Simulation and Analysis of Wireless Communication Systems using MATLAB

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Abstract:
Wireless communication systems have become an integral part of our daily lives, providing a convenient and efficient way to transmit and receive information. In this paper, we present a comprehensive study of wireless communication systems using MATLAB, a powerful and widely used tool for simulation and analysis. We begin by providing an overview of the different types of wireless communication systems and the challenges they face. The environment allows simulating the baseband processing of systems involving physical layers access techniques such as CDMA, and OFDMA and transmits diversity techniques such as OSTBC and V-BLAST. It is possible to include different modulation techniques, channel coding, multi-channelization, and multiple access techniques. Via the program's user interface, the system performance can be graphically observed through the bit error rate (BER) versus bit energy per noise density (Eb/No) curve. As a means of validation of the tool, the simulations were compared with results published in the literature for SC-CDMA, spatial multiplexing systems, and OFDM systems, finding good correspondence.
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1. Introduction

Wireless communications systems have particular characteristics depending on the access technique used, the bandwidth, the operating frequency, and the use or not of diversity, among other aspects. In the particular case of wireless communications, both 3G (third generation) and 4G (fourth generation) systems are demanding in terms of satisfying high information volume requirements. To achieve this objective, it is essential to make the most of time and bandwidth resources. Media access, spatial multiplexing, and multiple-input multiple-output (MIMO) techniques through the use of multiple transmit and receive antennas play a key role in achieving the capabilities required by 4G systems.

System simulation is an important tool used for the characterization and analysis of processes in different engineering disciplines. This strategy allows research to be done with relatively little equipment and materials and gives the researcher the opportunity to achieve a high level of understanding of the simulated system. With respect to communication systems, new simulation environments are constantly being developed [1–4]. In the context of wireless communications systems, the complexity of access techniques such as CDMA (code division multiple access) requires tools to simulate their behavior, as in [5,6], where a simulator is presented that implements.

different types of modulation for different CDMA systems, using spreading codes such as orthogonal. Moreover, the use of multiple transmitting and receiving antennas offer the possibility to obtain high transmission rates with respect to a single antenna system. In this context, in [7] the performance of the V-BLAST (Bell Labs vertical layer spacetime) spatial multiplexing technique is simulated through the algorithm described in [8,9], for eight transmitting antennas and twelve receiving antennas, improving the spectral efficiency of the system.

In order to achieve efficient spectrum usage in 4G wireless networks, OFDM (orthogonal frequency division multiplexing) is the main alternative to support this type of system. This technology allows the transmission of data on subcarriers at different frequencies, as well as the cancellation of ISI (inter-symbol interference) with the addition of the CP (cyclic prefix). In [10,11], the simulation of an OFDM system under the IEEE 802.16 standard, implementing Matlab®, is presented. Pilot insertion, guard insertion, and cyclic prefix addition are used, and the data source, OFDM modulator/transmitter, multipath channel, OFDM demodulator/receiver, and BER measurement are modeled.

In the context of communications systems, some components can be simulated using the Matlab® communications toolbox. However, to consider more complex systems, programming of additional functions is required. This paper presents a simulation environment under Matlab® for OFDM systems, CDMA systems, systems with V-BLAST spatial multiplexing, and MIMO systems using OSTBC (orthogonal space-time block code). The tool allows the simulation of the baseband process using different modulation, channel coding, multi-channelization, and multiple access techniques. From the user interface or from the Matlab® command window, it is possible to graphically observe the performance of a given system through the BER curve in relation to Eb/No.

2. Development

2.1.Code Division Multiple Access:

CDMA is a digital transmission technology that allows a number of users to access a radio frequency channel by assigning a different code to each user. The capacity of the system will depend on many factors. Each device using CDMA is programmed with a pseudocode, which is used to spread a low-power signal over a wide frequency spectrum. The base station uses the same code to de-spread and reconstruct the original signal. Codes associated with other users remain to spread out, indistinguishable from the background noise.

