Comparative Study of CDMA and OFDM in WI-FI

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Abstract

There have been extensive research efforts on simulating Wireless Local Area Networks. Many papers have studied the performance of IEEE 802.11 WLANs by using simulation under different channels and for different modulations. In this paper we first simulate a simplified IEEE 802.11a standard based on Orthogonal Frequency Division Multiplexing (OFDM) with the cyclic prefix and IEEE 802.11b standard based on Direct-Sequence Code Division Multiple Accesses (DS-CDMA). Then a comparative study will be performed to evaluate them in Additive White Gaussian Noise (AWGN) channel with Rayleigh fading to resemble the real world scenario. We investigated their physical layer performances on the basis of Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR). These parameters are discussed and compared in the two models. It has been demonstrated that OFDM system provides better performance in noisy conditions.

Key words: *WLAN, IEEE 802.11a/b, CDMA, OFDM, Rayleigh channel.*

1. Introduction

Wireless Local Area Networks provide wideband wireless connectivity and allows high-speed data transfer without the need for wires or cables installation. WLANs can be used in different environments such as home users, public and enterprise applications. Different types of terminals are already or planed to be equipped with WLAN such as laptops, cameras, automobiles and mobile phones. In the next generation of WLAN standard, increasing the link throughput reliably to support a number of novel multimedia applications is a key point to develop new standards and to promote compatibility and interoperability between competing technologies. To gain widespread success, broadband wireless systems must deliver multimegabit per second throughput to end users, with robust quality of services (QoS) to support a variety of services.

Developing reliable transmission and reception schemes to push broadband data through a hostile wireless channel, achieving high spectral efficiency and efficiently multiplexing services with a variety of QoS requirements are the most important technical design challenges [1]. The first and most fundamental challenge for WLANs comes from the transmission medium itself. Wireless communication channels constitute a hostile propagation medium, which suffers from fading. Several non-conventional transmission solutions based on single-carrier and multi-carrier modulations (DS-CDMA and OFDM) have been proposed as solution for mitigating this problem. And as such, it is important to explore the basics of the OFDM and CDMA techniques.

OFDM is attractive and widely studied in recent years. It has received considerable attention for its advantages in high bit-rate transmission over frequency-selective channels. It has also several desirable attributes, such as high spectral efficiency, robustness with respect to multi-path delay spread all of which are making OFDM to be incorporated in various wireless standards. The presence of a cyclic prefix (CP) completely eliminates inter-symbol interference and replaces the complex time-domain equalizer by a simple single tap frequency-domain equalizer. Nowadays, the OFDM technology is widely adopted for many WLAN standards such as IEEE802.11a and HIPERLAN2. It has become the basis for the digital audio broadcasting, digital video broadcasting, fixed broadband wireless access systems (WiMAX standard), Wireless Personal Area Networks (WiMedia, Bluetooth), Long-term evolution of third-generation (3G) cellular systems, Cable broadband access (ADSL/VDSL) and power line communications [2-6].

CDMA is a multiple access scheme where several users share the same physical medium, that is, the same frequency band at the same time. Each user is assigned a distinguished code for transmission. The origin of spread spectrum is in the field of military applications and radar systems. During the late 1970, the employment of spread-spectrum techniques was proposed for efficient cellular communication [4]. Nowadays, the most prominent applications of CDMA are mobile communication systems like cdmaOne (IS-95), UMTS or cdma2000 [2] [7-8].

In this paper, we evaluate performances in terms of BER with respect to the SNR of IEEE 802.11 which is also often referred to as "Wireless Fidelity". Knowing that, today's Wi-Fi [9] is gaining a lot of popularity because is deployed in home, office, restaurants, airports, university campus, streets and is recognized as one of the main access technologies to the Internet. For this reason we chose it like an example for our study. We investigated the physical layer performance on the basis of BER and SNR. These parameters are discussed and compared in two models. The first model is IEEE 802.11a standard based on OFDM with the cyclic prefix, while the second model is IEEE 802.11b standard based on DS-CDMA. According to the IEEE specification the WLAN should transmit the data in frames. But in our studies the preamble and the header are not implemented; only the part which contains the data to be transmitted is implemented. Simulation results are obtained using MATLAB 6.5 programming language. Our important contribution is to establish a comparative study between these two models, furthermore, in this paper different aspects of these models were investigated and with MATLAB simulations it has been demonstrated that OFDM modulation schemes provides better performance in noisy conditions.

