

DIRECT SEQUENCE CDMA SOFTWARE SIMULATION TESTBED: COMPREHENSIVE METHOD OF ALGORITHM EVALUATION FOR CDMA COMMUNICATION SYSTEMS

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Abstract

Spread Spectrum is a modulation technique that spreads a transmit signal across a bandwidth which is much wider than the usual bandwidth required for transmitting the signal. DS-CDMA is a form of Code Division Multiple Access (CDMA) system that uses the Direct Sequence Spread Spectrum (DS-SS) technique. In this work, we have developed a software testbed for simulating a DS-CDMA using a block diagram simulation system built in the Matlab and Simulink environment. The system was successfully implemented while highlighting the important design options and trade-off issues involved in the basic design of a DS-CDMA communication system. This testbed can be used as a veritable tool for teaching and demonstration of the concept of a DS-CDMA system. Apart from this, it can also be used as a basic design tool for studying the performance of a CDMA communication system under certain system parameters and channel conditions. In our study, we used the Bit Error Rate (BER) as the performance indicator. The results we obtained showed that among the three sequences used as spreading codes, Gold sequences provided the best autocorrelation and cross correlation properties followed by Kassami and Pseudo random sequences in that order. Results of multipath versus single path simulations showed that multipath effect is exploited to an advantage by the use of rake receivers. Finally, the results of single user versus multiuser simulations support the interference rejection property of DS-CDMA systems.

Keywords: Spread-spectrum, CDMA, wireless, Simulink, testbed

1.0 Introduction

The chief interest or target of every designer of a communication system is the efficient utilization of available bandwidth. Thus for better usage of available bandwidth, researchers have been working on developing new signal processing algorithms for different components of communication systems. For example, the developments in the physical layer structure have led to new algorithms both in the detection components (in the receiver) and in the coding schemes. Therefore, the designer of such a system has got a wide variety of algorithms and configurations to choose from. A simulation testbed for wireless communications allows the evaluation of different choices in such a design. There are other variables in the system such as the properties of the channel, which are affected by environmental factors. A complete algorithm evaluation needs to consider all of such factors [1] [2] [3].

This work presents the different techniques a designer can use to evaluate different algorithms and channel properties in any proposed CDMA wireless communication system. The model developed in this work is built up from existing Simulink communication systems libraries. The methodology used in the design demonstrates various techniques involved in developing communication system models in the Matlab and Simulink environment. One major merit area of this work is that it is a software testbed. This means that all test parameters can be generated and applied without making use of any hardware component apart from the computer on which the simulation is run. Thus a CDMA designer does not have to set up a real world wireless communication system comprising of mobile equipment, base stations, transmitters and receivers, antennas and so

on and so forth in order to test or analyze the performance of the system. Going further, if the designer desires to test and compare different parameters like environmental effects, coding schemes, modulation techniques etc in order to decide which best suits his/her envisaged system, then that will surely be a very expensive exercise. Thus the need for this testbed cannot be overemphasized. All parts of a wireless communication system including different possible coding schemes, modulation techniques, environmental factors, and other algorithms have been modeled in Matlab & Simulink environment and these have been employed in creating this testbed. Therefore, the designer of a CDMA communication system is presented with a tool that can be used to evaluate almost all possible design considerations before moving ahead to hardware implementation.

This testbed can also be used as a very useful teaching aid especially in demonstrating the key features of a typical direct sequence communication system. The testbed consists of various communication blocks each having a graphical user interface (GUI) feature with which the parameters of the block can be set and/or varied. Thus the student is provided with a software experimental environment which can be used to generate certain data required in verifying the known features of spread spectrum communications.

1.1 Scope of this work

This work is intended to provide a tool for teaching and demonstrating the basic concept of a Direct Sequence CDMA communication system. So many works have been done in this area especially in the area of generating models for different components and algorithms used in wireless communication systems. Thus in this work, we have used these existing tools which are available in Matlab and Simulink to evaluate and analyze different design considerations with particular respect to Code Division Multiple Access (CDMA) wireless communication system. Specifically this work is limited to the simulation of a DS-SSMA system with

three users. However, the testbed can be made to have more users by simply adding similar corresponding blocks for the new users and making the necessary parameter settings via the GUIs of the blocks.