Within CDMA, there are two widely used families of codes, PN (pseudorandom) codes and orthogonal codes. PN codes are pseudo-random sequences generated by a feedback shift register. The most commonly used is generated by a line shift register. Walsh sequences are the most commonly used orthogonal codes for spectrum spreading and for channel or user separation in W-CDMA systems [12–14].

2.2. Frequency Division Orthogonal Multiplexing

OFDM is a technique that consists of sending modulated information on a set of carriers of different frequencies. OFDM processing is normally performed after passing the signal through a channel encoder to correct errors in the transmission. Due to the technical problem of generating and detecting in continuous time the hundreds of equispaced carriers that form an OFDM word, the modulation and demodulation processes are performed in discrete time using the Inverse Discrete Fourier Transform (IDFT) and Discrete Fourier Transform (DFT) respectively.

In OFDM, the data is distributed over a generally large number of carriers that are spaced in certain frequency ranges. This spacing provides the orthogonality in this technique by allowing each subcarrier to be received without interference from the other subcarriers. A block diagram of an OFDM system is shown in Figure 1. At the transmitter, the signal is defined in the frequency domain. Each OFDM carrier corresponds to an element of the Fourier transform spectrum.

In order to avoid inter-symbolic interference caused by the delayed spread of the multipath channel, a guard interval is introduced. In the receiver, an equalizer is used to correct the amplitude and phase variations introduced by the channel.

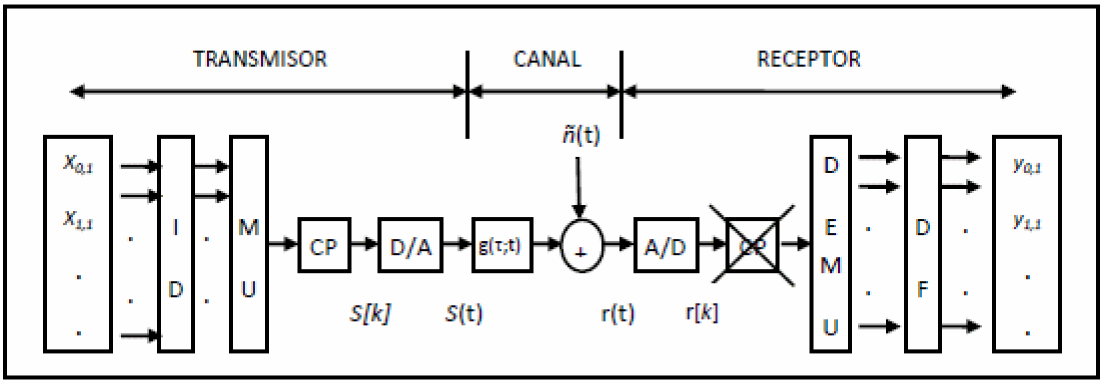

Figure 1. Diagram of an OFDM system.

The guard interval may consist of null information, i.e., no signal. In that case, however, the problem of inter-carrier interference (ICI) may arise. ICI is a type of interference generated by one subcarrier on some other subcarrier. In the presence of ICI, the OFDM signal may lose orthogonality between subcarriers. To avoid both ICI and ISI, the guard interval is obtained by cyclically extending the OFDM word in the guard period [9].

2.3.Spatial multiplexing

Foschini et. al. [15,16] proposed the use of spatial multiplexing using the Bell Labs layered space-time architecture (BLAST) to exploit multiple antenna systems. The objective of the spatial multiplexing technique, unlike space-time coding, is to maximize the transmission rate, i.e. spectral efficiency. In this technique, independent streams of information are transmitted by each antenna, all occupying the same bandwidth and the same time slot. Thanks to the decorrelation between channels produced by the multipath and the knowledge of the channel at the receiver, it is possible to separate the different information flows. Thus, in an M×N system, M-independent symbols are transmitted simultaneously in one symbol period, so the code rate for a unit frame length is M.

