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Original Article

Design and FPGA Implementation of Enhanced MC-MC-CDMA System Based on Proposed M-Ary BPSK Multicode System

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Abstract *- In recent years, wireless communication has achieved significant advancements. There are many services for information transmission with high data rates and high quality, such as the Multicode-Multicarrier Code Division Multiple Access (MC-MC-CDMA). The proposed M-ary BPSK CDMA Multicode system uses to enhance the MC-MC-CDMA. The enhanced MC-MC-CDMA has been designed, simulated, and implemented in the Kintex-7 KC705 FPGA board; then, it is compared with the classical MC-MC-CDMA. The two systems are simulated in the Additive white Gaussian noise (AWGN) and multipath Rayleigh fading channels using orthogonal Hadamard spreading codes. The proposed M-ary BPSK Multicode CDMA system is improved in terms of its constellation points that are used in the mapping process, where these points have been selected with a large average sum of Euclidian distances between them to reduce the interferences during data transmission. The enhanced MC-MC-CDMA depends on combining the proposed M-ary BPSK Multicode system and the multicarrier CDMA system. The results show that the enhanced MC-MC-CDMA gives better bit error rate (BER) performance than the classical MC-MC-CDMA in the case of 2-ary and 4-ary mapping schemes, and they have equal performance in the case of M=8 and 16 at the same code length. Moreover, the enhanced MC-MC-CDMA permits more users to access it than the MC-MC-CDMA when using equal spreading code lengths.*

Keywords *- Wireless Communication, Multicode CDMA, Multicarrier CDMA, MC-MC-CDMA, Enhanced MC-MC-CDMA.*

1. Introduction

There has been a great need for wireless communications in many areas, such as data, image, and media transmission. The MC-MC-CDMA system is one of the important systems to meet this need. It is configured by merging the Multicode and the Multicarrier CDMA systems [1,2]. The CDMA technique provides multiple access services for all customers at the same frequency bands; this is achieved by spreading data in the frequency domain by orthogonal spreading codes such as the Walsh-Hadamard codes. These codes can be used to separate customers where a single code is assigned for each user [3,4]. The Multicode CDMA (MTC-CDMA) technique provides a multi-data transmission rate in the CDMA communication system. This technique depends on using m-ary mapping for data symbols where the data symbols are mapped to different spreading codes [5]. Depending on the way of mapping scheme and the form of constellation points, there are different schemes for the Multicode CDMA system, such as orthogonal codes system, Multicode system, parallel Multicode system, and M-ary-BPSK Multicode system [6,7].

The Multicarrier CDMA (MC-CDMA) technique is a multiple access system depending on the merging of CDMA and OFDM [8]. It spreads the data in the frequency domain and uses OFDM to transmit signals on orthogonal subcarriers. It is robust to multipath interference, using bandwidth efficiently. In addition, it also has the advantages of OFDM in frequency diversity and eliminating inter-symbol interference [9,23].

1.1. Multicode Multicarrier CDMA System

In order to improve the performance of MC-CDMA and MTC-CDMA systems in fading channels, the Multicode and the Multicarrier systems can be combined into one system to form the MC-MC-CDMA system [11]. As in a Multicode CDMA transmitter, each M-ary symbol chooses one of the M code sequences to be transmitted. The code sequence length N is chosen to be constant regardless of the value of M. Therefore, when the data rate changes, N does not vary; only M changes. To ensure linear independence between code sequence sets, the condition $M \leq N$ must be applied [12-14].

Each customer is assigned the same code sequences $G_m(n)$

$$G_m(n) = (g_m(n) / 1 \le m \le M) \quad (1)$$

where $G_m(n)$ is the code sequences matrix [15].

In the M-ary mapping, each symbol $d_{k,j}$ takes one code from the M code sequences of the $G_m(n)$ matrix. For user K, the selected j^{th} code, which has length N, can be explained as

$$S_{k,j}(t) = (\sum_{n=0}^{N-1} g_{d_{k,c}}(n) f(t - nT_r - jT_s) \quad (2)$$

where Ts represents the duration of the symbol, and Tr represents the duration of the rectangular pulse (f) [17,24].

For a specific M-ary symbol, a one-code sequence is assigned for that symbol. After that, each chip of that code will be spread by the user-specific sequence, and the spread signal will be modulated through orthogonal subcarriers (L) then the result will be summed. Figure 1 below illustrates the MC-MC-CDMA transmitting system [15].

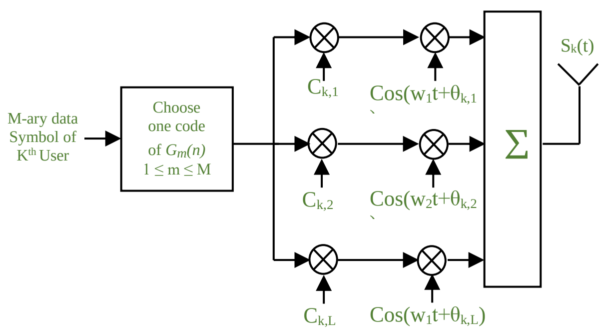


Fig. 1 MC-MC-CDMA transmitting system [18]

For user K, the signal $S_k(t)$ to be transmitted through the channel is expressed as :

$$s_k(t) = \sum_{j=-\infty}^{+\infty} \sum_{l=1}^{L} \sum_{n=0}^{N-1} \begin{matrix} g_{d_{k,j}}(n) f(t - nT_c - jT_s) \\ c_{k,l}(Nj + n) \cos(w_l t + \theta_{k,l}) \end{matrix} \quad (3)$$

The l^{th} carrier frequency is denoted by w_l, the random phase of the l^{th} sub-carrier of costumer K is denoted by $\theta_{k,l}$ where the uniform distribution of the random phase, and (Nj+n) is the position of l^{th} chip that will be multiplied with the nth bit or in the j^{th} code sequence of length N [18].

