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PERFORMANCE OF FADING CHANNELS ON ASYNCHRONOUS OFDM BASED COGNITIVE RADIO NETWORKS

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ABSTRACT

This paper deals with the performance study of an asynchronous multicarrier based Cognitive Radio (CR) networks. We investigate the effect of asynchronism on the system's performance through a theoretical analysis and by using different types of fading channel in simulations. Since asynchronous interference could be very harmful on the system's QoS level, our work was principally to develop a new theoretical approach to model the asynchronous interference in CR networks. Furthermore, we are leading a comparison between different fading channel models which are suited to wireless CR networks. This performance evaluation was in term of BER using Matlab when different types of Rayleigh fading channels are used (Pedestrian A, Vehicular A,....). Simulation results showed that the pedestrian and indoor Hiperlan/2 channel give the best performance for our asynchronous OFDM based CR network.

KEYWORDS

Cognitive Radio, OFDM, Asynchronous Interference, fading channels.

1. INTRODUCTION

Fundamental research for 5G networks primarily aim to improve data rate and coverage. Therefore, interference evaluation is considered as an important issue causing degradation for QoS especially in CR networks [1]. Since the multicarrier system performance suffer in some cases from degradation because of imperfect time and frequency synchronization, many works are dealing with asynchronous interference. Therefore, for cognitive radio , non cooperative base stations or Ad-hoc networks, it is very difficult to have perfect synchronization. Consequently, we study the asynchronous interference's effect on the performance of the system.

In our work, we provide a theoretical aspect of the asynchronous interference within a Cognitive Radio (CR) network. The scarcity and underutilization of spectrum has led to the development of CR technology, which exploit the existing spectrum opportunistically by Dynamic Spectrum Access (DSA)[2], it can be defined as a system where unlicensed or SU (Secondary User) can temporarily communicate over unused spectral bands, the licensed or PU (Primary User) are in reality their owners [3].

The awareness of the surrounding radio environment is essential to enabling cognitive devices to react, adapt, and eventually optimize resource usage and performance, as a function of radio conditions. Many possible paradigms may be used in CR [4].

In fact, different models have been proposed to investigate the issue of interference such as the classical Gaussian Approximation (GA) techniques [5], and the Power Spectral Density (PSD) modeling [6]. In our work, we are using instantaneous interference tables in order to model asynchronism in multicarrier CR networks.

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In [7], a new interference model for cognitive radio networks was proposed for two multicarrier modulation techniques : OFDM and FBMC, our analytic approach was developed for a simple case, where we consider only one PU and one SU.

Our purpose is to model the theoretical expressions of asynchronous interference of CR networks (limited number of PU and SU). For different values of timing offsets and types of Rayleigh fading channels, we present the interference levels and compare the system's performance of each of them.

The rest of this paper is organized as follows: First, we make a brief overview of related works available in literature in our context in Section 2; we provide the system model and general problem formulation in Section 3. Section 4 is dedicated for a theoretical background of asynchronous interference. Numerical results are given in Section 5. Finally, this paper will be concluded in Section 6.

2. RELATED WORK

To answer the challenge of Next Generation of wireless networks (5G), important research efforts have been offered in order to model and evaluate the effect of asynchronism on the system performance.

To the best of the authors knowledge, asynchronous interference can be quantified with the Power Spectral Density (PSD)-based model as in [8]. The PSD is generally used to evaluate the mutual interference between two systems but this method does not consider the real level of interference since the asynchronism is absorbed. As interference optimization is an important issue for better QoS, the impact of asynchronism, specially for different OFDM and FBMC techniques was investigated in literature [9], [10], [11].

In [12],we compare the theoretical results of detection probability of different fading environments like Rayleigh, Rician, Nakagami-m, Weibull fading channels with the simulation results using energy detection based spectrum sensing.

3. SYSTEM MODEL

Interference, in wireless communication, is considered as the main cause leading to quality degradation of the system's quality of services. In our work, we present a global analytic model of the interference in asynchronous multi-carrier systems in the CR context. This type of interference is the result of the loss of the orthogonality between different subcarriers.

