# Towards a Comprehensive Comparison of OFDM and CDMA techniques

DIMITRIOS A. KARRAS
Sterea Hellas Institute of Technology, Automation Dept, Psachna, Evoia, 34400, GREECE,
dakarras@teiste.gr, dimitrios.karras@gmail.com, dimitrios.karras@ieee.org

*Abstract:* - It is known that OFDM and CDMA modulation techniques are used in modern wireless communication networks as important modules of the relevant transmitters and receivers. There are several reports in the literature comparing these techniques in different conditions and simulation setups making quite difficult the overall cross-comparison. The goal of this paper is to analyze modelling and simulation requirements of these techniques and develop a unified MATLAB platform in order to make possible their comparison as modules of different communication systems. Some results of this educational oriented preliminary simulation system are herein presented concerning the BER performance of these algorithms involving different number of users.

*Key-Words:* - OFDM, CDMA, comparison of modulation techniques, MATLAB, BER Performance

## 1 Introduction

The field of wireless communications has witnessed revolutionary technology developments during last decades.

While previously there existed only 2G GSM, 2.5G (GPRS). 2.75G (EDGE) etc. based communication systems, which supported a data rate of around 10 Kbps and up to 384Kbps (downlink for EDGE), several radical wireless technologies have been developed in the last 15 years to enable broadband wireless access with rates in excess of 100 Mbps. These have subsequently led to the development of 3G and 4G wireless technologies such as HSDPA (High Speed Downlink Packet Access), LTE (Long Term Evolution) and WiMAX (Worldwide Interoperability for Microwave Access).

This has been made possible through breakthrough wireless technologies such as Code Division for Multiple Access (CDMA), Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input Multiple Output (MIMO). These techniques form the basis of understanding the world of 3G/4G wireless communication systems as well as that of the newest 5G. [1-6]

The background of these technologies is that they are Multiple Access communication schemes. There are three common such technologies used by mobile communication networks for transmitting information. These are:

- Frequency Division Multiple Access (FDMA),
- Time Division Multiple Access (TDMA),
- Code Division Multiple Access (CDMA).

These three technologies can be represented graphically in figure 1 below:

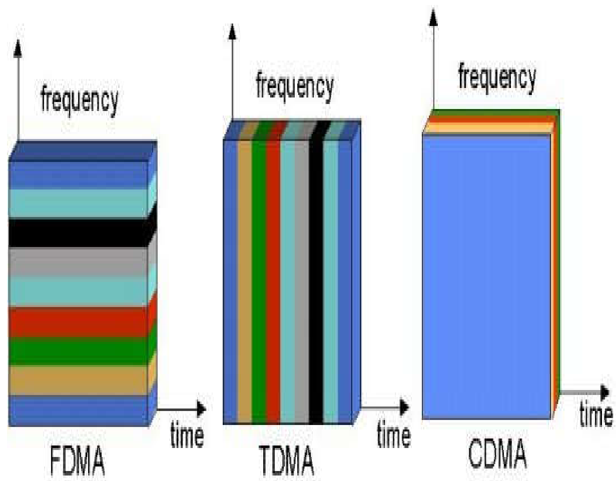



**Fig.1** The basic Multiple Access Techniques for Wireless Communications

- FDMA puts each call on a separate frequency.
- TDMA assigns each call a certain portion of time on a designated frequency.
- CDMA gives a unique code to each call and spreads it over the available frequencies. [1-6]

### 1.1 Frequency Division Multiple Access (FDMA)

In FDMA, the available bandwidth is divided into a number of frequency non-overlapping subchannels, one channel per carrier at a time. The available channels are assigned on demand, on first come first serve basis. As shown in Figure 2 below each frequency subchannel carries one single call at any one time in continuous form. The bandwidth for each channel is usually small about 25-30 kHz or less (i.e. narrowband). The rates are not very high (approximately 25 kbits per second) which results in a symbol duration time of 40 microseconds, if one bit per symbol is required. A few overhead bits need to be inserted in the bit stream to allow synchronisation, framing and other control functions. The number of channels available is simply obtained by dividing the available bandwidth between the bandwidth needed for each channel.

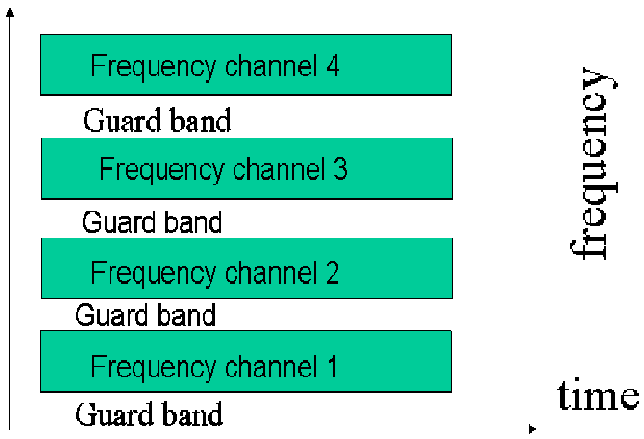



**Fig.2** FDMA principle of dividing the spectrum

Some advantages provided by this multiple access technique are [1-6]:

• No equalisation is needed because the delay spread of the symbol is smaller than the long symbol duration. This results in a reduced system cost.
• The system is flexible and can be easily adapted to handle both large rural cells and small urban cells.
• Very low overhead bits are needed.
On the other hand, some disadvantages emerge [1-6]:
• The real limitation is the need to use bandpass filters, both, in the transmitter and the receiver.
• The maximum bit rate per channel is fixed at a low value.
• More equipment is required for the same amount of trunks than with other methods.

Nowadays OFDM is the prevalent FDMA technique.

### 1.2 Time Division Multiple Access (TDMA)

In Time Division Multiple Access (TDMA), each frequency carrier is divided into several individual channels where the division and the assignment of the circuits are done according to time. In Figure 3 below it is shown how a frame or period of time is divided into a number, N, of non-overlapping subintervals, called time slots. If the frame duration is T, each slot will have a period of T/N in each frame. Each radio channel carries a number of trunk circuits (slots), which are time division multiplexed (multiple circuits per carrier). The channel assignment is established through the control or signalling channels by the base stations, which assign the frequency and time slot to be used by the mobiles.

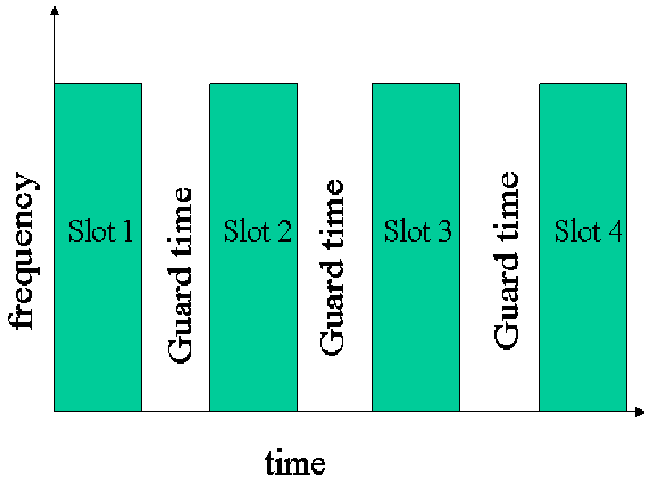



**Fig. 3** TDMA principle

The bandwidth usage can be narrowband, about 20-30 kHz, or wideband (approximately ten times greater), and is determined by the system designer based on the modulation scheme used. The channel transmission rate is no longer equal to the coding rate or even the coding plus the overhead rate. The channel rate is faster by a factor equal to the number of slots in a frame, which is the period of time between two slots from the same channel. The transmission is not continuous, in bursts. This has implications for circuit design and system control. Synchronisation must be acquired on every burst, used to separate one slot from another.