This article is organized as follow. In section 2, we describe the advanced access techniques such as OFDM and CDMA technologies. Section 3 is focused on the Wi-Fi characteristics (IEEE 802.11a and IEEE 802.11b description). The main results are discussed in section 4. Finally the conclusion is presented in section 5.

2. Advanced access techniques description

2.1 OFDM

In OFDM, the data stream is not sent out "as is", but rather is serial to parallel converted prior to transmission. This leads to N low-rate data streams, each demonstrating a narrow bandwidth. As a result, when sent over the channel, each low-rate data stream experiences a flat fade, i.e., the gain is constant over all the frequencies that make up one low-rate data stream. Here, no equalizer structure is required at the receiver. At the receiver side, the incoming data stream is first returned to base band by use of an appropriate mixer. Next, the incoming data stream is separated into its N low-rate data streams by: to extract the i^{th} low-rate data stream, apply the i^{th} carrier's frequency followed by a low pass filter. Once the data streams have been separated one from another, a simple decision device is applied [5]. Intersymbol interference (ISI) can also be eradicated through the insertion of a guard interval (GI) to the front of an OFDM symbol, provided the GI is longer than the delay spread of the channel. The transmitted OFDM signal can be represented by:

$$s(t)=\sqrt{\frac{2P}{N_s}}\sum_{n=1}^{N_s} b_n \exp\left(j2\pi f_n t\right), \quad 0<t<T_s \tag{1}$$

where P denotes the symbol power, b_n denotes the i^{th} data symbol, N_s is the number of subcarriers for which the n^{th} subcarrier frequency is given by $f_n = f_c + n/T_s$. This subcarrier frequency configuration represents 50% spectral overlapping such that the spacing between adjacent subcarriers is $\Delta f = 1/T_s$. If the transmitted OFDM symbol in (1) is sampled N_s times at time instants $t=\frac{m}{N_s}T_s$, it can be expressed in the form

$$s\left(\frac{m}{N_s}T_s\right)=\sqrt{\frac{2P}{N_s}}\sum_{n=1}^{N_s} b_n \exp\left(j2\pi\left\{f_c+\frac{n}{T_s}\right\}\frac{m}{N_s}T_s\right), \quad m=1,\dots,N_s \tag{2}$$

Considering the baseband representation for which $f_c = 0$ gives

$$s\left(\frac{m}{N_s}T_s\right)=\sqrt{\frac{2P}{N_s}}\sum_{n=1}^{N_s} b_n \exp\left(j2\pi\frac{n.m}{N_s}\right), \quad m=1,\dots,N_s \tag{3}$$

$$s\left(\frac{m}{N_s}T_s\right)=\sqrt{\frac{2P}{N_s}}N_s.IDFT\{[b_1,\dots,b_{Ns}]\}, \quad m=1,\dots,N_s \tag{4}$$

One of the major attractions of OFDM is the reduction in transmitter/receiver structure complexity offered by the IFFT/FFT implementations.

2.2 DS-CDMA

CDMA employs spread-spectrum technology and a special coding scheme where each transmitter is assigned a code to allow multiple users to be multiplexed over the same physical channel. Spread spectrum means enhancing the signal bandwidth far beyond what is necessary for a given data rate and thereby reducing the power spectral density of the useful signal so that it may even sink below the noise level. Spreading is achieved by a multiplication of the data symbols by a spreading sequence of pseudorandom signs. These sequences are called pseudo noise (PN) sequences or code signals [2] [4]. In conventional system structure of the DS-CDMA, serial data is first spread by the appropriate code at the transmitter and the reverse operation is performed upon reception. The despread signal is then passed through a matched filter adapted to the rectangular shape of the data; the conventional systems utilize rectangular codes, however, alternative waveforms are possible. Finally, a decision device is applied yielding the final estimate of the desired information signal. The effect of spreading transforms a low data rate signal into a higher data rate signal. The input signal, comprised of serial data symbols of duration T_s, is directly multiplied by the appropriate code consisting of N chips of duration T_c. This has a spreading effect in the frequency domain. The signal bandwidth increases by a factor of $N = T_s / T_c$ referred to as the spreading factor or power gain. The transmitted signal (spread spectrum signal) of the k^{th} user can be expressed as