Let's consider the transmission in OFDM based multi-cellular networks, interference analysis is related to asynchronous effect in frequency selective fading channels. We can then consider a CR system consisting of Primary Users (PUs) and secondary Users (SUs), as presented in Figure 1.

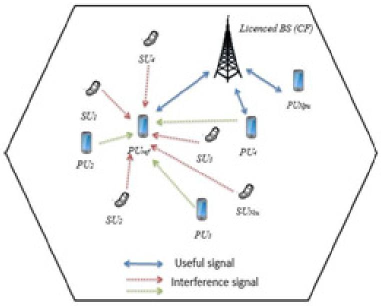


Figure 1. Cognitive Radio Network

$$h_k(t) = \sum_{i=0}^{L-1} h_{k,i}\, \delta\left(t - \frac{n_{k,i}}{N} T\right) \quad (1)$$

Where

- T is the symbol duration
- N is the total number of subcarriers
- L is the total number of nodes
- $n_{k,i}$ are the maximum delay spreads of the channel.

3.1. COGNITIVE RADIO CONSIDERATIONS

Since cognitive radio is performing : Spectrum sensing, Spectrum management, Spectrum sharing and Spectrum mobility [13], we consider a cellular network operating in a wide band, in which the Base Station has the role of a Coordination Function (Fusion Center FC) , its principle role in the spectrum sensing. The term of cognitive radio has evolved over the years to make the radio more capable and more powerful. We also classify CR into overlay or known interference models and underlay or interference avoidance models. It is a paradigm for wireless communication in which either a network or a wireless node changes its transmission or reception parameters to communicate efficiently avoiding interference with licensed or unlicensed users.

An important requirement of the CR network is to sense the spectrum holes and be aware of and respond correspondingly to its surroundings; the proposed CR system operates as follows: First, the frequency band's status (active/idle) is checked in the first spectrum sensing. When idle, the secondary transmitter concludes the frame by transmitting information to the secondary receiver. Finally, if we detect that the PU is present, the transmission will be interrupted, so that we don't affect the PU by the SU interference. Otherwise, the SU will access the band in the next frame, and the process is repeated [14]. An important requirement of the CR network is to sense the spectrum holes and be aware and respond correspondingly to its surroundings.

3.2. OFDM TRANSMISSION CHAIN

Conventional orthogonal frequency-division multiplexing (OFDM) is generally accepted as well matched technology for CR physical layer.It has been probably the most successful multi-carrier modulation (MCM) scheme for the wired or wireless communication in the past two decades. Each sub-carrier is independently modulated using QPSK phase modulation[15].

3.3 DIFFERENT FADING CHANNELS

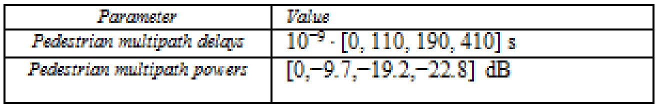
When the signal could be disturbed and suffer from channel conditions, the can say that we are dealing with fading channels. Different types of fading channels could be used depending on environment and condition, such as Rayleigh, Rician.

The choice of propagation models is guided by the requirements. Since CR networks is use of unlicensed band for a range of wireless devices and services. The ITU channel models Pedestrian-A, Pedestrian-B, Vehicular-A... was chosen to evaluate the BER performance of our asynchronous system for Rayleigh fading channel [16].

3.3.1. PEDESTRIAN A CHANNEL

The multipath intensity profile of the Pedestrian-A (3Km/h) channel is defined as follows:

Table I
Channel Parameters Used In Simulations

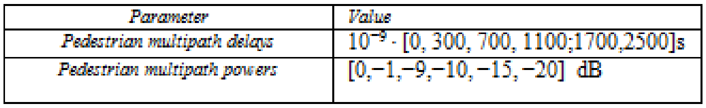


Parameter	*Value*
Pedestrian multipath delays	$10^{-9} \cdot [0, 110, 190, 410]$ s
Pedestrian multipath powers	$[0, -9.7, -19.2, -22.8]$ dB