Some advantages provided by this multiple access technique are:

• Flexible bit rates are possible. Multiples and submultiples of the standard bit rate per channel can be made available to users. Bandwidth can be supplied on demand.

• It offers the opportunity of frame by frame monitoring of the signal strength and bit error rate to enable either base stations or mobiles to initiate handoffs. The handoffs or other signalling procedures can be carried out during idle slots, when there is no transmission.
• It is very adaptable to technological change.
• It provides more trunks compared to FDMA for the same equipment. A shared system leads to a reduction in cost.
On the other hand, there are some disadvantages:
• On the uplink (mobile to base station), TDMA requires high peak power in the transmit mode. This is a particular problem for hand held portables with limited battery life.
• Adaptive equalisation is usually necessary in TDMA systems, since the transmission rates are generally very high when compared to FDMA channels and intersymbol interference appears.
• TDMA requires a significant amount of signal processing to realise the full potential of digital transmission. This increases power consumption and also introduces delay.

## 1.3 Code Division Multiple Access (CDMA)

Code Division Multiple Access is a Spread Spectrum technique that permits its transmitters to use the complete available bandwidth or frequency all the time. This can be seen in Figure 4 below.

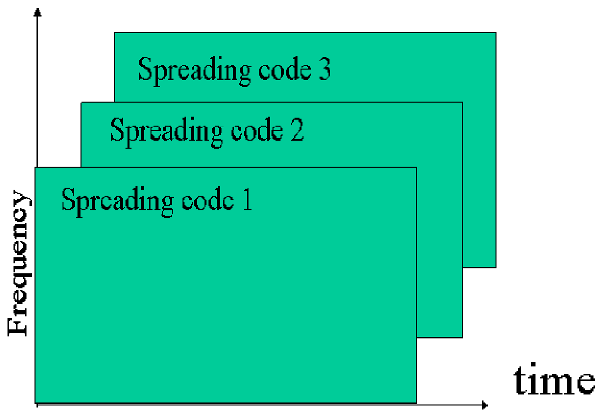



**Fig. 4** CDMA principle

These technologies can be separated in narrowband and wideband systems, depending on how the available bandwidth is allocated to the users. All the users share the same channel at once and their signals appear as additive interference to others. It is called a spread spectrum system because a user occupies a much wider frequency band that it is actually needed.

CDMA has some features that are listed below:

- Many users of a CDMA system share the same frequency.
- Unlike TDMA or FDMA, CDMA has a soft capacity limit. Increasing the number of users in a CDMA system raises the noise floor in a linear manner. Thus, there is no absolute limit on the number of users in CDMA. Rather, the system performance gradually degrades for all users as the number of users is increased. And improves as the number of users is decreased.
- Multipath fading may be substantially reduced because the signal is spread over a large spectrum. If the spread spectrum bandwidth is greater than the coherent bandwidth of the channel, the inherent frequency diversity will mitigate the effects of small-scale fading.
- Channel data rates are very high in CDMA systems. Consequently, the symbol (chip) duration is very short and usually much less than the channel delay spread.

## 1.4 Advantages of Code Division Multiple Access

CDMA offers some exceptional advantages:

- *Privacy*
  When the code for a particular user group is only distributed among authorized users, the CDMA process provides communication privacy, since the transmission cannot easily be intercepted by unauthorized users without the code.
- *Fading channels*
  If a particular portion of the spectrum is characterized by fading, signals in that frequency range are attenuated. In an FDMA scheme, a user who was unfortunate enough to be assigned to the fading position of the spectrum might experience highly degraded communications for as long as the fading persists. However, in an FH-CDMA scheme, only during the time a user hops into the affected portion of the spectrum will experience degradation. Therefore, with CDMA, such degradation is shared among all the users.
- *Jam resistance*
  During a given CDMA hop, the signal bandwidth is identical to the bandwidth of conventional MFSK, which is typically equal to the minimum bandwidth necessary to transmit the MFSK symbol. However, over a duration of many time slots, the system will

hop over a frequency band which is much wider than the data bandwidth.

- *Flexibility*
  The most important advantage of CDMA schemes, compared to TDMA, is that there need be no precise time coordination among the various simulations transmitters. The orthogonality between user transmissions on different codes is not affected by transmission-time variations.

## 2 The Need for an OFDM/CDMA Unified Testbed for Algorithm Evaluation

A wide range of advanced signal processing algorithms and system configurations are available for designing a future mobile communication network based on OFDM or CDMA which are the most prevalent modulation subsystems in nowadays wireless communications. The simulation testbed allows the evaluation of the design choices in systems based on mobile communication networks. Other variables such as the properties of the channel are affected by environmental factors. A complete algorithmic evaluation needs to consider all such factors. The simulation testbed is envisioned to have the following capabilities:

- ✓ **A comprehensive method of algorithm evaluation**
  The typical method of evaluating a new algorithm, by doing a localized simulation, does not provide accurate insights into the algorithm behaviour in a real system. The OFDM/CDMA wireless testbed aims at providing an environment, which models all facets of a real wireless system and provides a complete picture of system behaviour with various algorithms.
- ✓ **Algorithm trade-off issues**
  The algorithmic choices for each block differ in the computational complexity and in the resulting performance.
- ✓ **Generation and analysis of performance indicators**
  At this stage long bit-streams are passed through the simulated communication system and the errors in the received bit-stream are counted. The bits are grouped into frames, the exact specification of which depends on the standards that are being used. The performance of the system is quantified using the average bit error rate (BER).

## 3 An Analysis of OFDM and CDMA Tx/Rx Subsystems

### 3.1 A brief Description of Orthogonal Frequency Division Multiplexing modulation (OFDM)

When doing radio transmission on high frequencies (VHF and higher) we are often confronted to a multipath environment. Such environment are found mostly in urban areas where buildings reflects waves.

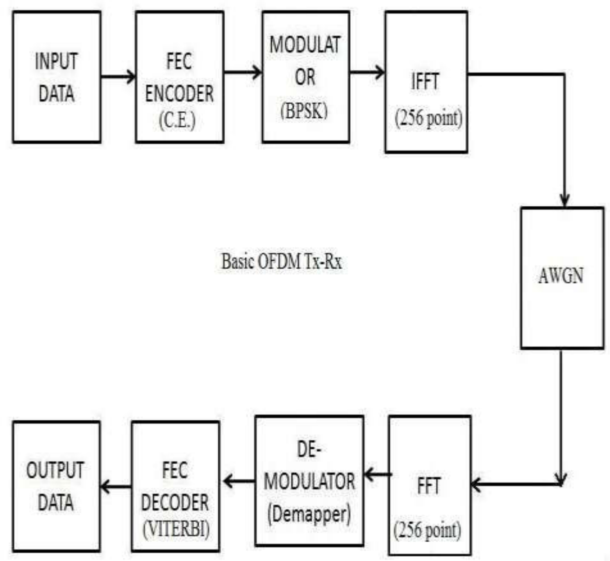



**Fig.5** The block diagram of an OFDM transmission subsystem

Implementation of OFDM modulation nowadays is almost everytime performed digitally.
In fig.6 below a model of an OFDM transmission system is presented based on the following concepts and techniques

- Data coming from the input are arranged into vectors with number of components equal to the number of carriers. Each component is composed by a number of bits depending on the alphabet of the modulation scheme used on the next stage. For example, if we use a 1536 carriers system with BPSK, we'll have vectors of 1536 component each one composed by 1 bit (BPSK is 2-ary).

