MC-CDMA Scheme in Wi-Fi Environment

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Abstract

The combination of OFDM and Code Division Multiple Access (CDMA) is seen as an attractive and practical solution to enhance the throughput and/or robustness for future high-speed indoor WLANs. The multi-path Rayleigh channel represents a hostile environment for WLANs communication. So, we have proposed the MC-CDMA system to overcome the impact of this kind of wireless channel.
The focus of this article is to simulate a modified physical layer (PHY) based on the IEEE 802.11a combined with a stage of spread spectrum. This modified layer particularly concentrates on IEEE 802.11a standard. Basically, the proposed schemes can be split in different types depending on the CDMA code used. We investigated the modified physical layer performance on the basis of Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR). The numerical results show that the MC-CDMA is a powerful multi-carrier multiple access technology.

Key words: *WLAN, IEEE 802.11a, OFDM, MC-CDMA, Rayleigh channel.*

1. Introduction

Wireless Local Area Networks (WLAN) have evolved as the quantity and types of mobile devices have increased. The number of devices that support Wi-Fi continues to expand. The term Wi-Fi is an industry acronym meaning wireless fidelity for devices with support for the IEEE 802.11 wireless standard. The type of devices that include Wi-Fi support continues to expand from laptops to many other devices, such as cameras, phones, automobiles, and other consumer devices. The uses of Wi-Fi have expanded beyond just data usage, often including voice, video, and innovative contextual applications [1].

The standards of WLANs that currently gain the most momentum are IEEE 802.11a and IEEE 802.11b. The IEEE 802.11a standard is based on OFDM. The main reason that OFDM was selected as basis for this standards is its capability to deal with the strong multi-path propagation present in indoor propagation channels. In general, OFDM splits a wideband frequency-selective fading channel into a number of narrowband frequency-flat fading channels (i.e., subcarriers). Moreover, the ability to include a proper guard interval between subsequent OFDM symbols provides an effective mechanism to handle Inter Symbol Interference (ISI) caused by severe multi-path propagation [2, 3].

The IEEE 802.11b standard applied direct sequence spread spectrum (DSSS) or frequency hoping spread spectrum (FHSS) and provided 1 or 2 Mbps. In 1999, the IEEE 802.11b was available. It was designed to operate in an indoor environment. For the 1 and 2 Mbit/s modulation, the Barker sequence shall be used as code [3, 4].

The combination of OFDM and CDMA is seen as an attractive and practical solution to enhance the throughput and/or robustness for future high-speed indoor WLANs.

The focus of this article is to simulate a modified physical layer (PHY) based on the IEEE 802.11a combined with a stage of spread spectrum. This modified layer particularly concentrates on IEEE 802.11a standard because its physical layer design is considered to be more robust against harsh propagation conditions. According to the IEEE specification the WLAN should transmit the data in frames, but the preamble and the header are not implemented in our studies. Only the part which contains the data to be transmitted is implemented with Matlab software. Basically, the proposed schemes can be split in different types depending on the CDMA

code used. The numerical results show that the MC-CDMA is a powerful multi-carrier multiple access technology.
The rest of the paper is organized as follows: Section 2 gives a short overview of Wi-Fi technologies. Section 3 provides the background information for the MC-CDMA technique. In Section 4 a detailed presentation of the proposed scheme is given. Section 5 contains a discussion on simulation results. Section 6 summarizes this work with concluding remarks.

2. Overview of Wi-Fi technologies

In June 1997 the Institute of Electrical and Electronics Engineers (IEEE) defined an international interoperability standard, called IEEE 802.11 wireless LAN, also known as Wi-Fi. This standard specifies a number of Physical Layers (PHYs). Two of these PHY are based on radio communication and use the 2.4GHz band, license free ISM (Industrial, Scientific and Medical bands) and the others PHY uses infrared light. All three PHYs support a data rate of 1Mbps and optionally 2 Mbps.

In 1998, Lucent Technologies and Harris Semiconductor proposed a standard called Complementary Code Keying (CCK) to achieve 5.5Mbps and 11Mbps transmit rates. The IEEE adopted the CCK and released a new standard, named IEEE 802.b, in 1999.