$$s_k(t) = \sqrt{2P}\sum_{i=-\infty}^{\infty} b_{ki}.c_k(t - iT_s)\cos(\omega_c t + \theta_k) \qquad (5)$$

where b_{ki} is the i^{th} data symbol of user k, ω_c is the carrier frequency, θ_k is the initial carrier phase of user k and

$$c_k(t) = \sum_{n=1}^{N} c_{kn}.u_{Tc}(t - nT_c + Tc) \qquad (6)$$

represents the spreading code allocated to user k for which c_{kn} denotes the n^{th} chip and

$$u_{Tc}(t) = \begin{cases} 1, & 0 \le t \le T_c \\ 0, & elswhere \end{cases} \qquad (7)$$

is the rectangular pulse shaping waveform.

3. Overview of IEEE 802.11WLAN

3.2 IEEE 802.11

The Institute of Electrical and Electronics Engineer IEEE 802.11 or Wi-Fi denotes a set of Wireless LAN standards developed by working group 11 of the IEEE LAN/MAN Standards Committee [11]. The IEEE 802.11 WLAN standard was approved and the corresponding standard specification was published in 1997. After the finalization of Legacy standard, several standard amendments were released and even currently other amendments have been discussed in working groups in IEEE 802.11. The standard is composed of both Physical Layer (PHY) and Medium Access Control (MAC) specifications for wireless LANs. New PHY specifications now allow much higher data rates to be used (e.g., up to 11 Mbps in 802.11b [12] and 54 Mbps in 802.11a [13]), as compared to the 1Mbps and 2Mbps in the initial version (Tab.1).

Table 1. IEEE 802.11 standards overview [14]

Standards	***Description***	***Ratification***
802.11	Based definition of MAC; IR, FHSS, and DSSS in 2.4 GHz band PHYs with 1 and 2 Mbps data rates	1997; amended 1999, 2007
802.11a	OFDM PHY in 5.8GHz UNI-II spectrum, data rates up to 54 Mbps	1999
802.11b	DSSS PHY extension in 2.4 GHz band for data rates up to 11 Mbps	1999
802.11n	Higher-throughput 802.11 WLANs	2009
802.11ac	Very high throughput	Targeted for 2012 at press time

3.3 IEEE 802.11b

The first generation of the IEEE 802.11 standard applied direct sequence spread spectrum (DSSS) or frequency hoping spread spectrum (FHSS) and provided 1 Mbps DBPSK modulation or 2 Mbps DQPSK modulations. In 1999, the IEEE 802.11b was available. It was designed to operate in an indoor environment and delivers a maximum of 11 Mbps in the generally unlicensed Industrial, Scientific and Medical (ISM) 2.4 GHz radio band. The Barker sequence shall be used as the code sequence for the 1 and 2 Mbit/s. The extended direct sequence specification defines two additional data rates (5.5 Mbit/s and 11 Mbit/s). Hence, chipsets and products were easily upgraded to support the 802.11b enhancements. The dramatic increase in throughput of 802.11b along with substantial price reductions led to the rapid acceptance of 802.11b as the definitive wireless

LAN technology. 802.11b is usually used in a point-to-multipoint configuration, wherein an access point communicates via an omni-directional antenna with one or more clients that are located in a coverage area around the access point. With high-gain external antennas, the protocol can also be used in fixed point-to-point arrangements, typically at ranges up to 8km although some report success at ranges up to 80–120 km where line of sight can be established. IEEE 802.11b divides the spectrum into 14 overlapping, staggered channels whose center frequencies are 5 MHz apart. The 802.11b standards do not specify the width of a channel; rather, they specify the center frequency of the channel and a spectral mask for that channel. The spectral mask for 802.11b requires that the signal be attenuated by at least 30 dB from its peak energy at ±11 MHz from the center frequency, and attenuated by at least 50 dB from its peak energy at ±22 MHz from the center frequency. Since the spectral mask only defines power output restrictions up to ±22 MHz from the center frequency, it is often assumed that the energy of the channel extends no further than these limits. In reality, if the transmitter is sufficiently powerful, the signal can be quite strong even beyond the ±22 MHz point. Therefore, given the separation between channels 1, 6, and 11, the signal on any channel could be sufficiently attenuated to minimally interfere with a transmitter on any other channel. Hence the channels 1, 6, and 11 are considered as non-overlapping. If transmitters are closer together than channels 1, 6, and 11 (e.g. 1, 4, 7, and 10), overlap between the channels will probably cause unacceptable degradation of signal quality and throughput [12] [15].