1.2. Related Works

M. G. Zia (2013) explained the effect of using the chaotic sequences for the MC-MC-CDMA in wireless data transmission. The chaotic codes were employed as spreading codes in the mapping stage of the Multicode system, and then this code was compared with the Walsh spreading code. The chaotic codes are created using a single chaotic generator based on various initial conditions. The research results showed that the system that relies on the use of chaotic code for spreading gave better results than the system that relies on the use of the Walsh spreading codes [19].

In 2014, K. Vamsi et al. exploited the feature of the Multicarrier- CDMA transmission by eliminating the multipath and signals interferences effects and the feature of the Multicode system through the transmission at different and adaptive data rates. Different spreading codes have been utilized, which are Walsh-Hadamrd, Gold, and Kasami codes in AWGN and fading channels. The data rate of a user has been calculated through the use of a rate adaptive algorithm, which improves the total capacity of the system. The introduced system has better BER compared with the Multicode CDMA system so that more customers can be accessed at the same BER performance [20].

In 2016, M. Z. Abdulhak depended on the M-ary BPSK Multicode CDMA scheme with the Multicarrier technique to form MC-MC-CDMA. The selection of the constellation points for the mapping and the spreading process was random. Where they choose any 16 constellation points between 26 points for the 16-ary BPSK mapping, each constellation point includes three coordinates; hence, each user will be assigned three spreading codes to configure the combination codes. The data has been spread in time and frequency domains by using interleaving with the MC-MC-CDMA [18].

S. Khan et al. (2020) present the MC-MC-CDMA technique for drone communications. The system describes the throughput requirements and differing ranges of communication links between drones and between drones to control stations on the ground. The MC-MC-CDMA has been applied in the Gaussian channel. It was concluded that when the modulation level is changed, the speed of data transmission changes. A low modulation level must be achieved for higher improvements [21].

In 2023, we introduced the M-ary BPSK Multicode CDMA depending on an optimization technique to achieve the best BER performance. The Walsh spreading code has been utilized with various code lengths, such as 32, 64, 128, and 256 in the Gaussian noise channel. The Ant-Colony algorithm has been used to obtain the best and worst constellation points that are used in the mapping process of the M-ary-BPSK Multicode technique. The outcomes demonstrate that the proposed system, which used the best points, overcomes the system that does not use the best points in terms of BER. Accordingly, more users can be accessed at the same BER [22].

For the conventional MC-MC-CDMA, the main problem is the need for a large number of orthogonal codes where each user requires a number of codes for mapping and spreading. For M=16, each user needs 16 codes for data symbols mapping and another code as a signature. For example, If the spreading code length is 256 and M=16, there are 256 orthogonal codes, and each user requires 16 codes, then 16 users can be connected to the system. The enhanced MC-MC-CDMA has been proposed to increase the maximum number of users and improve the BER. In this work, proposed constellation points have been used for the mapping process of the M-ary BPSK Multicode technique to improve its performance. After that, this system will be combined with the multicarrier CDMA to form the developed MC-MC-CDMA. These points keep the same criteria as the constellation points used in our previous work in reference [22]; also, they have a larger average sum of Euclidean distances. Two systems have been designed and simulated, which are the classical MC-MC-CDMA and the developed MC-MC-CDMA, which depended on the proposed M-ary-BPSK Multicode CDMA system. Then, the two systems are implemented in the Kintex-7 KC705 FPGA board.

2. System Models

Two models were designed, simulated, and implemented, which are the enhanced MC-MC-CDMA and the classical MC-MC-CDMA models. The first system model depends on the proposed M-ary-BPSK multicode system, whereas the other model depends on the use multicode system.

2.1. The Enhanced MC-MC-CDMA Model

The following block diagram has been used for the enhanced MC-MC-CDMA, which depends on the proposed M-ary BPSK Multicode technique. Firstly, the input data is transformed from serial to parallel to form the M-ary symbols. Each symbol includes $\log_2 M$ bits of data which is then mapped to a specified constellation point among M points. There are M constellation points proposed for each user. Each chip of that constellation points is then spread by a Walsh spreading code, and these spread sequences are summed to form a combination code corresponding to a user symbol data. This is the transmitter of the proposed M-ary BPSK Multicode CDMA technique, as explained inside the dashed lines of Figure 2. This system will be merged with the multicarrier system (OFDM-CDMA) to form the proposed MC-MC-CDMA, as explained in Figure 2 below. The obtained combination codes after that will be converted to parallel form to compute its inverse fast Fourier transform. Then the cyclic prefix is appended to get the coded sequences for a specific user. The same process will occur for other users, where each user is assigned eight different spreading codes for 16-ary mapping, four different spreading codes for 8-ary mapping, and two different spreading codes for 4,2-ary mapping. The coded sequences of all users are then summed to be sent through the channel.

