functions of the spectrum sensing parameters and the OFDM transmission parameters. Here, the case with carrier frequency offset is considered. The interference from the primary user (licensed) narrowband interference on the synchronization performance OFDM system. The most commonly used Schmidl & Cox synchronization algorithm has been examined. It has been shown that a complex sinusoid is quite simple source of interference that models influence of a practical PMSE system quite well. It is clear that the OFDM based cognitive radio receiver needs new synchronization from the simulation results is that a proper synchronization caused by the sensing errors degrades the performance of the OFDM-based cognitive radio transmission. The amount of degradation depends on the spectrum sensing and the OFDM data transmission parameters. consists of reception part and comparing the transmission and reception and evaluating the BER calculation. After calculating the BER values and evaluating the spectrum errors and it's effect, we devise different methods to reduce the interference caused due to spectrum sensing errors.

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