- Each component (group of bits) is mapped into a complex symbol depending on the alphabet of the modulation scheme used. For example, with BPSK the alphabet is { -1 ; +1 }.

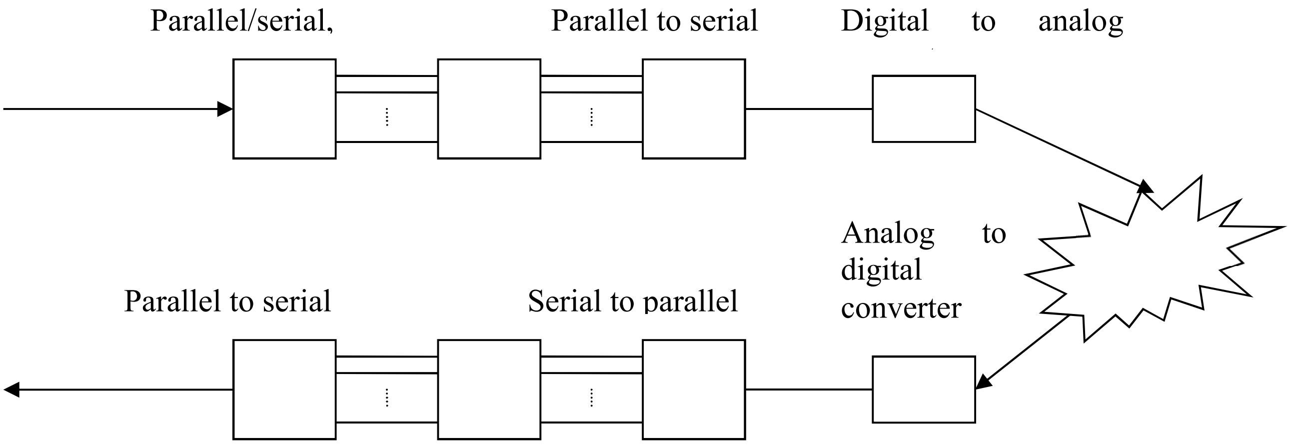



**Fig.6** Modules of an OFDM transmission subsystem

- In order to obtain real samples after IFFT, a 2*Number of carrier points IFFT is done applying the following formulae

$$X_{N-k} = X_k^*, k = 1,..., \tilde{N} - 1$$
$$X_0 = Re(X_0), X_{\tilde{N}} = \mathrm{Im}(X_0)$$

* The Inverse Fast Fourier Transform algorithm (IFFT) is applied to the vector giving a real samples vector.
* The guard interval is added at the beginning of the vector by repeating the components of the end. Vectors are concatenated to form a time signal (parallel/serial conversion)
* Windowing the signal is necessary to limit the bandwidth. Most used window is the raised cosine.
* The signal is then passed trough the channel. Channel is modeled by a linear system with frequency response c(t) together with a source of additive Gaussian noise.
* At the reception, signal is rearranged again into vectors (serial/parallel conversion) and guard interval is dropped.
* Fast Fourier Transform (FFT) is computed in order to get back the complex vector of symbols.

### 3.2 A brief Description of Code Division Multiple Access (CDMA)

As it was mentioned before in CDMA each user is assigned a unique code sequence that he or she uses to encode his or hers information signal. The receiver, knowing the code sequences of the user, decodes the received signal after reception and recovers the original data. Because the bandwidth of the code signal is chosen to be much larger than the bandwidth of the information signal, the encoding process enlarges the spectrum of the signal and therefore also known as spread- spectrum (SS) modulation. The resulting encoded signal is also known an SS signal.

For a technique to be classified as an SS modulation technique, two criteria must be met:

1. The transmission bandwidth must be much larger than the information bandwidth.
2. The resulting radio-frequency bandwidth must be determined by a function other than the information being sent. This excludes such modulation techniques as FM and PM.

SS modulation transforms an information signal into a transmission signal with a much larger bandwidth. This transformation is achieved by encoding the information signal with a code signal that is independent of the data and has a much larger spectral width than that of the data signal. This encoding spreads the original signal power over a much broader bandwidth, which results in a low power density. The ratio of the transmitted bandwidth to the information bandwidth is called a processing gain $G_p$ of the SS system,

$$G_p = \frac{B_t}{B_i}$$

Where $B_t$ is the transmission bandwidth and $B_i$ is the bandwidth of the information signal.

Below is the block diagram of a CDMA Tx/Rx system

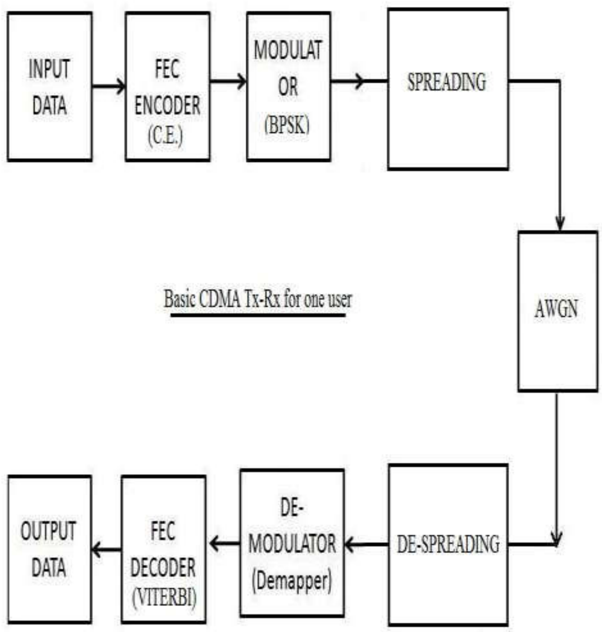
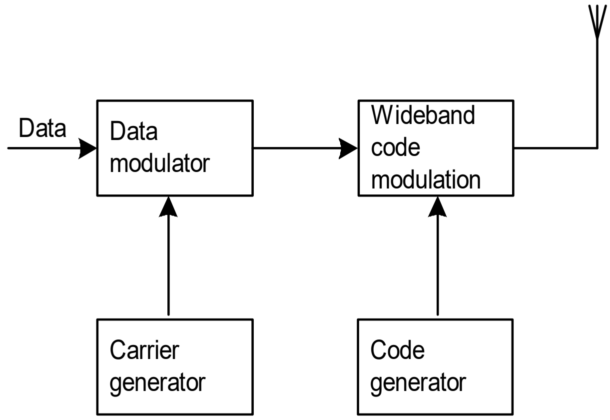