2.0 Spread Spectrum Modulation

Spread spectrum modulation is the technique applied in the implementation of Code division Multiple Access (CDMA). In spread spectrum technique, the transmitted signal occupies a bandwidth which is kept much larger than that which is required by baseband information signal [4]. This technique sacrifices transmission bandwidths for enhanced detectability and interference rejection. Spread spectrum techniques can be used to provide simultaneous use of a wide frequency band by many users via Code Division Multiple Access (CDMA) technique [5]. Figure 1 shows a DSSS system with K multiple users i.e. more than one user sharing the same bandwidth for transmission of their individual signals. In such a system, each user has a PN sequence with n chips per message symbol period T such that $T = nT_c$.

In general, the transmitted signal of the k_{th} user can be expressed as follows

$$s_k(t) = \sqrt{\frac{2E_b}{T_b}} m_k(t) c_k(t) \cos(2\pi f_c t + \theta_k) \quad (1)$$

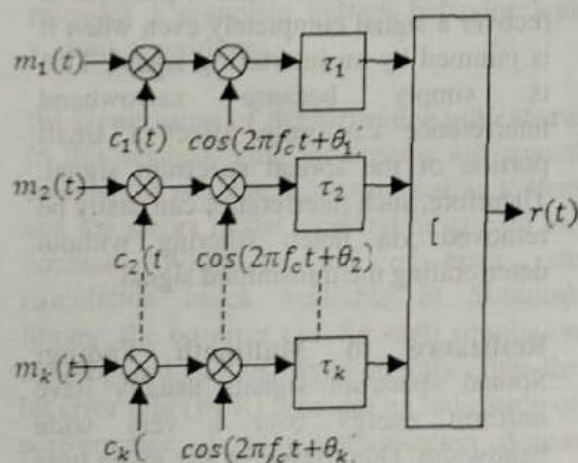


Figure 1 - A DSSS system with K multiple users

Where $m_k(t)$ is the message data sequence of the k_{th} user, and $c_k(t)$ is the PN code sequence of the K_{th} user.

The received signal $r(t)$ is composed of the sum of the transmitted signals from all the K users in the system (i.e. one desired user and $K - 1$ interfering users).

2.1 Advantages of spread spectrum modulation

Spread spectrum has many properties that make it particularly well suited for use in wireless communication systems. These properties include [6] [7] [8] [9]:

- Interference Rejection Capability:** Since each of the users in a spread spectrum system is assigned a unique spreading code which is orthogonal to other users sharing the same spectrum, the receiver can separate each user based on their codes. In other words, interference between spread spectrum signals is negligible. It should be noted however that this interference rejection is limited to a certain number of users. That is to say that as the number of users increase, interference between the users becomes more and more significant.
- Anti-jamming Capability:** Spread spectrum techniques make it possible to recover a signal completely even when it is jammed by an interfering signal. This is simply because narrowband interference can only affect a small portion of the spread spectrum signal. Therefore, such interference can easily be removed via notch filtering without deteriorating the transmitted signal.
- Resistance to Multipath Fading:** Spread spectrum signals usually have uniform energy over a very wide bandwidth. Due to this, at any given time only a small portion of the spectrum will undergo fading. This property of multipath resistance stems from the fact that delayed versions of the transmitted pseudorandom signal will exhibit poor correlation with the original

pseudorandom sequence and therefore will be ignored by the receiver. In spread spectrum systems, multipath effect can in fact be exploited to improve system performance; this is achieved by the use of RAKE receivers. A RAKE receiver combines the signals from several resolvable multipath components in order to obtain the final estimate of the desired signal.