3.3.2. VEHICULAR-A CHANNEL

The multipath intensity profile of the Vehicular-A (60Km/h) channel is defined as follows:

Table II
Channel Parameters Used In Simulations

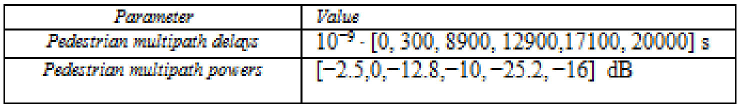


Parameter	*Value*
Pedestrian multipath delays	$10^{-9} \cdot [0, 300, 700, 1100; 1700, 2500]$s
Pedestrian multipath powers	$[0, -1, -9, -10, -15, -20]$ dB

3.3.3. VEHICULAR-B CHANNEL

The multipath intensity profile of the Vehicular-B (60Km/h) channel is defined as follows:

Table III
Channel Parameters Used In Simulations

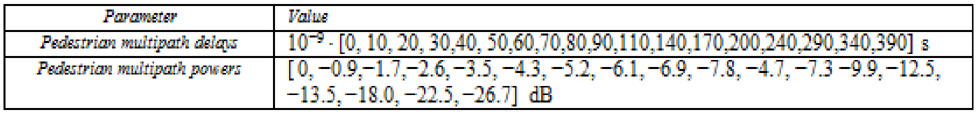


Parameter	*Value*
Pedestrian multipath delays	$10^{-9} \cdot [0, 300, 8900, 12900, 17100, 20000]$ s
Pedestrian multipath powers	$[-2.5, 0, -12.8, -10, -25.2, -16]$ dB

3.3.4. INDOOR HIPERLAN/2 CHANNEL

The multipath intensity profile of the HiperLAN/2 channel is defined as follows:

Table IV Channel Parameters Used In Simulations



Parameter	*Value*
Pedestrian multipath delays	$10^{-9} \cdot [0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 110, 140, 170, 200, 240, 290, 340, 390]$ s
Pedestrian multipath powers	$[0, -0.9, -1.7, -2.6, -3.5, -4.3, -5.2, -6.1, -6.9, -7.8, -4.7, -7.3\ -9.9, -12.5, -13.5, -18.0, -22.5, -26.7]$ dB

4. THEORETICAL APPROACH

This part will be dedicated to present the asynchronous interference model, we consider that the reference mobile user is perfectly synchronized with its base station but it is not necessarily synchronized with the other base stations. The other PUs and SUs are not necessarily synchronized with their BSs and between each other [17].The composite signal at the reference receiver is then expressed as the sum of the desired signal coming from the reference base station and the interference signal coming from the surrounding nodes, which can be secondary or primary signals.

The total received signal at the reference PU is described by the equation (3),

$$r(t) = \sum_{k=1}^{K} S_{p_k}(t) + \sum_{l=1}^{L} S_{s_l}(t) + n(t) \qquad (3)$$

where

- K is the total number of Primary User.
- L is the total number of Secondary User.
- S_{pk}(t)The transmitted signal from the Primary User
- S_{sl}(t)The transmitted signal from the Secondary User
- Additive White Gaussian Noise (AWGN)

As we consider the asynchronous case, the following equation can be deduced from (3):

$$r(t) = A(t) + B(t) + C(t) + n(t) \tag{4}$$

where A(t), B(t), C(t) and n(t) are represented below and denotes respectively the desired signal, the interference signal coming from primary, the interference signal coming from secondary users and the AWGN noise.

$$A(t) = d_1^{-\beta/2} s_{p_1}(t) * h_1(t) \tag{5}$$

$$B(t) = \sum_{k=2}^{K} d_k^{-\beta/2} s_{p_k}(t - \tau_k) * h_k(t) \tag{6}$$

$$C(t) = \sum_{l=1}^{L} d_k^{-\beta/2} s_{s_l}(t - \tau_l) * h_l(t) \tag{7}$$

Where

- denotes the timing offset between the reference node and the PU.
- denotes the timing offset between the reference node and the SU.
- path loss exponent.