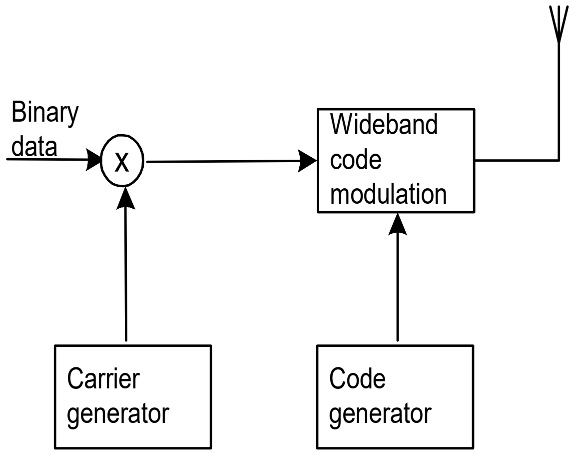

**Fig.7** The block diagram of CDMA Tx/Rx subsystem

**Direct Sequence CDMA**

In the DS-CDMA protocols, the modulated information signal (the data signal) is directly modulated by a digital code signal. The data signal can be either an analogue or a digital signal. In most cases, it is digital. In the case of a digital signal, the data modulation is often omitted, the data signal is directly multiplied by the code signal, the resulting signal modulates the wideband carrier. It is from the direct multiplication that the DS-CDMA protocol gets its name. A block diagram of a DS-CDMA transmitter is shown below:




The binary data signal modulates an RF carrier. The modulated carrier is then modulated by the code signal. The code signal consists of a number of code bits called "chips" that can be either +1 or -1. To obtain the desired spreading of the signal, the chip rate of the code signal must be much higher than the chip rate of the information signal. For the code modulation, various modulation techniques can be used, but forms of PSK, such as BPSK, or MSK are employed. If we omit the data modulation and use BPSK for the code modulation, we get the block diagram shown in the Figure below:




After transmission of the signal, the receiver that uses coherent demodulation to despread the SS signal by using a locally generated code sequence. To be able to perform the despreading operation, the receiver must not only know the code sequence used to spread the signal, but also synchronize the codes of the received signal and the locally generated code. This synchronization/tracking block performs this operation. After despreading a data modulated signal is generated and after demodulation, the original data can be recovered.

**DS-CDMA Properties**

The important properties of SS signal of CDMA point of view are the multiple access capability, multipath interference rejection, and the narrowband interference rejection are listed and discussed below:

- Multiple access: If multiple users use the same channel at the same time, there will be multiple DS signals overlapping in time and frequency. At the receiver, coherent demodulation is used to remove the code modulation. This operation concentrates the power of the desired user in the information bandwidth. If the cross-correlation between the code of the desired user and the code of the interfering user is small, coherent detection will put only a small part of the power of the interfering signals in the information bandwidth.
- Multipath interference: If the code sequence has an ideal autocorrelation function, then the correlation function is zero outside the interval [$-T_c$, $T_c$] where $T_c$ is the chip duration. This means that if the desired signal and the copied signal that is delayed for more than 2 $T_c$ are received, coherent demodulation will treat the delayed signal as an interfering signal, only a small part of the power of this signal in the information bandwidth.
- Narrowband interference: The coherent detection at the receiver involves a multiplication of the received signal by a locally generated code sequence. As it was shown at the transmitter, multiplying a narrowband signal by a wideband code sequence spreads the spectrum of the narrowband signal so that its power in the information bandwidth decreases by a factor equal to the processing gain.

**Generation of a spreading code**

In CDMA systems, the choice of the type of code sequence is important with respect to the resistance against both multipath interference and multiuser interference. To overcome the interference, several requirements must be satisfied:

1. Each code sequence generated from a set of code-generation functions must be periodic with a constant length.

2. Each code sequence generated from a set of code-generation functions must be easy to distinguish from its time-shifted code.

3. Each code sequence generated from a set of code-generation functions must be easy to distinguish from other code sequences.

The first and second requirements are important with respect to the multipath propagation effects that occur in mobile outdoor and indoor radio environments. The third requirement is important with respect to the multiple access capability of communications systems. To measure the distinction level of the codes for requirements (1) and (2), an autocorrelation function and a cross-correlation function are used, respectively. The autocorrelation function is used to measure the distinction level, and it is defined as follows:

**M-Sequence**

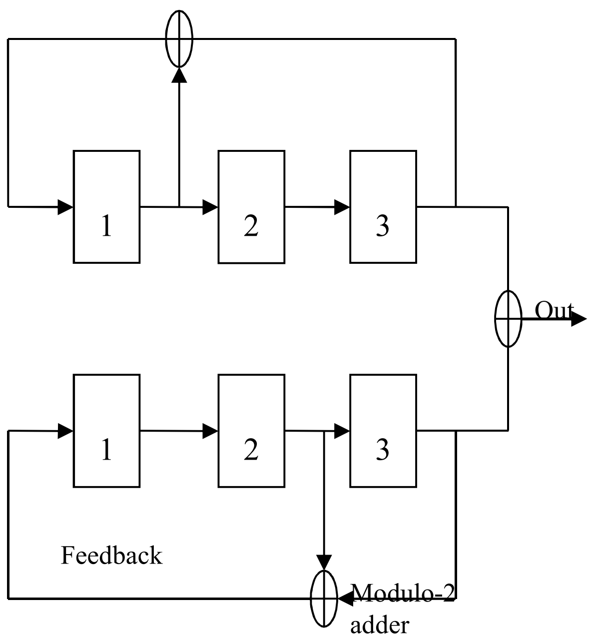
M-sequences are generated by a single LSR. In particular, a sequence with the maximum possible period, ($N_c = 2^n - 1$), is generated by an *n*-stage binary shift register with linear feedback. To generate an M-sequence, the generator polynomial must be a generation polynomial of degree *n*. Thus the periodic autocorrelation function of an M-sequence is given by

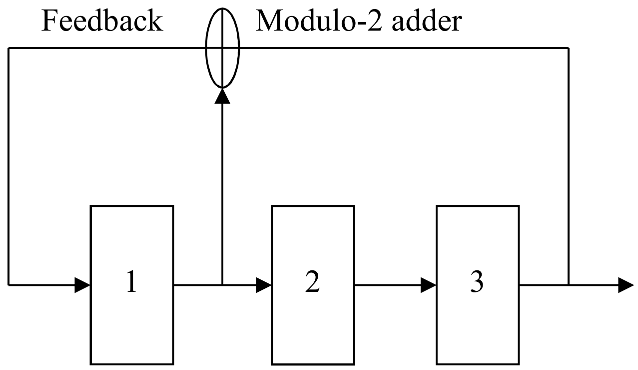
$$r_{xx}(t) = \begin{cases} 1, t = 0 \bmod N_c \\ -1/N_c, otherwise \end{cases}$$

If $n \neq 0$ mod 4, there exist pairs of maximum length sequences with a three-valued cross-correlation function, where the two values are $\{-t(n), t(n) - 2\}$ with

$$t(n) = \begin{cases} 1 + 2^{(n+1)/2}, n : odd \\ 1 + 2^{(n+2)/2}, n : even \end{cases}$$

The function to generate M-sequences is programmed as mseq.m. The number of registers, the initial values of the registers, and the position of the feedback taps are given as arguments of mseq.m.




**Gold Sequence**

The M-sequence has good autocorrelation characteristics. However, the number of mobile communications systems that use the M-sequence as a function is very small. This is because the number of M-sequences that have the same code length and the same correlation characteristics is limited. When a CDMA system where many users communicate to each other is realized, many different codes are needed that have the same correlation value.

**Orthogonal Gold Sequence**

The Gold sequence has many different codes compared to those of the M-Sequence. However, there are several problems associated with the Gold sequence:

- The proportion of 0 and 1 is not always balanced
- The cross-correlation value of the Gold sequence is not 0 in a synchronized environment.
- The code length is an odd number. As a result a special clock is needed to generate the gold sequence.

To solve the problems, one chip is added to the Gold sequence to balance the proportion of 0 and 1. This sequence is called an Orthogonal Gold sequence. The cross-correlation value of the orthogonal Gold sequence is 0 at the synchronous point. At other points, the characteristics of the sequence are similar to those of Gold sequence.