3. Methods and materials

As a first step in the established procedure, a review of the Matlab® communications toolbox was carried out. As a result, we obtained a list of available functions that could be used in the project, for example:

- randint: random number generation.
- normrnd: generates vectors or matrices with a normal distribution.
- convenc: convolutional code.

· poly2trellis: generates the trellis structure from the generator polynomial that the convenc function uses to encode.

The systems to be simulated were then defined with their respective block diagrams and flow diagrams: SISO (single input - single output) single carrier, SISO-OFDM, MIMO-OFDM with orthogonal space-time (OSTBC), and space-frequency (OSFBC) codes, SISO-CDMA and V-BLAST. The necessary program code was built for each block of the above-mentioned systems. For the simulation of the radio channel, a C language function was built as a Matlab® executable file to obtain the convolution of the transmitted signal with the impulsive response of the time-varying multipath channel. Subsequently, a user interface was designed to run the program in a user-friendly way.

4. Results and discussions

The simulation environment presented here allows the study of single carrier SISO, SISO-OFDM, SISO-CDMA, V-BLAST, and MIMO-OFDM systems with OSTBC and OSFBC, where the Alamouti code and the ¾ rate sporadic orthogonal code were specifically implemented for four transmit antennas [17–19]. In each of these systems, any of the following modulation schemes can be used: BPSK, QPSK, 8PSK, 16PSK, 16QAM, and 64QAM. Convolutional coding may be included as a channel coding system. As a radio channel, multipath channels defined in the literature or with user-defined power-delay profile (PDP) are considered, with the only limitation that the statistics of each multipath obey the Rayleigh distribution. The additive noise was taken as a blank. In general, results are presented through BER curves as a function of Eb/No, but it is possible to use environment functions to consider other figures of merit. Additionally, an OFDM system design assistant routine is included.

In the following, the results of some simulations carried out with the simulation environment are presented. The purpose of this presentation is to show some of the capabilities and versatility of the built environment. Figure 2 shows the simulation results for a SISO-OFDM system without interleaving and a SISO-OFDM system with interleaving. Better system performance is observed when interleaving is used, noting a decrease in BER. The simulation has been performed with a correlated channel (using a Doppler filter) with a fading depth measured in a number of channel samples (100 samples for a 100-bit interleaving). The interleaving depth is calculated as the product of the fading depth and the number of bits per symbol. In this case, the number of bits per symbol is equal to one for BPSK modulation.

The implementation of orthogonal block codes in Matlab was done with both OSTBC and OSFBC. In case two transmitting antennas are used with the Alamouti space-time code, two simultaneous signals are transmitted from two antennas in one symbol period, in the next symbol period the same two signals are transmitted but coded. The coding can also be done in space frequency but instead of two adjacent symbol periods, two adjacent subcarriers would be used [20–22]. In space-time coding, the channel remains constant over two-time slots, whereas in space-frequency coding, the channel is constant over two successive subcarriers. Figure 3 shows the simulation results for both systems using the Alamouti code. The same BER curve with respect to Eb/No is observed for both types of orthogonal coding in the presence of a flat channel.