Consider the transmission of a single complex symbol x, on the k^{th} frequency slot, from the interfering BS which is defined by:

$$x = a + jb$$

$$s(t) = x\, g(t - \tau)\, e^{j\frac{2\pi}{T}k(t-\tau)+j\varphi}$$

Then the interference signal corresponding by the secondary user is described by equations below:

$$S_s(t) = \sum_{k=1}^{k} s_{s_k}(t) = \sum_{k=1}^{M_K} x_k\, g(t - \tau_k) e^{j\frac{2\pi}{T}k\,(t-\tau_k)} \tag{8}$$

where

- The complex transmitted symbol
- The total number of subcarriers of all spectrum holes
- The transmit pulse shape having the form as below:

$$g(t) = \begin{cases} \frac{1}{\sqrt{T}}, & t \in [0, T + \Delta] \\ 0, & elsewhere \end{cases} \tag{9}$$

where

- represents the cyclic prefix
- represents the symbol duration

Supposing we have only one PU and one SU, the asynchronous OFDM interference signal received on the kth subcarrier for a PU, considering the transmission of a single complex symbol $x_{k',0}$ (by another user, PU or SU) on the k'^{th} subcarrier is given by :

$$y_{k'}(\tau,\varphi) = \langle s_{s_1}(t-\tau,\varphi), f(t-(T+\Delta))e^{-j\frac{2\pi}{T}k'(t-k(T+\Delta))}\rangle \qquad (10)$$

where

- k is the SU frequency slot (spectrum hole)
- k$'$ is the PU frequency slot
- $f(t)$ receiver filter impulse response expressed by

$$f(t) = \begin{cases} \frac{1}{\sqrt{T}}, & t \in [0,T] \\ 0, & elsewhere \end{cases}$$

Let's denote $l=k-k'$. Then, we can deduct the equation (11),

$$y_{k'}(\tau,\varphi) = x_k e^{-j\frac{2\pi}{T}k\tau + j\varphi} \int_{-\infty}^{+\infty} g(t'-\tau)\, f(T+\Delta-t')\, e^{j\frac{2\pi}{T}lt'}\, dt' \qquad (11)$$

$$y_{k'}(\tau) = u_{k'} \begin{cases} \delta(l)\,, \ \tau \in [0,\Delta] \\ e^{j\frac{\pi l}{T}(T+\tau+\Delta)} \dfrac{\sin^{\pi l(T+\Delta-\tau)}/_T}{\pi l}, \ \tau \in [\Delta, T+\Delta] \\ 0 \quad elsewhere \end{cases} \qquad (12)$$

where

$$u_{k'} = x_{k'} e^{-j\frac{2\pi}{T}k'\tau}$$

The corresponding interference power is

$$I(\tau) = |y_{k'}|^2 = \begin{cases} \delta(l)\,, \ \tau \in [0,\Delta] \\ \left| \dfrac{\sin^{\pi l(T+\Delta-\tau)}/_T}{\pi l} \right|^2, \ \tau \in [\Delta, T+\Delta] \\ 0 \quad elsewhere \end{cases} \qquad (13)$$

5. NUMERICAL RESULTS

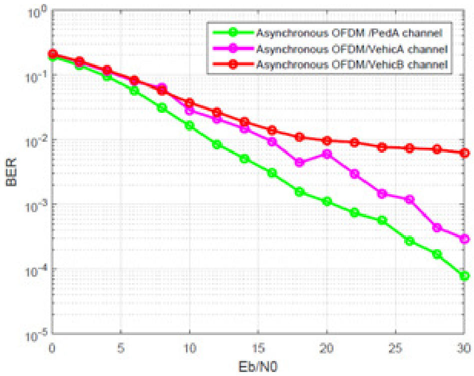
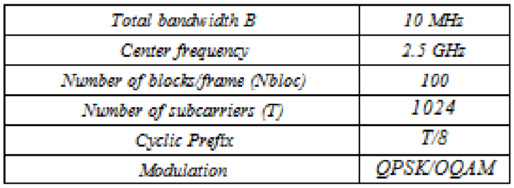