## 4 Experimental Evaluation

**System Construction**

In order for a simulation testbed to be created in Matlab an M-file has to be written. The M-files contain all the necessary information that is needed so that the main program to work properly, in this case ofdm-dscdmaTestbed.m. As it can be seen in Appendixes a lot of m-files were needed that helped to generate the ofdm-dscdmaTestbed.m file as this file recalls them at the time of its simulation. The number of users had to be increased and then to check the Bit Error Rate performance by creating a graph. At this point the maximum number of users was 50 and having made the appropriate calculations this number has been increased to 800. There were some difficulties as far as the increment of the users. When trying to apply for 1000 or 2000 a message appeared in Matlab's main window, proposing to see 'help Memory' file, probably due to a limited memory old PC with Windows 7 we had at our disposal.

**Graphical User Interface Development Environment (GUIDE)**

GUIDE is MATLAB Graphical User Interface development environment which provides a set of tools for creating graphical user interfaces (GUIs). These tools simplify the process of designing and building GUIs. It is easy to layout the GUI as by dragging or clicking the appropriate components (panels, buttons, text fields, sliders, and menus) into the layout area. This way the Graphical part of the GUI is completed and has the form that is required. Matlab automatically generates an M-file that controls how the GUI operates. The M-file initializes the GUI and contains a framework for all the GUI callbacks, the commands that are executed when a user clicks a GUI component. Using the M-file editor, the necessary coding to the callbacks has to be done in order to perform the functions that we desire.

Having implemented the graphical part the result is shown in Figure 8

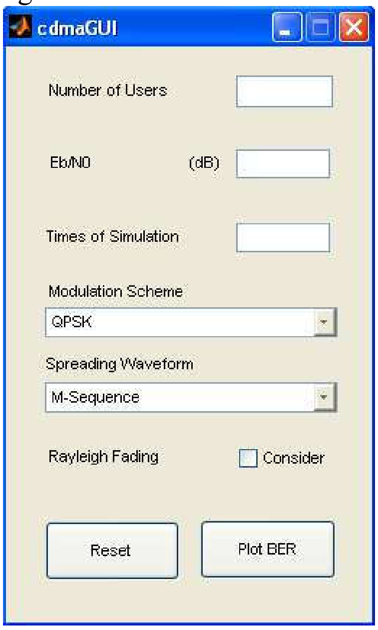



**Fig. 8** The main GUI unit

The creation of such a system is very useful as it can be used as an educational tool for simulating OFDM/CDMA methodologies. All the parameters can be changed as in the first three boxes the user of this system can be completed with the desired one. For the Modulation Scheme and the spreading waveform there is a selection of choices.

## Changing Parameters

In this program there are some parameters that can be changed in order to check the system's error performance under different conditions. The parameters, as easily understood are not the same for OFDM and DS-CDMA herein involved. The parameters that can be changed are specific as the number of users that can vary from 1 to N, and the type of sequence also, M-sequence, Gold and Orthogonal Gold, as it is shown below in the case of DS-CDMA.

In order to check how the systems performance varies using different number of users, each time this number has to be changed with the desired one, changing also the number of simulation times.

By pressing enter the program is running and in the command window appear all the BER results. In the last line, there is a four number display; these numbers, from left to right, represent the Eb/N0 level of 7 dB, the number of total errors (noe), the number of transmitted data (nod), and the average BER result of all these results.

The BER performance graph is appeared in a separate window representing the BER result for these specified system parameters. Every time that runs ofdm-dscdmaTestbed, only one single point in the graph is represented, as it appears in the next figure..

The complete BER performance graphs that are depicted later on are obtained by recording one BER value for different Eb/N0 level, between the range of 0 to 25dB. So the BER performance in an AWGN environment of a synchronous DS-CDMA system is simulated and the results are shown in figures 9-21.

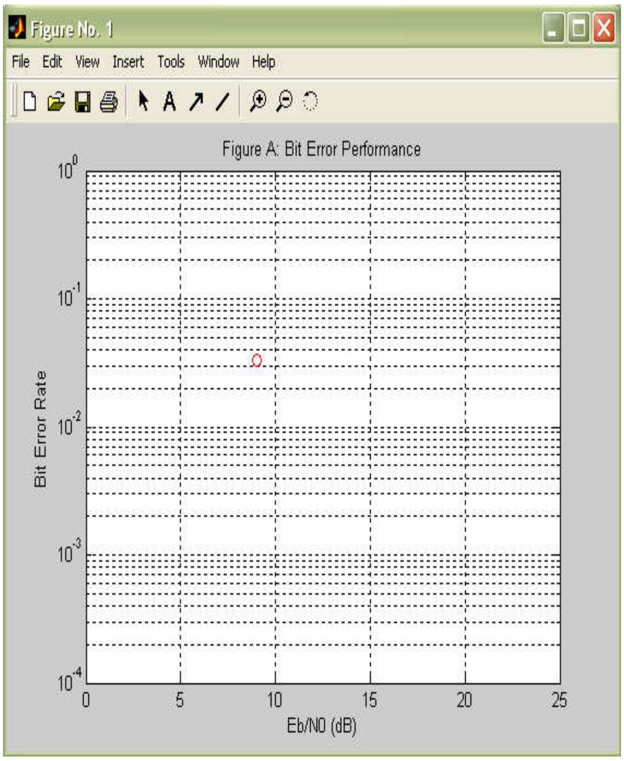



**Fig.9** The bit error rate performance graph

### ❖ Using M-Sequence

These set of values in an AWGN environment, use the M-sequence as spreading code, for both QPSK and QAM modulation schemes. The number of users sampled in order to complete and compare the BER performance graphs, is 1, 3, 5 and 7 users.

In the M-sequence, the cross-correlation value is not 0 at the synchronized point. Therefore, this nonzero correlation becomes interference for the others users. As a result, as the number of users increases, the BER degrades. The BER graphs are depicted in the next page for the QPSK and 16-QAM modulation scheme and for M-sequence spreading code.