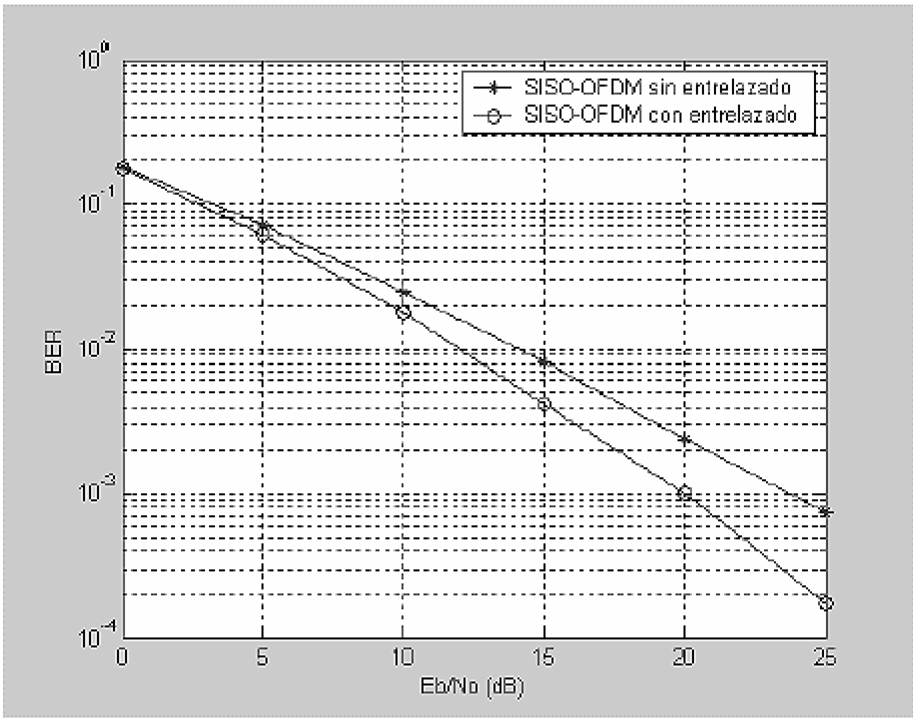

Figure 2. Performance of a non-interleaved SISO-OFDM system and an interleaved SISO-OFDM system