At the receiver, the first step includes removing the cyclic prefix from the received sequence and then converting it from serial to parallel to get its FFT. After that, the signal is converted to serial, and then it is de-spread by the Hadamard codes of the specific customer. The receiver must calculate the Euclidean distances between the de-spread signal and all mapping points and then choose the point closest to the de-spread signal. After obtaining the constellation point, it will be de-mapped to the symbol related to it. The dashed line at the receiving system represents the receiver of the proposed M-ary-BPSK Multicode CDMA technique.

Keeping the same condition for choosing constellation points where for any value of H, the constellation points have been based on the following equation:

$$\sum_{h=1}^{H} q_h^2 = 1 \tag{4}$$

The above condition will retain that equal average power is given for all constellation points for any value of H. Therefore, a comparison can be made between two systems with different M-ary and a different number of spreading codes. The proposed points have more coordinates than that of reference [22], keeping equal average power and providing a greater average sum of Euclidean distances *(AvS)*, and hence it provides higher performance.

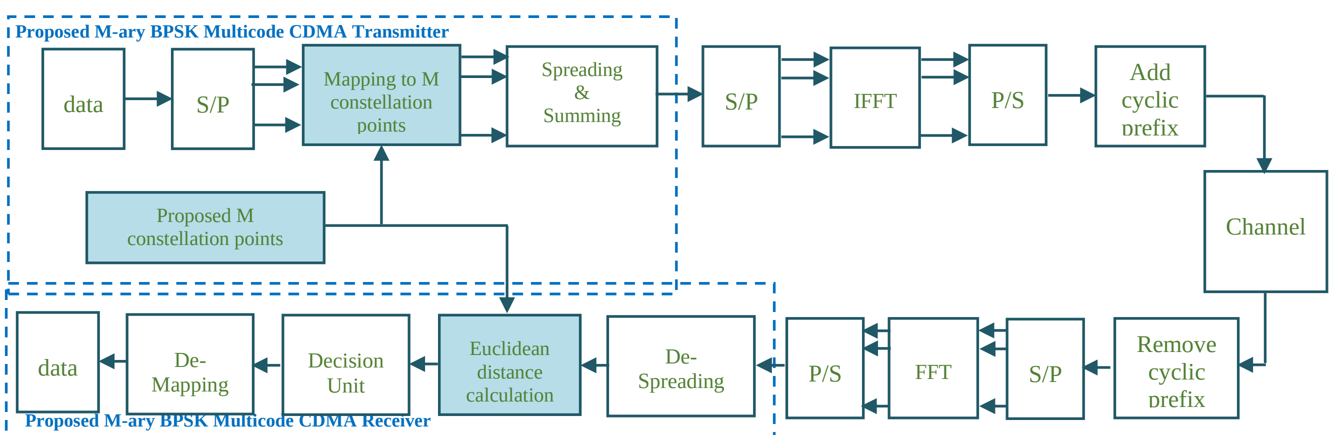


Fig. 2 The enhanced MC-MC-CDM system model

Table 1 below explains the proposed constellation points for M = 16 with normalized average power. Each user is assigned eight codes (H=8), and each symbol of Log_2M bits has been represented by one of these constellation points.

Table 1. Proposed sixteen constellation points for a 16-ary.

C_1 (q_1 , q_2, … , q_8)	**C_2 (q_1 , q_2, … , q_8)**
C1= (1,0,0,0,0,0,0,0)	(-1,0,0,0,0,0,0,0)
C_3	C_4
(0,1,0,0,0,0,0,0)	(0,-1,0,0,0,0,0,0)
C_5	C_6
(0,0,1,0,0,0,0,0)	(0,0,-1,0,0,0,0,0)
C_7	C_8
(0,0,0,1,0,0,0,0)	(0,0,0,-1,0,0,0,0)
C_9	C_{10}
(0,0,0,0,1,0,0,0)	(0,0,0,0,-1,0,0,0)
C_{11}	C_{12}
(0,0,0,0,0,1,0,0)	(0,0,0,0,0,-1,0,0)
C_{13}	C_{14}
(0,0,0,0,0,0,1,0)	(0,0,0,0,0,0,-1,0)
C_{15}	C_{16}
(0,0,0,0,0,0,0,1)	(0,0,0,0,0,0,0,-1)

For an 8-ary system, the data symbol contains Log_28 bits, and four codes (q_1 to q_4) are assigned for each user. Table 2 below shows eight constellation points for H=4 utilized for mapping data symbols.

Table 2. Proposed eight constellation points for an 8-ary.

C_1 (q_1, q_2, q_3,q_4)	**C_2 (q_1, q_2, q_3, q_4)**	**C_3 (q1, q2, q3,q4)**	**C_4 (q_1, q_2, q_3,q_4)**
(1,0,0,0)	(-1,0,0,0)	(0,1,0,0)	(0,-1,0,0)
C_5	C_6	C_7	C_8
(0,0,1,0)	(0,0,-1,0)	(0,0,0,1)	(0,0,0,-1)

For a 4-ary mapping system, two spreading codes (H=2) are used for each user. Four constellation points are proposed for the mapping of data symbols. These points are (1,0), (-1,0), (0,1), and (0,-1).

For a 2-ary mapping system (M=2) where each data symbol includes a single bit, two spreading codes are assigned for each user. Also, two constellation points are used for symbol mapping, which is (1,0) and (-1,0).