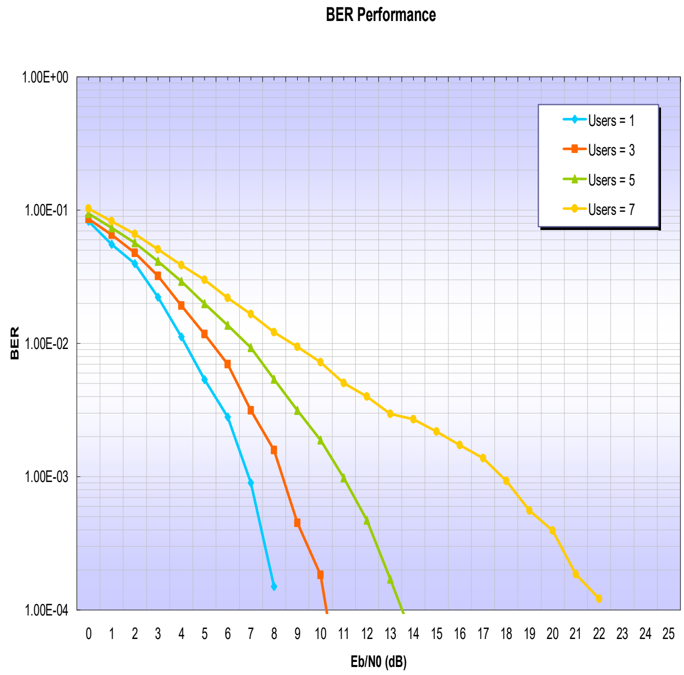



**Figure 10:** BER performance of DS-CDMA with M-sequence for QPSK scheme in an AWGN environment.

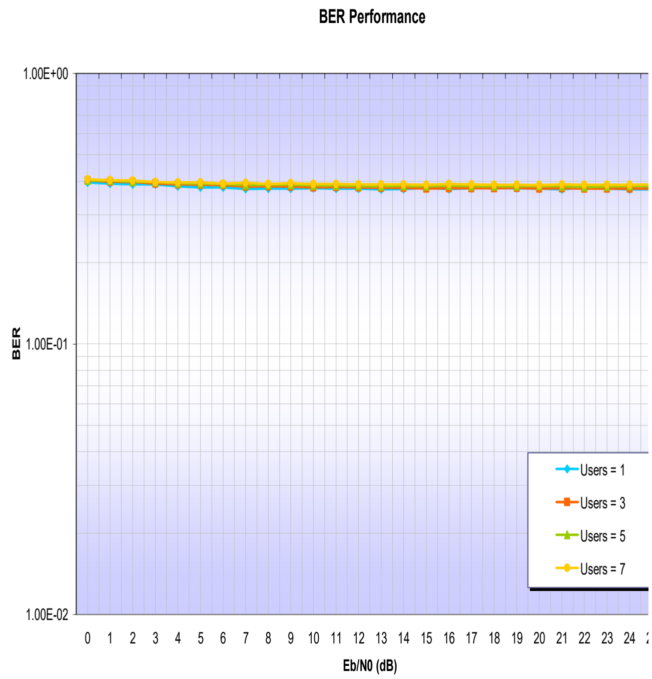



**Figure 11:** BER performance of DS-CDMA with M-sequence for 16-QAM scheme in an AWGN environment.

## ❖ Using Gold Sequence

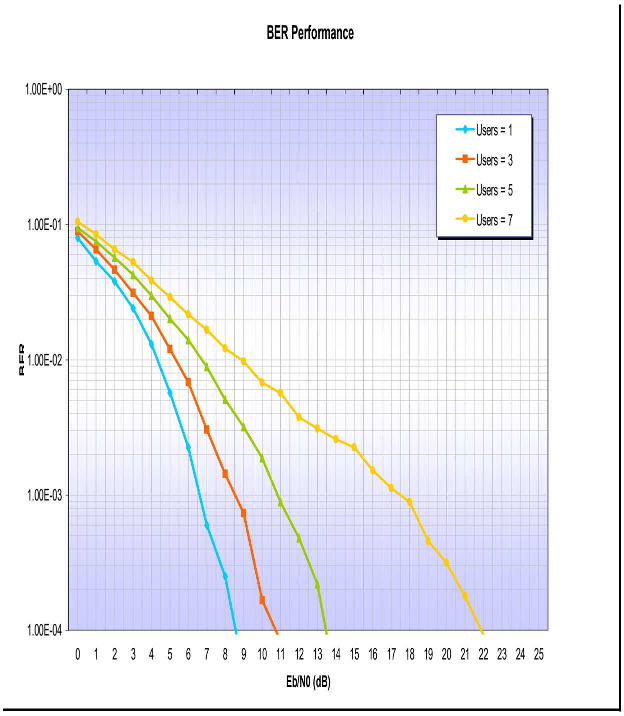



**Figure 12:** BER performance of the DS-CDMA system using Gold sequence, QPSK modulation scheme in an AWGN environment.

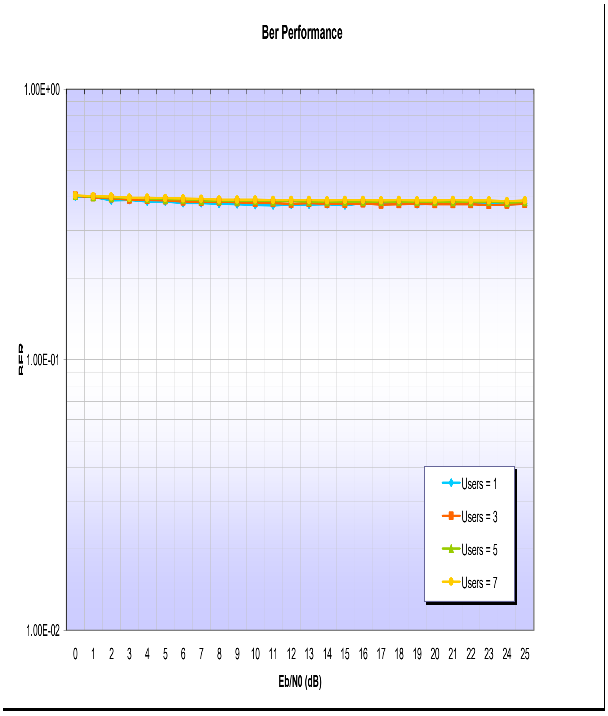



**Figure 13:** BER performance of the DS-CDMA system using Gold sequence, 16-QAM modulation scheme in an AWGN environment.

### ❖ Using Orthogonal Gold Sequence

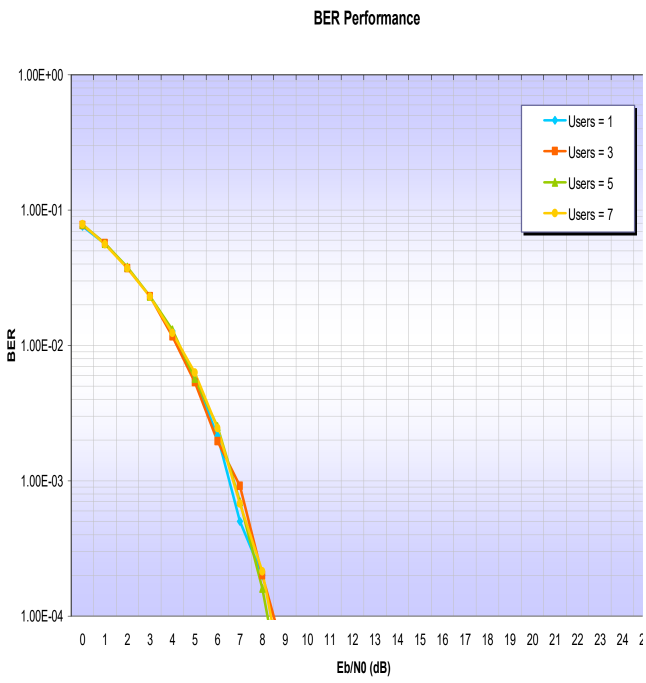



**Figure 14:** BER performance of the DS-CDMA system using Orthogonal Gold sequence, QPSK modulation scheme in an AWGN environment.