Figure 2. The **OFDM** average BER against the Eb/N0 for different channel Models and τ in [0, T]

In the context of CR, we assume that some licensed spectrum band resources are already obtained by CR spectrum sensing. We've designed our system as an OFDM based CR used network. The different characteristics of the model we developed are described in Table I and Table II. The source, which is a binary signal, is always randomly generated. We have different fading channels propagation channel where the parameters are given in Table IV [18]. In this section, we present numerical results for the downlink of OFDM systems with the use of different models of channels as described in Section II. Simulations that are presented in this section are done using Matlab. On the other hand, we consider a system with T = 1024 subcarriers and the sampling frequency is 10 MHz. The noise term is characterized as an Additive White Gaussian Noise. The prefix cyclic duration for the OFDM multicarrier technique is fixed at Δ = T/8, the CR network as shown in Figure 1 with one primary system and a secondary system is simulated for some users and different spectrum holes.

Table V
System Simulation Parameters



Total bandwidth B	*10 MHz*
Center frequency	*2.5 GHz*
Number of blocks/frame (Nbloc)	*100*
Number of subcarriers (T)	*1024*
Cyclic Prefix	*T/8*
Modulation	*QPSK/OQAM*

In Figure 3, we present the BER against Eb/N0 by considering asynchronous CR approach using OFDM multicarrier technique. We note that the best performance is obtained when we use the pedestrian and indoor Hiperlan/2 channel, which is so logic since these channel have the least attenuation and delay values.

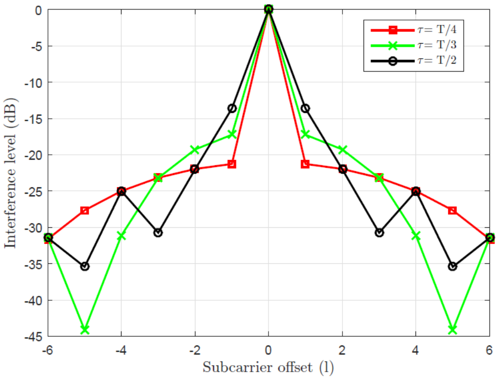


Figure 3. OFDM instantaneous interference tables (Simple Case) for $\tau = \frac{T}{4}, \tau = \frac{T}{5}, \tau = \frac{T}{2}$

For high SNR, i.e, high E_b/N_0, the system have lower BER values, this evolution is similar to the proposed theoretical approach. Then we can see that the Vehicular B channel is better suited than Vehicular A for asynchronous OFDM based CR system.

In order to evaluate the effects of interference caused by the imperfect synchronization in multi-carrier techniques, we consider the system model depicted in Figure 1. The reference receiver is assumed to be perfectly synchronized with its corresponding transmitter. Moreover, the timing offset of each user τ and the phase offset of each user ϕ are assumed to be uniform random variables that are distributed on τ in $[0, T]$ and ϕ in $[0, 2\pi]$, respectively.

Our theoretical approach results are presented for different values of timing offset and by varying the number of secondary users. In figure 3, we present the interference level in CR networks in the simple case for OFDM. We plot the asynchronous interference for three values of timing offset $\tau = \frac{T}{4}$ $\tau = \frac{T}{5}$ $\tau = \frac{T}{2}$ in order to compare the performance between both multicarrier schemes. Indeed, the comparison between the theoretical curves confirms the precision of the analytic approach for simple case.

6. CONCLUSIONS

In this paper, we have studied and developed a new theoretical aspect of asynchronous interference analysis in a CR networks using OFDM wave forms. In fact, this study is valid for analyzing the impact of the asynchrony on OFDM for a limited number of users(One PU, One SU), by estimating the interference introduced and establishing analytic expressions of the SINR. We further explored simulation results and compared the system performance when using different fading channels (Pedestrian A, Vehicular A, Vehicular B).

Finally, in our future research, we plan to extend this work in the case when using Filter Bank Multicarrier (FBMC) and for a multi-user case of Npu and Nsu.

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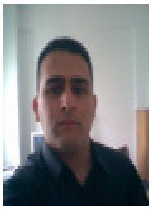

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