2.2. Classical MC-MC-CDMA Model

The MC-MC-CDMA system model is explained in the block diagram of Figure 3 below. In the beginning, the input data bits are changed to parallel M-ary symbols. Then each symbol of Log_2M bits is mapped to one Walsh-Hadamard spreading code. Each chip of this code is then spread by Walsh, spreading code for a specified user. After the spreading process, the code sequence will be transformed to parallel to find its inverse fast fourier transform (FFT). Then cyclic prefixes are appended to get the coded sequence for a specific user. The same process will take place for other users, and the coded sequence for all users will be summed and sent over the channel.

At the receiver, the first step includes removing the cyclic prefix from the received sequence and then converting it from serial to parallel to get its FFT. After that, the signal is converted to serial and then de-spread by the user-specific spreading code. Later the matched filter will find the correlation between the retrieved sequence and all the M spreading sequences used at the mapping. The transmitted one will be the spreading sequence that returns a larger correlation value. It is then de-mapped to the corresponding M-ary symbol.

2.3. The Hardware Design of the Enhanced MC-MC-CDMA Systems

The system design depends on using reconfigurable FPGA blocks for the hardware implementation of MC-MC-CDMA. The system software design was achieved using MATLAB system generator and then performing compilation and generation of VIVADO IP to be downloaded to the Kintex-7 KC705 FPGA board. Figure 4 shows the hardware and software components required to implement the systems. It consists of two computers, four Arduino boards, and Kintex-7 KC705 (xc7k325tffg900-2) FPGA board.

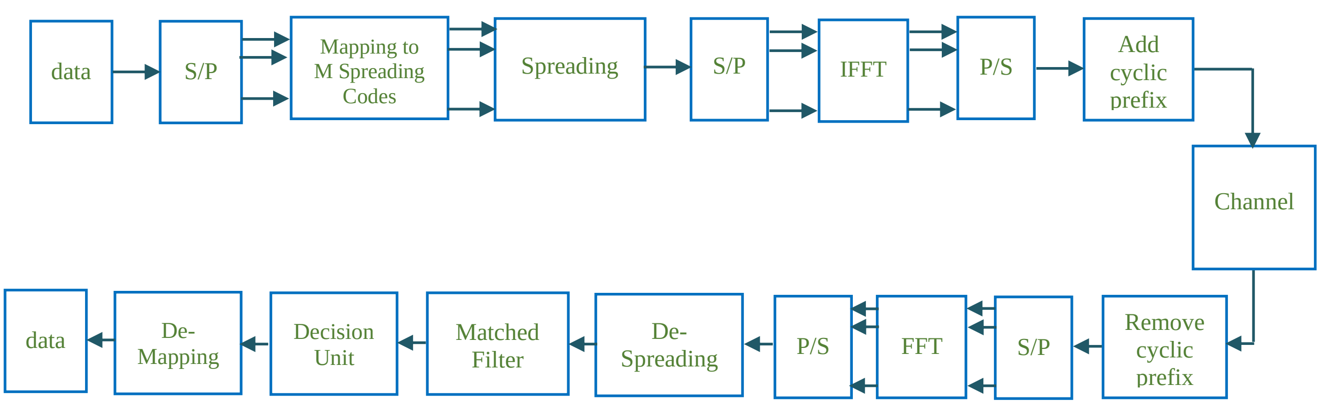


Fig. 3 MC-MC-CDMA System Model

There have been two users, and each user requires two Arduino boards for the source and sink of data. The users' data sources are connected to one computer, and their sinks are connected to the other computer. The Kintex-7 KC705 FPGA board is connected to a computer to download the generated Bitstream. Figure 5 below shows the system generator Simulink of the developed MC-MC-CDMA transmitter for two users. The first block of the figure includes the mapping Lookup Table (LUT) and the spreading operations. It was created from the MCode block of the system generator, where a MATLAB function has been built inside it, including the mapping and spreading operations.

The LUT includes mapping each data symbol into one constellation point for M=16. After that, each chip of these points will be spread by the orthogonal spreading sequences allocated for the specified user, and the spread sequences will be combined to form a combination code. The combination code then enters the second stage to calculate its IFFT. After calculating the IFFT for the data of each user, the output of the two users will be summed and then converted from parallel to serial to be transmitted through the AWGN channel.

The system generator blocks of the proposed MC-MC-CDMA receiver are explained in Figure 6 below. It includes FFT calculation, dispreading of data for each user, and then calculating the distances between the de-spread data and the used constellation points and choosing the point closest to the de-spread signal. The last step is de-mapping the obtained point to the corresponding data symbol. The same process will be done for the other users. These recovered data symbols for each user will be an output of the FPGA board and inputs of the Arduino board. The Arduino will convert these binary data to text and display them on the serial monitor.

The IFFT algorithm has been constructed based on its basic mathematical model. It contains eight stages, as explained in Figure 7 below, where the design manipulates the real and imaginary parts separately.