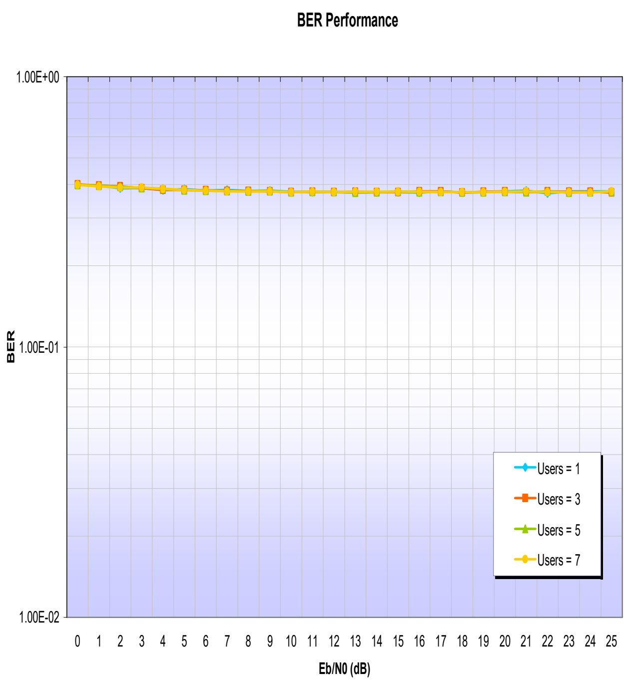



**Figure 15:** BER performance of the DS-CDMA system using Orthogonal Gold sequence, 16-QAM modulation scheme in an AWGN environment.

## BER performance in a Rayleigh Fading environment

### ❖ Using M-Sequence

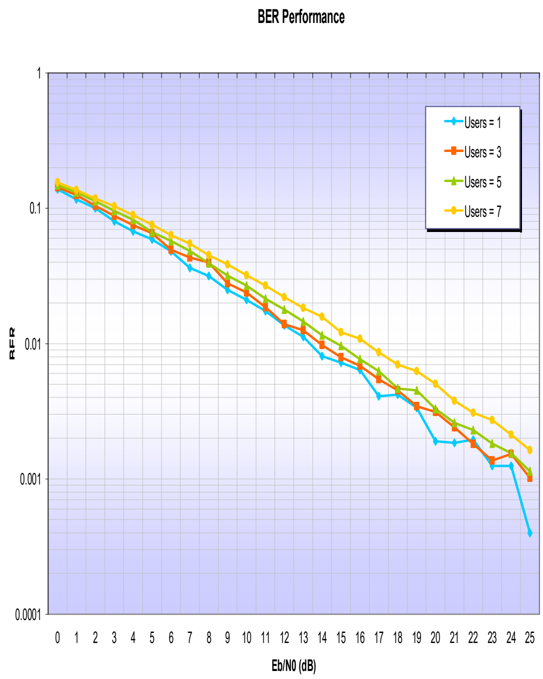



**Figure 16:** BER performance of the DS-CDMA system using M-sequence, QPSK modulation scheme in a Rayleigh fading environment.

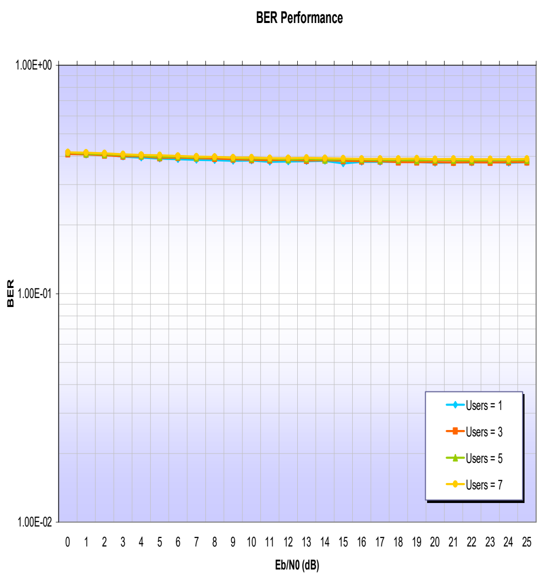



**Figure 17:** BER performance of the DS-CDMA system using M-sequence, 16-QAM modulation scheme in a Rayleigh fading environment.

### ❖ Using Gold Sequence

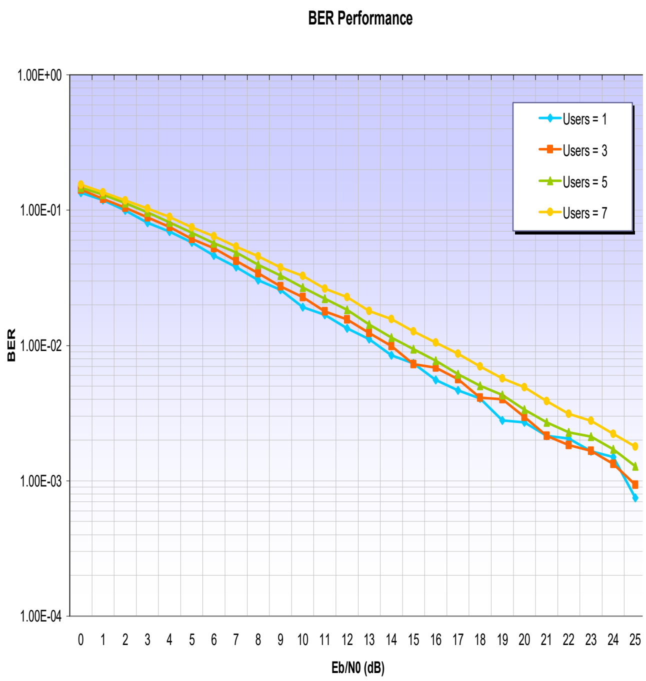



**Figure 18:** BER performance of the DS-CDMA system using Gold sequence, QPSK modulation scheme in a Rayleigh fading environment.

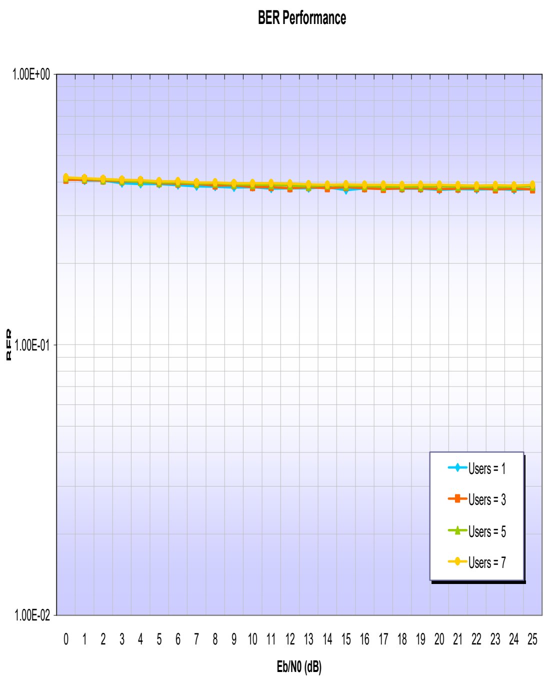



**Figure 19:** BER performance of the DS-CDMA system using Gold sequence, 16-QAM modulation scheme in a Rayleigh fading environment.

### ❖ Using Orthogonal Gold Sequence

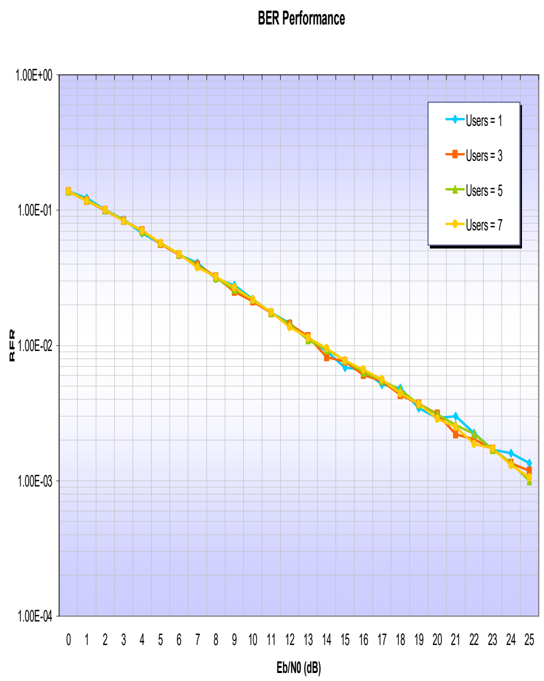



**Figure 20:** BER performance of the DS-CDMA system using Orthogonal Gold sequence, QPSK modulation scheme in a Rayleigh fading environment.