- Elimination of Frequency Planning:** In spread spectrum systems, all users share this same bandwidth (or spectrum). Thus there is no need for frequency planning unlike in other multiple access techniques like FDMA and TDMA. This is because all cells in the system can use the same channels.

3.0 Block Diagram Simulation Method

The block diagram based tools provide an interactive environment for the evaluation of communications systems. A modular system can be designed using blocks from built-in libraries or using custom blocks created from the back-end MATLAB/C code [3]. They can be classified into two categories according to the method of simulation namely *cycle-based simulation* and *dataflow or stream driven simulation*. In cycle-based simulations, the system simulates all blocks in the system for each time step and can be expected to provide comprehensive and reliable simulation results. A common clock provides global timing information to all the blocks. In the case of dataflow or stream driven simulations, each block in the system is triggered by the data entering a block. This method of simulation is computationally less demanding and well suited for signal processing applications. We have to note that Simulink, which is the chosen block diagram simulation tool used in developing our testbed makes use of a combination of the two mentioned techniques. The drawing in figure 4 shows a block diagram representation of the testbed depicting the arrangement of the various blocks and processes involved in the system for each user. In the diagram shown (figure 2), each block has its own algorithm which generates

its output. An important aspect of design of a simulation system using this methodology is that the signal generated in one block (as its output) must have the same data type as that specified for the input of the block to which it is fed. For example, if the output of the data source (data generation block) of Boolean type, the input to the BPSK modulation block must have Boolean input data type.

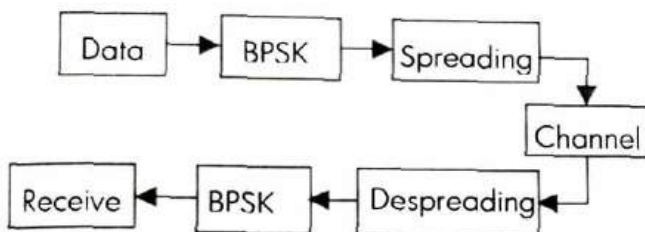


Figure 2 - A simple block diagram representation of the testbed

Justification for using Simulink: Simulink was chosen for this work basically because it is a block diagram based simulation system. Furthermore, almost all the known components of CDMA wireless communication system required in developing this testbed are available in the Simulink libraries. Thus the algorithms required for the simulation are already available in the form of blocks. In other words, there is no need to write fresh Matlab codes that will simulate the various parts of the required communication system. The modularity provided by this method is yet another great advantage, which allows for a high degree of flexibility in the design of the testbed.

3.1 Requirements for simulating a CDMA system

Due to the nature of CDMA systems, a simulation tool for such a system is required to have the following special capabilities [3]:

Fast and efficient data processing: The wide bandwidth generally associated with spread-spectrum systems requires large sampling rates in simulations. System-level simulations of these communication links normally employ a sampled-data representation of analog signals. This leads to long runtimes due to the large volume of

data flowing between the various model blocks in a simulation. So it is required to move and process data efficiently.

Multirate processing: The data rate in CDMA systems vary widely at various points. For example, the bit rate after the channel coding block increases by a factor which depends on the code used; similarly the data rate increases N (the spreading gain) times after the spreading block. Hence the system should be capable of accommodating these multiple rates.

3.2 Capabilities of the Testbed

The capabilities of the testbed are briefly described in the following subsections. These important features can be summarized as follows: (a) comprehensive method of algorithm evaluation, (b) Generation of performance indicators and (c) Study of algorithm trade-off issues.

(a) A comprehensive method of algorithm evaluation: A new algorithm is typically put to use by first doing a localized evaluation (using accepted values for some of the system parameters and channel properties) and then prototyping it. This method does not provide accurate insights into how the algorithm behaves in a real system until it is actually used in one. The CDMA testbed fills this gap by providing an environment which models all parts of a real wireless system and provides a complete system behavior with various algorithms.

(b) Generation of performance indicators: In this testbed, long bit-streams are passed through the simulated communication system and the errors in the received bit-stream are counted. With the aid of error rate calculation block available in Simulink library, the bit error rate for each simulation is computed and displayed directly. Thus the bit error rate (BER) provides an indication of performance of the communication system under the specified conditions.