Motivated by the demand for higher data rates and by the opening of new unlicensed spectrum in the 5GHz band for the use of a new category of equipment called Unlicensed National Information Infrastructure (UNII) devices, a new IEEE 802.11 working group started working on third generation of WLANs. In July 1998, this group selected OFDM as a transmission technique. In 2000, the standard was ratified and called IEEE 802.11a. It defines data rates between 6 and 54Mbps. To make sure that these data rates are also available in 2.4GHz band, mid 2003 IEEE standardisation group finalised a similar standard for this band named IEEE 802.11g. The growing success of IEEE 802.11b and IEEE 802.11a products together with the demand for even higher bit rates confirms the need for research to high data-rate extensions for WLANs.

3. MC-CDMA techniques

Multicarrier code-division multiple-access (MC-CDMA) represents a fusion of two radio access techniques, namely OFDM and the CDMA [5]. Such a combination has the benefits of both OFDM and CDMA [6]. In MC-CDMA symbols are modulated on many subcarriers to introduce frequency diversity instead of using only one carrier like CDMA. Thus MC-CDMA is robust against deep frequency selective fading compared to DS-CDMA [7]. Each user data is first spread using a given high rate spreading code in the frequency domain. A fraction of a symbol, corresponding to a chip of the spreading code, is transmitted through a different subcarrier. Hence each OFDM subcarrier has a data rate identical to the original input data rate. The transmitted signal of the ith data symbol of the jth user $s_i^j(t)$ is:

$$s_i^j(t) = \sum_{k=0}^{N-1} b_i^j c_k^j e^{2\pi(f_0+kf_d)t} p(t - iT) \tag{1}$$

where: N is the number of subcarriers, b_i^j is the ith message symbol of the jth user, c_k^j represents the kth chip, $k = 0,1,...,N-1$, of the spreading sequence of the jth user, f_0 is the lowest subcarrier frequency, f_d is the subcarrier separation and $p(t)$ is a rectangular signaling pulse shifted in time given by:

$$p(t) = \begin{cases} 1 & 0 \le t \le T \\ 0 & elsewhere \end{cases} \tag{2}$$

If 1/T is used for f_d, the transmitted signal can be generated using the IFFT, as in the case of an OFDM system. There for, if the original symbol rate is high enough to become subject to frequency selective fading, the input data have to be serial-to-parallel converted into P parallel data sequences and each serial-to-parallel output is multiplied with the spreading code of length N. Then each sequence is modulated using Ns subcarriers. Thus, all Ns = P.N subcarriers are also modulated in baseband by the IFFT.

4. Proposed schemes description

4.1 MC-CDMA model 1

In our simulations, the channel coding is not used. The proposed system uses MC-CDMA in the physical layer. As shown in Figure 1, first the input data stream is modulated with BPSK modulation.
Then the modulated data symbol sequence is serial-to-parallel converted to a maximum of P=5 parallel sequences. Each of the parallel sequences is duplicated into spreading factor parallel copies and each of the duplicated symbols is multiplied by a chip from the spreading code. As spreading sequences the orthogonal Barker code of length N=11 is used.

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After that an IFFT is performed and the pilot signal is used. Then a cyclic prefix is inserted after being converted to serial data stream to generate the MC-CDMA signal.
Finally, the signal is transmitted trough the channel. The channel consists of a multi-path fading with AWGN (10-Tap Rayleigh fading model is used as the channel); at the receiver the inverse operation is employed.