Fig. 4 The experimental system

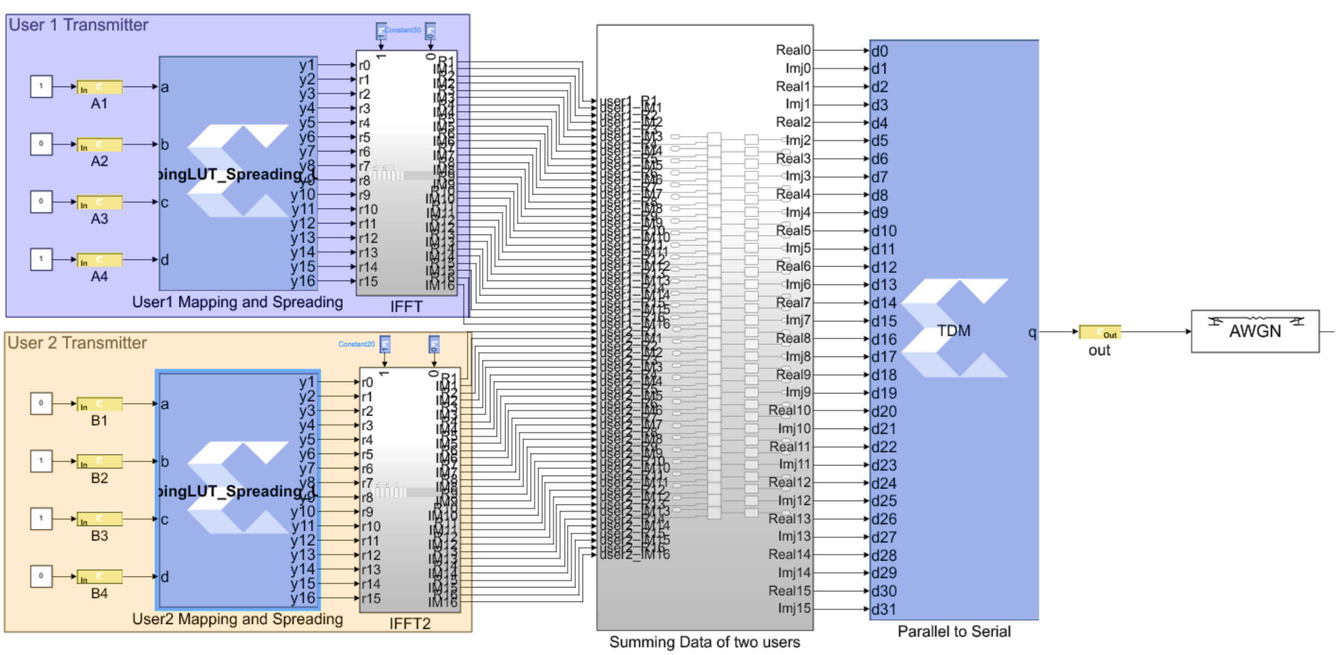


Fig. 5 System generator simulink of the enhanced MC-MC-CDMA transmitter for M=16

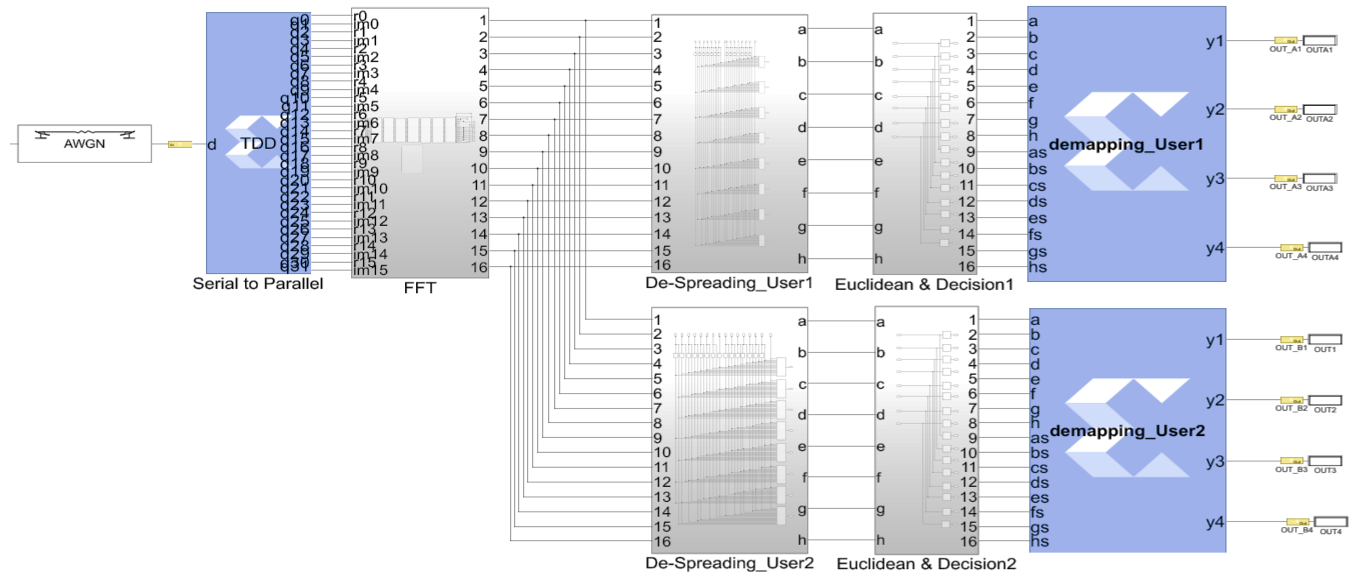


Fig. 6 System generator simulink of the enhanced MC-MC-CDMA receiver for M=16

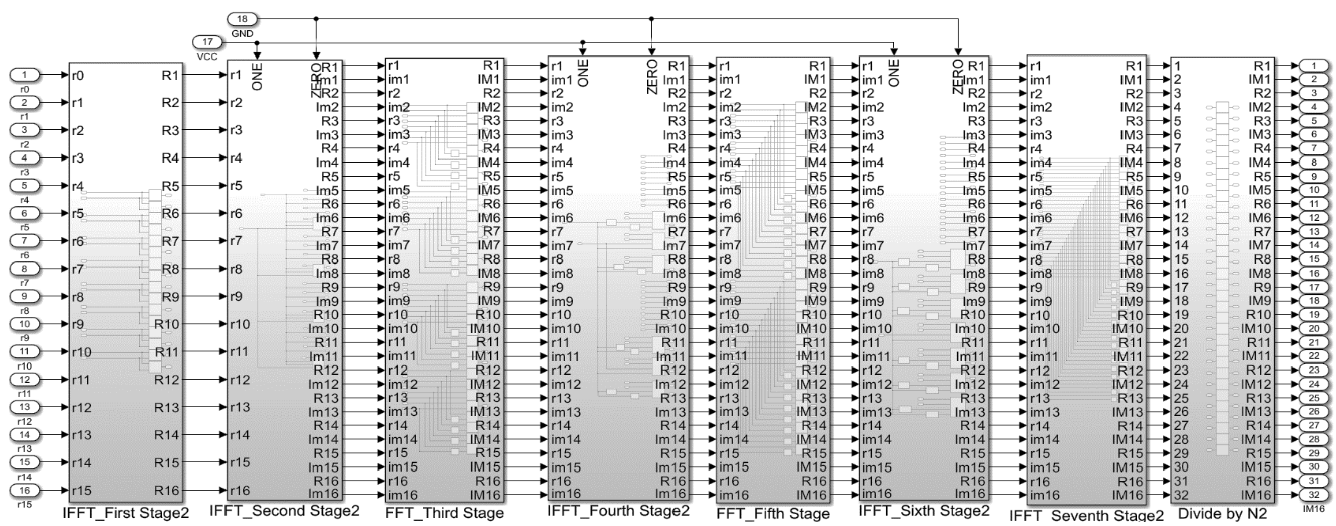


Fig. 7 System generator simulink of the 16-point IFFT

The VIVADO block design of the enhanced MC-MC-CDMA transmitter and receiver is explained in Figure 8. This design is simulated, synthesized, and implemented in the Kintex-7 KC705 FPGA board.

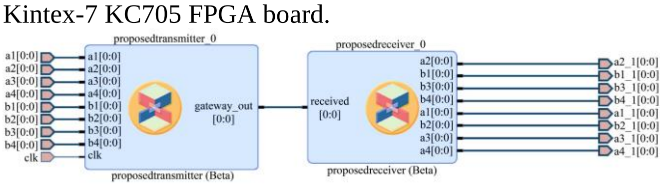


Fig. 8 VIVADO block design of the proposed MC-MC-CDMA

3. Results and Discussion

The result of the proposed M-ary BPSK Multicode CDMA technique dependent on the proposed constellation points is discussed below. The systems of the enhanced MC-MC-CDMA and the classical MC-MC-CDMA have been simulated in two different channels, and a comparison was made between them with regard to the BER and the number of subscribers. Finally, these systems are designed and implemented in the FPGA board.

3.1. The Proposed M-ary BPSK Multicode CDMA

The proposed 16-ary BPSK Multicode CDMA depends on using the 16 proposed constellation points shown in Table 1 above, where 8 codes (H=8) are assigned for each user. This system is compared with the 16-ary BPSK Multicode CDMA technique in ref [22], which depends on the best codes for H=3, where three codes