(c) Study of algorithm trade-off issues: One of the main uses of this testbed is to explore the effects of using different

combinations of algorithms in the simulations. Different algorithms for channel parameter estimations, detection and coding blocks in the receiver can be studied in various configurations. Each algorithm differs in computational complexity and in the resulting bit error rate. The testbed is intended to assist in the choice of an algorithm, which results in a trade-off between performance and implementation complexity.

3.3 Construction of the Testbed Model in Simulink

In constructing this testbed, we used a demo which is already available in Simulink as a guide. The demo with Matlab model name '*commspreading_randbpsk2ump*' is a Simulink block diagram model which was used to demonstrate a direct sequence spread spectrum system involving a '*Pseudo-Random Spreading - Two-User Multipath Scenario*'. The model considers pseudo-random spreading for a combined two-user transmission in a multipath environment [10]. It was found that the model contained virtually all the basic components required to simulate a complete direct sequence spread spectrum communication system. In addition, it also included more than one user in the system making it suitable to be adapted for CDMA simulation. For

reference, the model can be opened in the Matlab 7.4.0 (R2007a) window using the following command:

```
modelname
'commspreading_randbpsk2ump';
open_system(modelname);
sim(modelname);
```

Or simply by typing the model name in the command window and pressing the enter key (i.e. *commspreading_randbpsk2ump* + Enter).

The testbed developed in this work employed the same approach as that used in the demo described above. In actual fact, the blocks used in this testbed are basically the same as those used in the demo but with certain modifications which makes the testbed a CDMA simulation tool. For the system to be effectively monitored and studied at the same time, additional components which include the display devices namely the *scopes* and *error rate calculation* blocks and the *unbuffer* blocks were added. Note that the time scopes do not accept frame based inputs and thus, the *unbuffer* blocks are used to convert the frames to samples acceptable to the oscilloscopes. The Matlab window in figure 3 shows the complete Simulink model for the testbed ready for simulation. It can be seen that no values yet are displayed on the error calculation blocks.