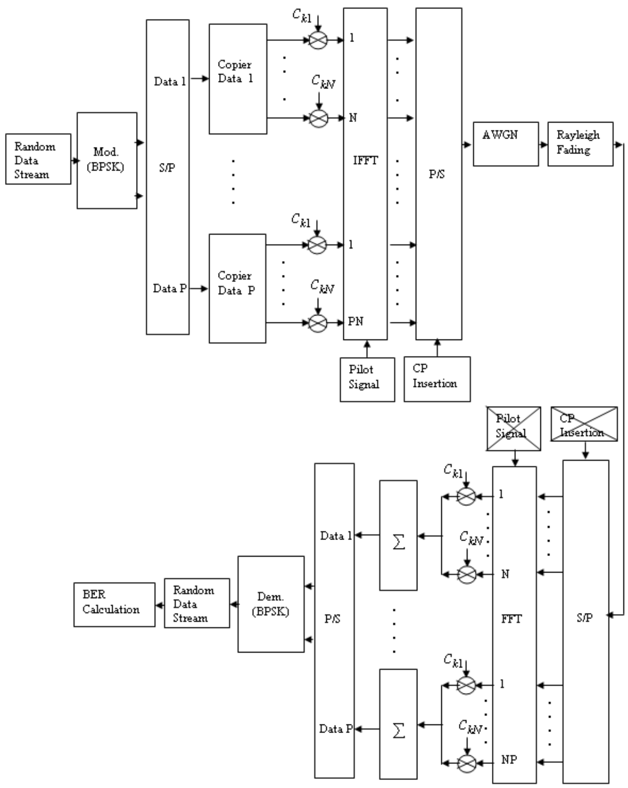

Fig.1 The first model simulation block diagram of MC-CDMA in Wi-Fi environment

4.2 MC-CDMA model 2

The 20 MHz channel is split into 52 subcarriers (48 subcarriers for data and 4 pilot subcarriers), like in the IEEE 802.11a OFDM physical layer.
Figure 2 illustrates the second MC-CDMA simulation model. The input data stream is first mapped into BPSK and then is multiplied by the spreading code of length N (the same symbol is transmitted in parallel through several subcarriers). Each chip of PN code modulates one subcarrier. The number of subcarriers in this scheme equals the length of spreading code.
All data corresponding to the total number of subcarriers are modulated in baseband by IFFT and converted back into serial data. Then a cyclic prefix is inserted between the symbols to combat the inter-symbol interference (ISI) and the inter-carrier interference (ICI) caused by multi-path fading.

Finally, the data are sent to the receiver over the same channels used before. At the receiver the inverse operation is employed.

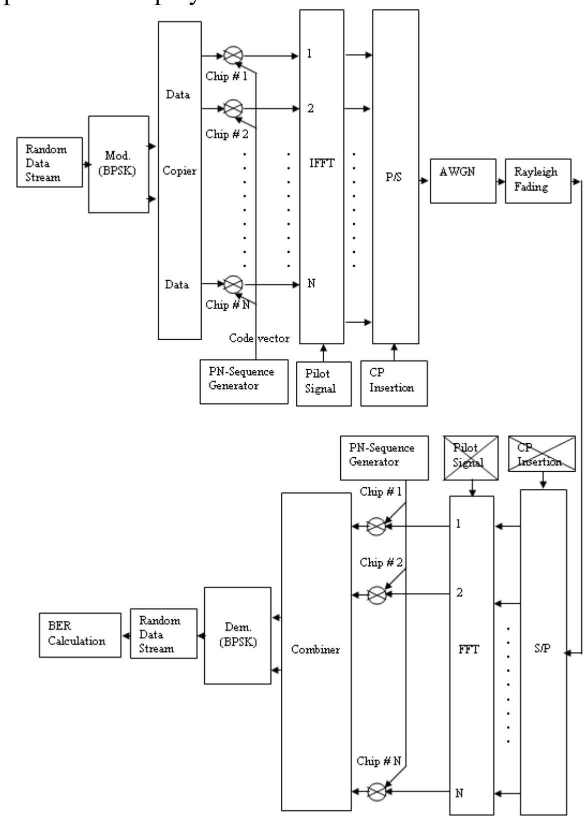

Fig.2 The simulation block diagram of MC-CDMA (2) in Wi-Fi environment

4.3 simulation parameters of the MC-CDMA models

Additional parameters of the PHY layer are presented in table 1.

Table 1. Simulation parameters of the MC-CDMA models

Parameter	***Value***		
	Model 1	Model 2	
		Case 1	Case 2
Channel Bandwidth	20 MHz		
Subcarriers Spacing	0.3125 MHz		
Symbol Interval	4µs = 3.2µs + 0.8µs		
Guard Interval	0.8µs		
FFT size	64	64	128
Number of subcarriers	55	52	104
Spreading factor	11	52	104
Spreading code	Barker	PN	PN
P: parallel data sequences	P=5	-	-