3.4 IEEE 802.11a

The 802.11a standard uses the same core protocol as the original standard, operates in 5 GHz band, and uses 52 subcarriers OFDM with a maximum raw data rate of 54 Mbit/s, which yields realistic net achievable throughput in the mid-20 Mbit/s. The data rate is reduced to 48, 36, 24, 18, 12, 9 then 6 Mbit/s if required. 802.11a has 12 non-overlapping channels, 8 dedicated to indoor and 4 are dedicated to point to point. Four of the 52 subcarriers are designated as pilot tones for correcting residual frequency offset errors that tend to accumulate over symbols. The PHY layer also pre-pends the physical preamble to the data frame, modulates, and codes the data frame at the MAC specified data rate. The physical preamble is used to allow the receiver to detect start of packet transmission and to synchronize to the transmitter's clock. The IEEE 802.11 MAC is primarily responsible for avoiding collisions due to simultaneous transmissions by CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance). The system uses 52 subcarriers that are modulated using BPSK, QPSK, 16QAM or 64QAM. Forward error correction coding (convolutional coding) is used with a coding rate of 1/2, 2/3, or 3/4 [13] [15]. Major specifications for the OFDM are listed in Table 2.

Table 2. Major parameters of the OFDM PHY of IEEE 802.11a [13] [15]

Parameter	*Value*
NSD : Number of data subcarriers	48
NSP : Number of pilot subcarriers	4
NS : Number of subcarriers, total	52 = (NSD + NSP)
ΔF : Subcarriers frequency spacing	0.3125 MHz (=20MHz/64)
TFFT : IFFT/FFT period	3.2 μs (1/ΔF)
TS : Duration of the SIGNAL BPSK-OFDM symbol	4.0 μs (TGI + TFFT)
TGI : GI duration	0.8 μs (TFFT/4)

4. Simulations and analysis

4.1 Simulation Environment

The simulations are designed and implemented using Matlab v6.5. 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. The rand function was used to create a random data stream. 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 statistical multipath channel model called Rayleigh fading channel model. Let the transmit bandpass signal be $x(t) = \Re\left\{x_b(t)e^{j2\pi f_c t}\right\}$, where $x_b(t)$ is the baseband signal, f_c is the carrier frequency and t is the time. In a multipath environment, the transmit signal reaches the receiver through multiple paths where the n^{th} path has an attenuation $\alpha_n(t)$ and delay $\tau_n(t)$. The received signal is, $r(t) = \sum_n \alpha_n(t)x[t - \tau_n(t)]$ Plugging in the equation for transmit baseband signal from the above equation,

$$r(t) = \Re\left\{\sum_n \alpha_n(t)x_b[t - \tau_n(t)]e^{j2\pi f_c[t - \tau_n(t)]}\right\} \tag{8}$$

The baseband equivalent of the received signal is,

$$r_b(t) = \sum_n \alpha_n(t)e^{-j2\pi f_c \tau_n(t)}x_b[t - \tau_n(t)] = \sum_n \alpha_n(t)e^{-j\theta_n(t)}x_b[t - \tau_n(t)] \tag{9}$$

where $\theta_n(t)=2\pi f_c\tau_n(t)$ is the phase of the n^{th} path. The impulse response is $h_b(t)=\sum_n \alpha_n(t)e^{-j\theta_n(t)}$.

When there is large number of paths, applying central limit theorem, each path can be modeled as complex Gaussian random variable with time as the variable. This model is called Rayleigh fading channel model, is reasonable for an environment where there are large number of reflectors. Different paths are represented as the taps, each path with a different power gain and a different time delay.

In our simulations the channel coding is not used. Figure 1 illustrates the general block diagram of the transceiver for the CDMA in IEEE 802.11b we used. The input data stream is first mapped into DBPSK and then the output is spread by Barker code. The spread signal is then passed through a matched filter adapted to the rectangular shape of the data; IEEE 802.11b systems utilize raise cosine filter. Finally, the data are sent to the receiver over the channel. The channel consists of a multi-path fading with AWGN; at the receiver the inverse operation is employed.