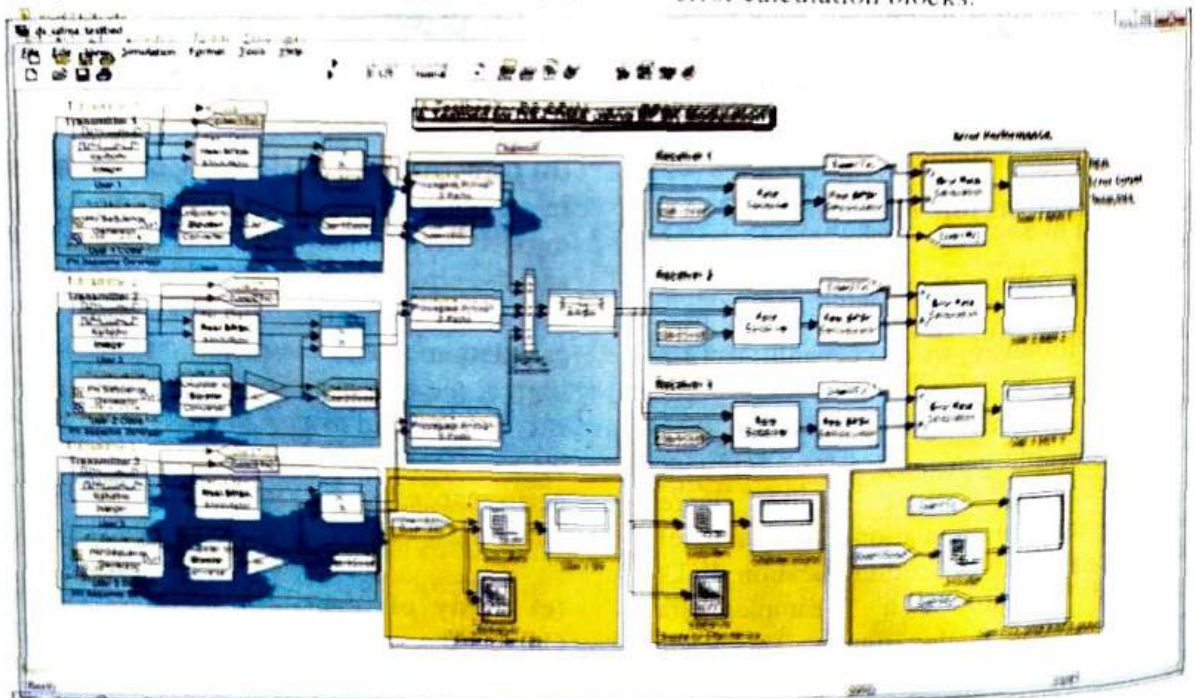


Figure 3 – Simulink Model of the Testbed ready for simulation

4.0 System Implementation

This testbed can only run in the Matlab environment precisely Matlab 7.4.0 (R2007a) and other Versions/Releases that support all the blocks used in developing the testbed. Thus to use this testbed, it must be saved in a computer on which the Matlab 7.4.0 is installed. With the Matlab program running, the testbed can be opened in any of the following two ways: either by typing the model name (name used to save the model in Matlab) e.g. "ds_cdma_testbed" in the command window followed by "enter" key on the computer keyboard or by opening the model directly from its file location. If any of the above two steps is taken, the testbed window opens and a Simulink model for the DS-CDMA system is displayed (exactly what we have in figure 3). Next, the

simulation stop time can be set by keying in the time in the appropriate dialog box. We left our default time at 0.125sec. This time can be set to any desired value at which the user (operator) wishes the simulation to stop. To start simulation, use the mouse to click on the "start simulation" button on the open window. The testbed begins to run immediately and this can be confirmed by the display block which displays error calculation results of the system. The scopes are used to view the waveforms and the spectrums of the signals connected to them. The scopes can be set to open automatically as soon as simulation begins or opened at any desired time during simulation. The view of the testbed window captured during the simulation is shown in figure 4.