are assigned for each user. The results illustrate that the proposed system for H=8 presents better BER than the system that utilizes the best points or codes for H=3, as shown in figure 9 below. For the proposed 16-ary-BPSK Multicode CDMA system of H=8, it is clear from the figure that at 2dB, the BER of the system is about 0.0014. On the other hand, for the system that depends on the best constellation points of H=3, the BER of 0.0014 has been obtained at 5.8 dB. As a result, there are about 3.8 dB were gained through using the 16 proposed constellation points. This is because the proposed 16 points for H=8 have larger (*AvS*) than that for H=3, as explained in Table 4.

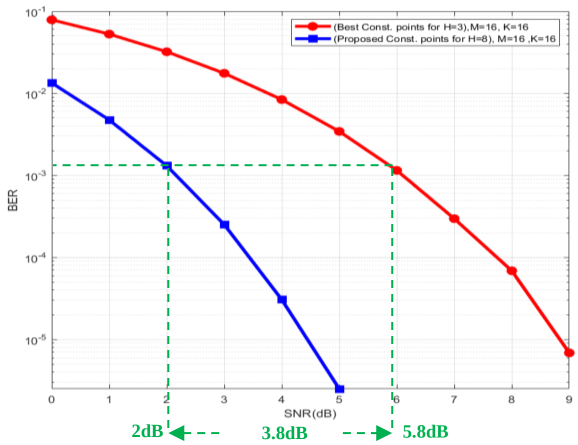


Fig. 9 Comparison of the proposed 16-ary BPSK Multicode CDMA for proposed points of H=8 and best constellation points of H=3

3.2. The Enhanced MC-MC-CDMA

The enhanced MC-MC-CDMA has been designed and simulated in the AWGN channel and multipath Rayleigh fading channel for different values of M. It combines the proposed Multicode and multicarrier CDMA systems. The Walsh spreading code with a length of 256 is used for the simulation. Table 3 below displays the number of orthogonal spreading codes used for a subscriber for different M-ary schemes. It also includes the calculated *AvS* of the proposed constellation points. It is clear that when the *AvS* value between points increases, the system performance will be improved.