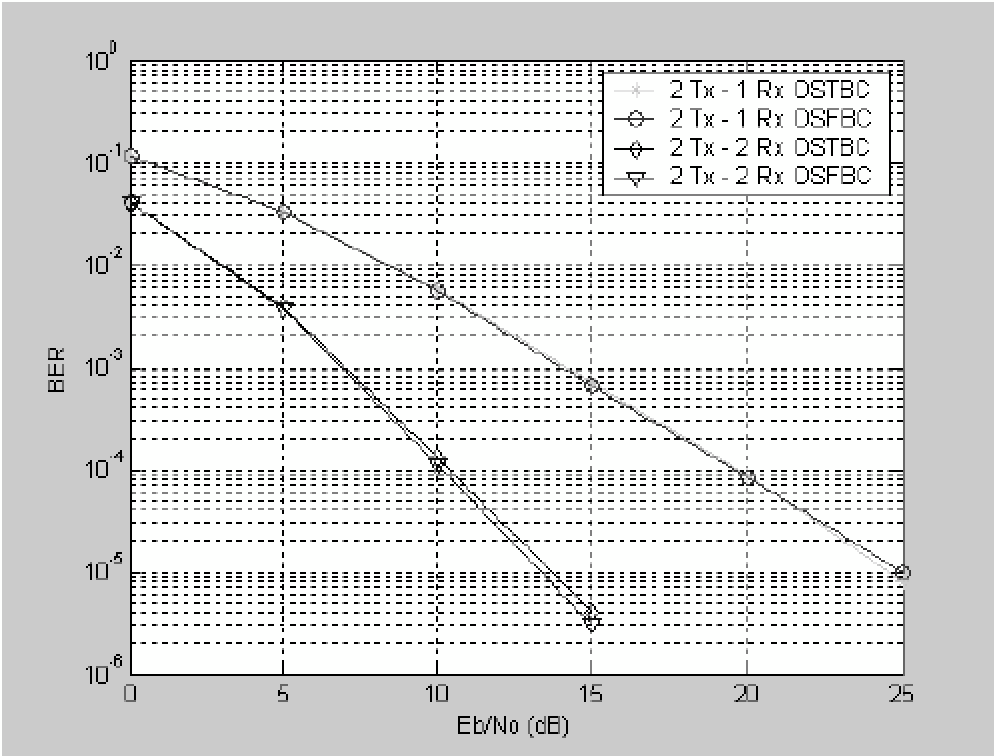

Figure 3. Performance of MISO and MIMO systems with OSTBC and OSFBC Alamouti

Figure 4 shows the performance of a SISO-OFDM system for different cyclic prefix lengths, a CDMA system using a RAKE receiver with PN or orthogonal codes, and a V-BLAST system with detection through successive interference cancellation with forcing to zero. The channel used for the simulation presented in this figure was an SUI type IV from [16,23,24] with a τrms (delay spread) of 1257 ns, typical of outdoor environments. In the case of OFDM systems, it can be seen that the BER increases with decreasing CP length, due to the introduction of ISI. Results are also shown for a SISO-CDMA system using orthogonal or pseudo-random spreading codes, as well as a RAKE receiver, in the presence of eight users. The variation in performance when using different types of spreading codes can be observed. Additionally, results can be observed for a V-BLAST system with two transmit antennas and four receiving antennas.

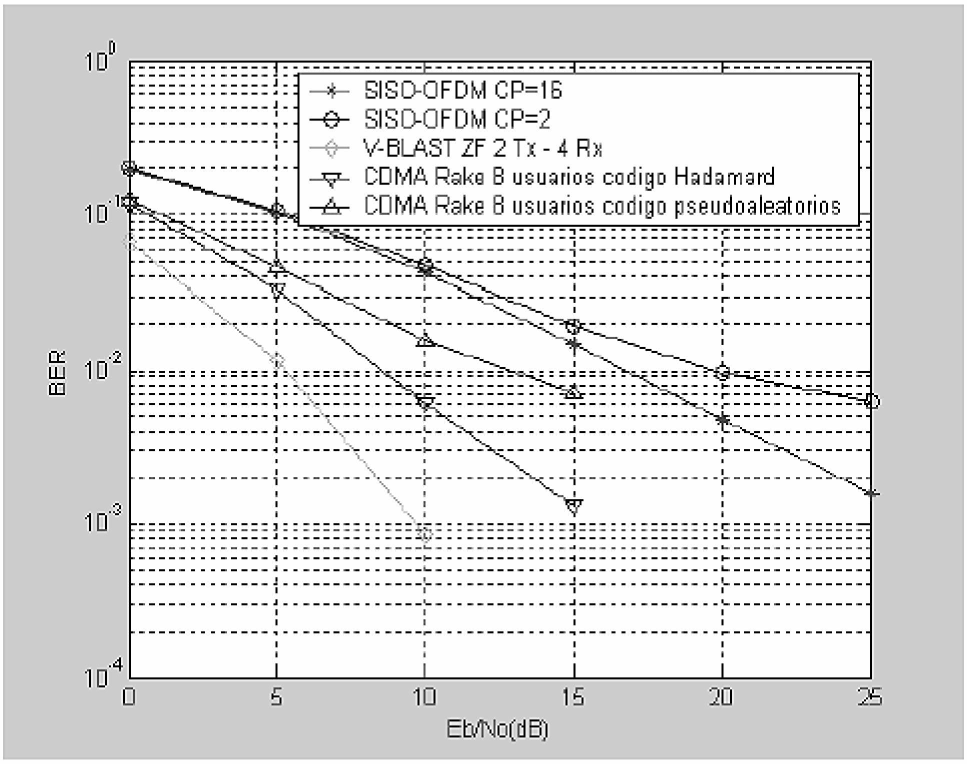

Figure 4. Performance of different types of systems.

5. Conclusions

- A simulation environment for wireless, multi-carrier, or single-carrier communications systems with one or more transmitting or receiving antennas was built, which allows the simulation of modulation, access, and diversity techniques widely used today.
- Using this tool, it is possible to simulate single-carrier SISO, SISO-CDMA, SISO-OFDM, MIMO-OFDM, and V-BLAST systems, taking the bit-error rate as the figure of merit.
- El entorno de simulación se desarrolló bajo Matlab® y puede ser utilizado en forma de comandos desde la línea de comandos de Matlab® o desde una interfaz de usuario.

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