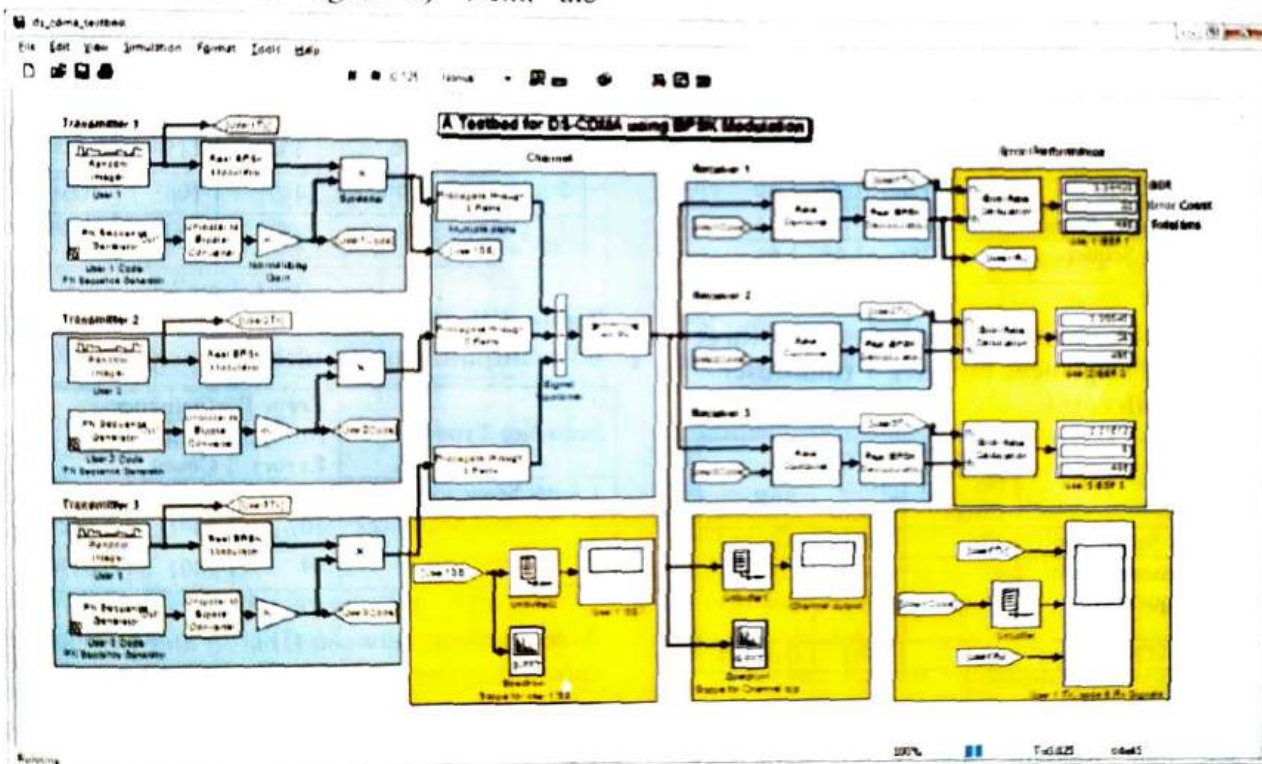


Figure 4 View of the testbed during simulation

In order to fully appreciate the purpose of this work which is majorly targeted at providing a study tool for DS-Spread spectrum application in CDMA systems, the implementation of this testbed was done in the stages discussed in the following subsections. The results are tabulated and analyzed accordingly.

5.0 Results and Analysis of Simulations

In this section, the results of the various implementation stages discussed earlier are tabulated and analyzed. The stages include (a) Implementation I (Performance evaluation of algorithms for pseudorandom sequences), (b) Implementation II (Study of multipath effect in CDMA systems) and (c) Implementation III (Study of interference rejection property of CDMA systems).

(a) Results and analysis of Implementation I – Performance evaluation of algorithms for pseudorandom sequences: Table 1 shows the results of simulation carried out with each of the three kinds of sequences used in the testbed. During simulation, streams of data are continuously generated at the transmitters and conveyed via the channel to the receivers. The received data and the transmitted data are compared and the detected errors are counted and recorded by the error rate calculation blocks.

Table 1: Simulation results showing error performance of the three sequences considered

Sequence Type		No of errors		
		User 1	User 2	User 3
1	PN Sequence	126	146	58
2	Kassami Sequence	76	98	53
3	Gold Sequence	38	68	61

Table 2 Performance analysis of the three types of sequences for user 1 (multiuser – multipath case)

Sequence Type		Error Performance		
		No of Errors	Total Count	BER
1	PN Sequences	126	2401	0.05248
2	Kassami Sequences	76	2401	0.03165
3	Gold Sequences	38	2401	0.01583

From the results shown in the Table 1 we can see that Kassami and Gold sequences performed better than PN sequences given that the total number of bits counted is the same for all the users. Table 2 gives a clearer picture of the error performance of the sequences. It shows the complete error analysis for User 1 with respect to the simulations involving the three sequences considered. It is important to note that Bit error rate (BER) is a good measure of the performance of a communication system. Therefore the better bit BER, the better the system performance. In the results shown in

table 5.2, Gold sequences with the BER of 0.01538 has the best performance followed by Kassami and PN sequences in that order.

(b) Results and analysis of Implementation II – Study of Multipath effect: The results already shown in tables 5.1 and 5.2 involved the multipath effect and will be used for comparison with the results of simulations involving no multipath scenario. Table 5.3 shows the results for the no multipath case. "No multipath" here means that the signals are propagated via a single path unlike in the earlier simulations involving three paths.