Table 3. Number of codes and *AvS* value of the proposed constellation points for different M

M constellation points	H (No. of codes)	*AvS*
16	8	1.4533
8	4	1.4979
4	2	1.6095
2	2	2

The *AvS* between any two proposed constellation points for a specified M-ary scheme has been calculated by the following formula.

$$AvS = E[d_j] = \frac{1}{M}\sum_{j=1}^{M} d_j \quad (5)$$

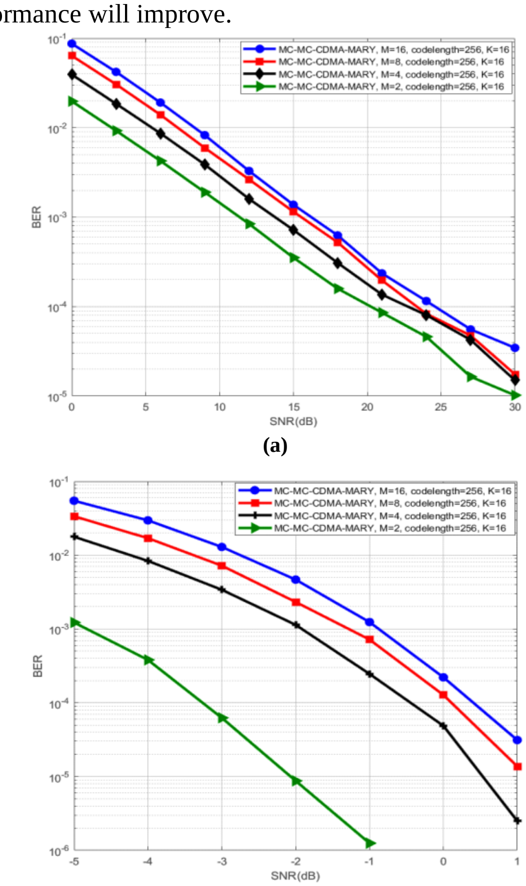
where d_j denotes the Euclidean distance between two chips of two points at the j position.

The proposed constellation points have been compared with the best constellation points used in reference [22]. Table 4 below displays the number of codes used with 16-ary mapping for each user, the AvS of the proposed constellation points, and the points used in [22].

Table 4. Number of codes and *AvS* of the proposed points and the points used in ref [22] for 16-ary mapping

	H (No. of codes)	*AvS*
Const. Points of ref. [22]	3	1.4053
Proposed const. points	8	1.4533

It is concluded that the proposed constellation points for 16-ary have *AvS* equal to 1.4533, which is greater than 1.4053 obtained for the best constellation points used in reference [22]. Obviously, as *AvS* increases, the transmission interferences will decrease, and then the transmission performance will improve.



(b)

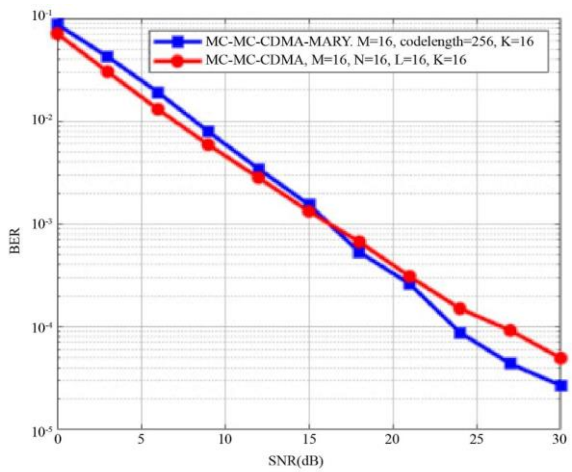
Fig. 10 BER with SNR for the enhanced MC-MC-CDMA with different M and 16 users in (a) Fading channel (b) AWGN channel

Figure 10 above displays the BER results of the developed MC-MC-CDMA for different values of M (M=2,4,8 and 16) for 16 users in the Gaussian noise channel and Rayleigh fading channel. Since the system performance increases with the decrease of the M-ary degree, therefore the system has better performance at M=2.

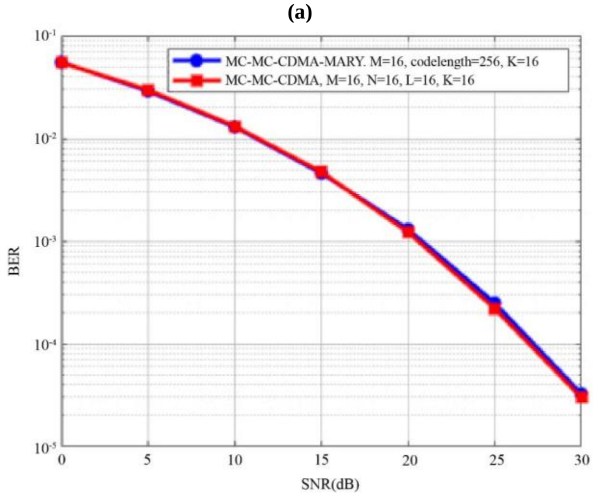
3.3. Comparison of the Classical and Enhanced MC-MC-CDMA

The classical and enhanced MC-MC-CDMA systems are used the same spreading code length and data rate. For the MC-MC-CDMA, the spreading is achieved in two steps; the first is to map each symbol to a Walsh spreading code with a code length of N=16, where the symbol includes Log_2M bits. So that for M=16, four information bits are encoded within each code symbol. Each bit of the Walsh code is then spread by another Walsh code with a code length of L=16 which represents the number of subcarriers; therefore, the overall spreading code length is 16×16 =256.