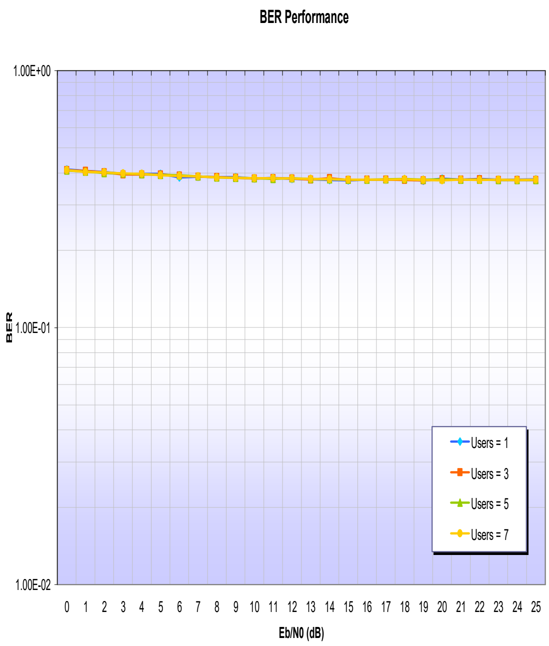



**Figure 21:** BER performance of the DS-CDMA system using Orthogonal Gold sequence, 16-QAM modulation scheme in a Rayleigh fading environment.

Having checked the main program (ofdm-dscdmaTestbed.m) and its results, it's time for the desired evaluation outcome of the OFDM-CDMA simulation/evaluation platform to be presented as a figure of Bit Error Performance, created during the simulation of ofdm-dscdmaTestbed.m with respect to Eb/No. At the beginning some problems came up and the GUI was not responding. After a long time of experimenting on it, in order to work, finally the desired results were accomplished as figures 22 and 23 below.

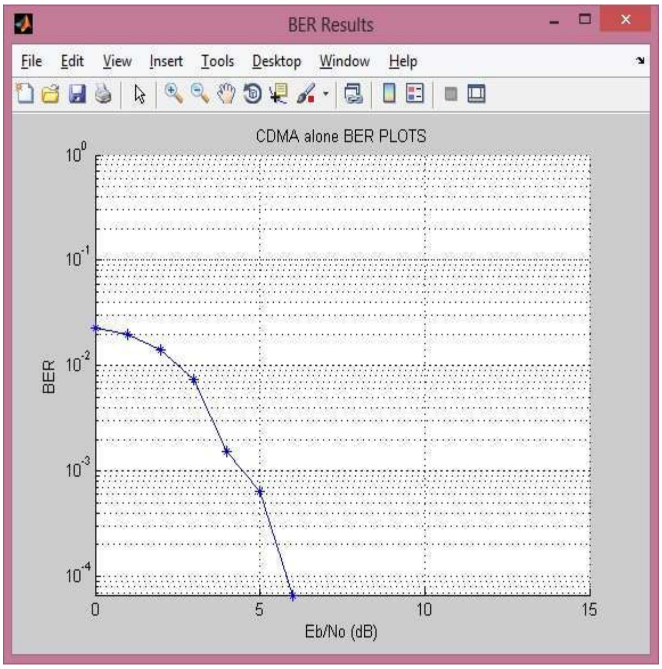



**Fig. 22** The CDMA BER plots per Eb/No (dB)

Careful inspection of Figures 21 and 22 shows that OFDM and CDMA achieve almost the same BER results but at higher level of energy per symbol to noise power spectral density, which is the definition of Eb/No (dB). Actually, when the signal bandwidth is well defined, $E_b/N_0$ is also equal to the signal-to-noise ratio (SNR) in that bandwidth divided by the "gross" link spectral efficiency in (bit/s)/Hz, where the bits in this context again refer to user data bits, irrespective of error correction information and modulation type. [7]. Such a performance indicates that CDMA at the same level of Eb/No can achieve smaller BER than OFDM, a result valid, however, under the hypothesis of small number of users. More detailed graphs are needed to support such a conclusion for different setups and number of users.

## 5 Conclusions and Prospects

In this paper we have analyzed from an educational perspective the basic procedures of OFDM and CDMA systems and their relevant advantages and disadvantages. Based on this analysis we have

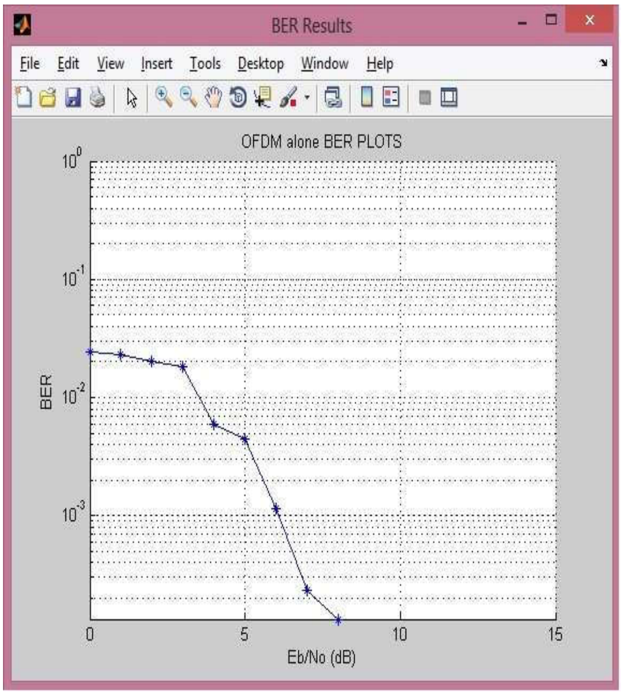



**Fig. 23** The OFDM BER plots per Eb/No (dB

attempted to realize in MATLAB a relevant evaluation package to compare these techniques, for different parameters and implementations. Although at preliminary stage and having confronted several difficulties in building a unified GUI, this educational simulation system, even at this stage, can provide useful results that need to be extended, however.

*References:*

[1] T. S. Rappaport, Wireless Communications: Principles and Practice, Dorling Kindersley, 2009 , ISBN 813172882X, 9788131728826

[2] W. C. Lee, Mobile Communications Engineering, 2nd ed. New Delhi: Tata McGraw-Hill, 2008.

[3] Pandya, Mobile and Personal Communication Systems and Services, 4th ed. New Delhi: PHI, 2004.

[4] Harada, H., Ramjee, P.,2002. Simulation and Software Radio for Mobile Communications. Artech House universal personal communications series

[5] Sklar, B., 2003. Digital Communications Fundamentals and Applications. New Jersey: Prentice- Hall, Inc.

[6] Shankar, P. M., 2002. Introduction to Wireless Systems. John Wiley & Sons, Inc.

[7] Chris Heegard and Stephen B. Wicker (1999). Turbo coding. Kluwer. p. 3. ISBN 978-0-7923-8378-9.