Table 3 Simulation results for "no multipath" case (multiuser case)

Sequence Type		No of errors		
		User 1	User 2	User 3
1	PN Sequence	134	115	115
2	Kassami Sequence	107	106	100
3	Gold Sequence	89	92	72

Table 4 Performance analysis for user 1 - no multipath case (multiuser case)

Sequence Type		Error Performance		
		No of Errors	Total Count	BER
1	PN Sequences	134	2401	0.05581
2	Kassami Sequences	107	2401	0.04456
3	Gold Sequences	89	2401	0.03707

A comparison between tables 3 and 1 clearly shows that better performance was achieved in the simulations involving multiple paths. This is evidenced by the higher number of errors recorded for all the users in the "no multipath" simulations. For example, in table 3, user 1 has error counts of 134, 107 and 89 as against 126, 72 and 38 recorded in table 1 respectively. Similar comparison between tables 4 and 2 also supports better performance of the multipath scenario. These results validate the known theory for multipath effect in CDMA technology. Thus in CDMA, multipath effect is exploited to an advantage by the use of Rake receivers.

(c) **Results and analysis of Implementation III – Interference rejection in CDMA systems:** The results of single user simulations are shown in table 5.5. Here we see that these results also support better performance of multipath propagation than single path propagation for all the three sequences. The results of multiuser simulations have been given in tables 5.1, and 5.2 for multipath case. The results for Gold sequences in tables 5.2 and 5.5 are used to make up the table shown in table 5.6. Comparison between single user and multiuser scenarios in CDMA systems can be studied using the results of the simulations recorded in table 5.6. Note also that the simulations considered are those of Gold sequences which according to our previous results produced the best error performance.

Table 5.5 Single user simulations results (for User 1)

Sequence Type			Error Performance		
			No of Errors	Total Count	BER
1	PN Sequence	Case 1	89	2401	0.03707
		Case 2	50	2401	0.02082
2	Kassami Sequence	Case 1	101	2401	0.04207
		Case 2	37	2401	0.01541
3	Gold Sequence	Case 1	85	2401	0.0354
		Case 2	34	2401	0.01416

Notes: Case 1 = no multipath simulation
Case 2 = multipath simulation

Table 5.6 Single user Vs Multiuser simulations results (for User 1) using Gold sequence as spreading codes

Type of System			Error Performance		
			No of Errors	Total Count	BER
1	Case 1	Single user	85	2401	0.03540
		Multiuser	89	2401	0.03707
2	Case 2	Single user	34	2401	0.01416
		Multiuser	38	2401	0.01583

Notes: Case 1 = "no multipath" simulation
Case 2 = multipath simulation

Table 5.6 shows that it is possible to have a near perfect despreading in direct sequence spread spectrum communication involving multiple users. Thus this validates the theory

that multiuser interference is eliminated in DS-CDMA systems. This is evidenced by comparing for example, 85 errors (and BER of 0.03540) recorded for single user system with 89 errors (and BER of 0.03707) recorded for multiuser system respectively in case 1. Similarly, in case 2, single user simulation produced 34 errors (a BER of 0.01416) while the multiuser simulation produced 38 errors (a BER of 0.01583).

It can be seen therefore, that the BER figures are close enough to show that multiuser interference in the system is minimal.

6.0 Conclusion

This work generally has provided a working teaching software tool that can be used to demonstrate a simple direct sequence spread spectrum communication technique as applied in code division multiple access (CDMA) systems. The testbed developed through this work has successfully been used to simulate a Direct Sequence – Code Division Multiple Access (DS-CDMA) system. It has been used to demonstrate the relative autocorrelation properties of three different pseudorandom sequences namely PN sequences, Kassami sequences and Gold sequences with respect to their performance in CDMA systems. Also the effect of multipath propagation in wireless CDMA systems was successfully demonstrated. Single user Vs multiuser comparison was also demonstrated highlighting the elimination of multiple user interference in direct sequence spread spectrum systems. The methodology used in this design demonstrates various techniques involved in developing communication system models in the Matlab and Simulink environment.

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