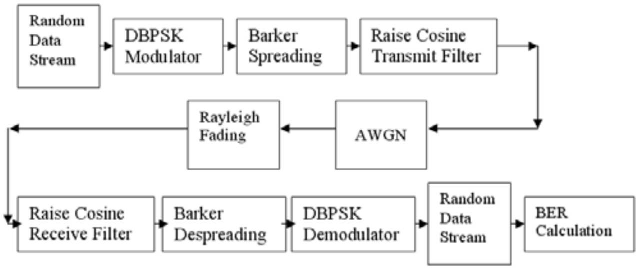

Fig. 1. Simulation Block diagram of the transmitter and receiver for the CDMA in IEEE 802.11b

The transceiver simulation model for the OFDM in IEEE 802.11a is shown in Figure 2. The input data stream is first mapped into BPSK and then the output is converted from serial to parallel into 64 points IFFT to generate the OFDM symbol. The output data from the IFFT is now converted from parallel to serial and a cyclic prefix is added. The data are sent to the receiver over the channel after being converted to a frame structure (serial data stream). The frame structure consists of modulated data and the pilot signal is used for estimation and compensation. The channel consists of a multi-path fading with AWGN; at the receiver the inverse operation is employed. The cyclic prefix is removed and a serial to parallel conversion is done for the signal. A FFT with 64 points is used to convert the signal from time to frequency domain. Then the effective channel is compensated after the OFDM demodulation, the signal de-mapper is used to recover the transmitted signal.

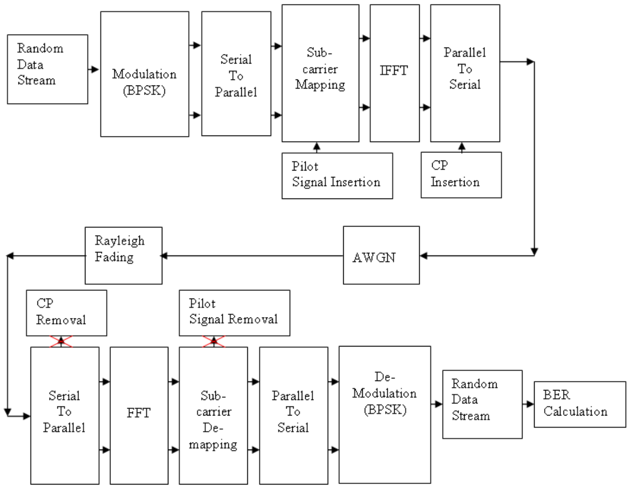

Fig. 2. Simulation Block diagram of the transmitter and receiver for the OFDM in IEEE 802.11a

4.2 Simulation Results

The presented result shows the BER performance as a function of the channel SNR. In log scale the SNR for a given Es/No can be found with:

$$\frac{E_s}{N_0}(dB)=\frac{E_b}{N_0}(dB)+10\log 10\left(\frac{N_s}{N_{FFT}}\right)+10\log 10\left(\frac{T_{FFT}}{T_{FFT}+T_{GI}}\right) \quad (10)$$

Where: N_s, N_{FFT}, T_{GI}, T_{FFT} are illustrated in table 2.

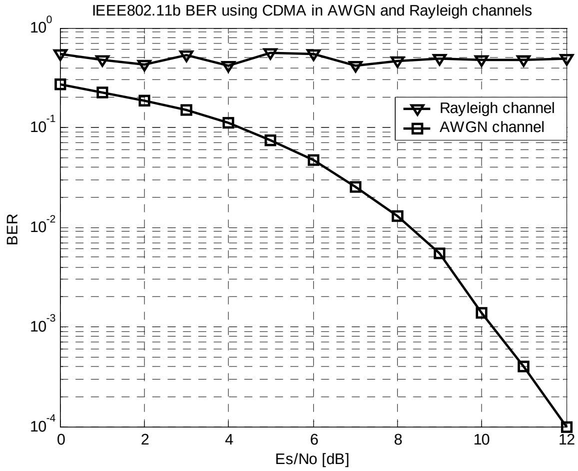

Fig .3: BER vs. Es/No for IEEE 802.11b using CDMA in AWGN and Rayleigh channels

For the first simulation both a simple AWGN channel and multipath Rayleigh fading channel model are presented, the graphs of BER versus Es/No for coherent DBPSK modulation and barker code spreading on a perfectly 802.11b link are shown in figure 3. The graph indicates that the transmission quality is more degraded in the Rayleigh channel when compared with AWGN channel.