5. Simulations, results and analysis

5.1 Simulations environment

The simulations are designed and implemented using Matlab. Performance is evaluated by transmitting randomly generated data stream over a channel. The stream is then received, demodulated and BER is calculated each time for every simulation. Multi-path appears in conditions where the transmitted signal experiences reflections, diffractions, and scattering. This is due to obstacles between transmitter and receiver. A channel in mobile communications can be simulated in many different ways. In our simulations, we have considered the two most commonly used channels: the AWGN model and a Rayleigh fading channel model. The channel model is based on the worst case scenario, assuming that no line-of-sight path is available between the transmitter and the receiver. On the other hand, a wideband fading channel can be modeled as a sum of several differently delayed, independent Rayleigh fading process. The corresponding channel impulse response is described as [7]:

$$h(t,\tau) = \sum_{p=1}^{P} a_p . R_p(t) . \delta(\tau - \tau_p) \quad (3)$$

where: a_p is the normalized amplitude, $R_p(t)$ is the Rayleigh fading process, τ_p is the delay of the pth path.

5.2 MC-CDMA simulation results

For the simulations a multi-path Rayleigh fading channel model is presented, the graphs of BER versus Es/No for the different models are shown in figure 3. The first model is based on the Barker code and the second model is based on PN code.

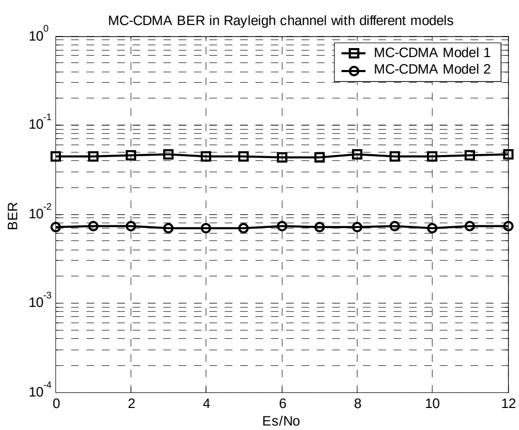

Fig.3 The BER vs. Es/No of MC-CDMA models in Rayleigh channel

The graphs indicate that the transmission quality is degraded in the Rayleigh channel. It is noted that the transmission quality is better for the second model.

Since the MC-CDMA model 2 presents a better performance then the first model, different subcarrier number are simulated. It is noted that the performances are influenced by the change of subcarrier number (FFT=64, FFT=128) as indicated in figure 4. The higher subcarriers number is better in BER.

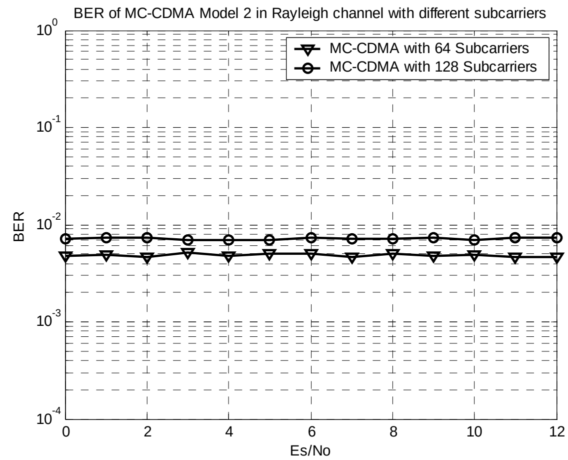

Fig.4 The BER vs. Es/No of the second MC-CDMA model in Rayleigh channel with 64 and 128 subcarriers

6. Conclusions

With the rapid development of wireless communications, two trends are gaining in popularity. One is the use of CDMA and the other is the use of OFDM. For future wireless applications, researchers have also started a new trend of combining these two techniques with the intention of obtaining advantages of both, and the proposed new technique is generally termed MC-CDMA. In this paper, we are proposing a modified version of the IEEE 802.11 system, based on MC-CDMA as PHY layer. In our simulations, we considered two different models. In order to verify the performances, we have evaluated them in multi-path Rayleigh fading channel which represent a hostile environment for WLANs communication. In each models, we measured the BER versus Es/No.

In the simulation results, it is interesting to note that:

- The transmission quality is degraded in the Rayleigh channel because of the multi path effects and the not use of the channel coding.
- The performances of the transmission are influenced by the choice of spreading code used (Barker, PN). The PN code shows a better transmission.
- The performances of the transmission are influenced by the change of subcarrier number (FFT=64, FFT=128). The higher subcarriers number is better in BER.

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