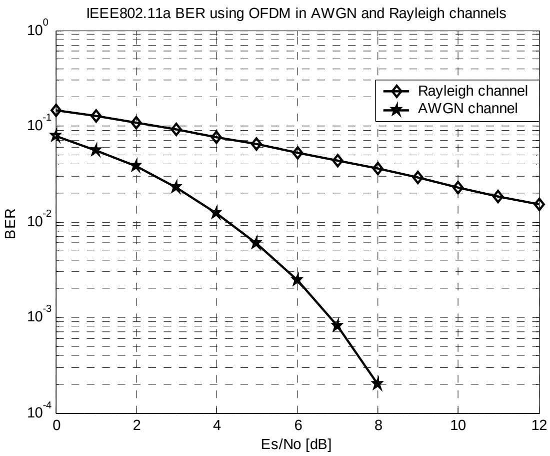

Fig .4: BER vs. Es/No for IEEE 802.11a using OFDM in AWGN and Rayleigh channels

Similarly the graphs of BER vs. Es/No for BPSK in AWGN and multipath Rayleigh fading channels for coherent BPSK modulation in encoded IEEE 802.11a based on OFDM link are shown in figure 4. Also, we note that the transmission quality is degraded in the Rayleigh channel when compared with AWGN channel. But this degradation is not very important like the previous simulation.

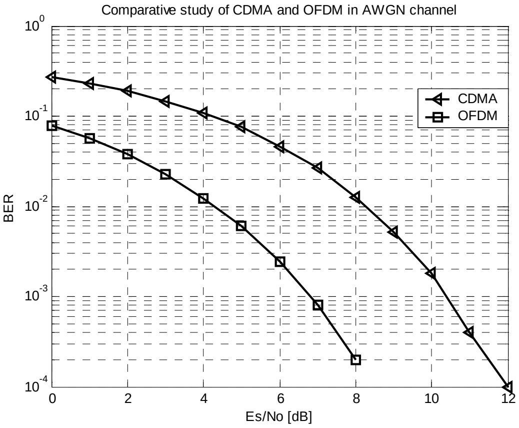

Fig .5: BER vs. Es/No for IEEE 802.11a/b in AWGN channel

By comparing the two techniques CDMA and OFDM, we remark that OFDM modulation represents the best results in AWGN and Rayleigh channels as illustrates in Figure 5 and 6. OFDM is very suitable in multipath environment.

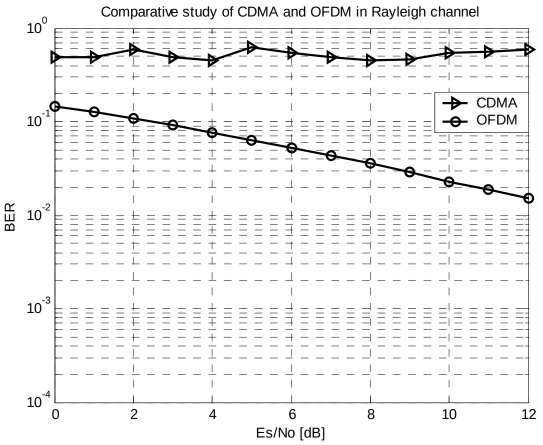

Fig .6: BER vs. Es/No for IEEE 802.11a/b in Rayleigh channel

5. Conclusions

The objective of this work is to investigate the performance of the IEEE.802.11a standard based on OFDM and IEEE.802.11b standard based on CDMA, then to compare them. The simulation results were plotted in terms of BER versus Eb/No for the performance of the two models: CDMA and OFDM considering AWGN and Rayleigh channels. Mainly the BPSK modulation technique was used to see the trade-off between these systems robustness. From the performed simulations, many fundamental results are highlighted. It was found that the OFDM performs the best of CDMA technique. The performances of DS-CDMA are significantly affected in Rayleigh channel.

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