For the developed MC-MC-CDMA that depended on the proposed M-ary BPSK Multicode technique, the dependent code length was 256. Figure 11 below shows the change of BER with SNR of the two systems for a 16-ary mapping scheme and 16 users. The results illustrate that the two systems have the same performance in the AWGN channel. In fading channel, the enhanced MC-MC-CDMA outperforms the MC-MC-CDMA for high SNR and vice versa for low SNR.



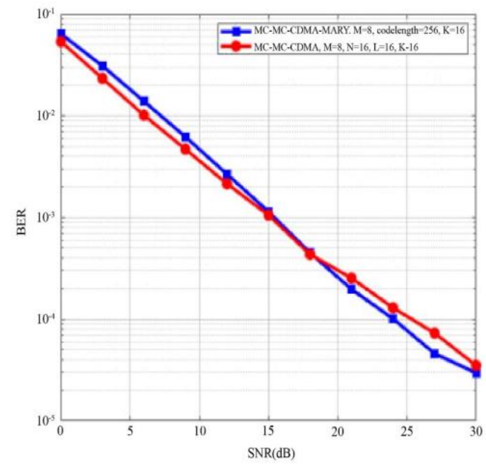
(a)



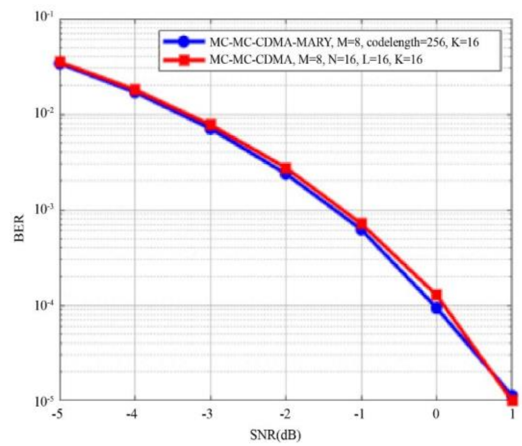
(b)

Fig. 11 Comparison of the enhanced and classical MC-MC-CDMA for 16-ary and 16 users in (a) Fading channel (b) AWGN channel

For 8-ary and 16 users, the two systems' performances are explained in Figure 12. The MC-MC-CDMA uses N=16 and L=16; therefore, the overall code length is 256, and the enhanced MC-MC-CDMA utilizes a code length of 256. The results show that the two systems are identical in the AWGN channel. In the Rayleigh fading channel, the enhanced MC-MC-CDMA is better than the conventional MC-MC-CDMA for high SNR and vice versa for low SNR.

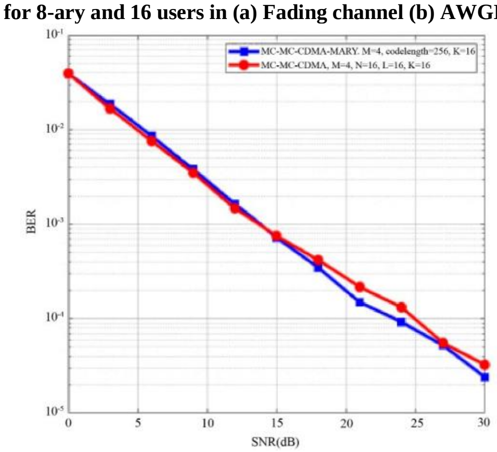


(a)

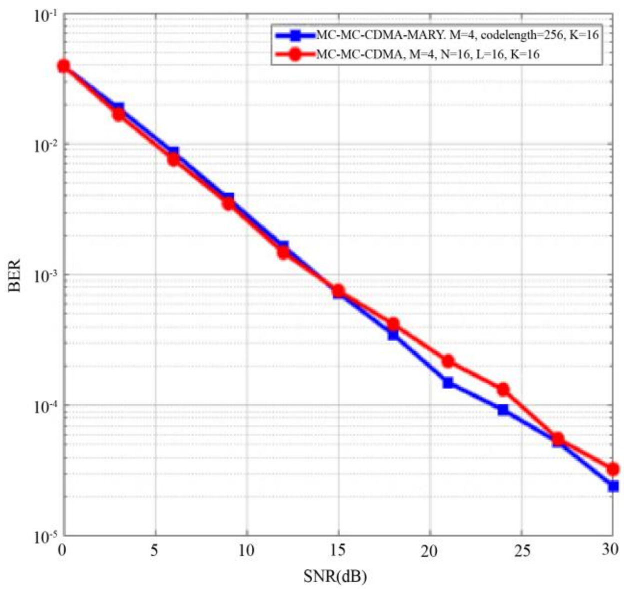


(b)

Fig. 12 Comparison of MC-MC-CDMA and the enhanced MC-MC-CDMA for 8-ary and 16 users in (a) Fading channel (b) AWGN channel



(a)

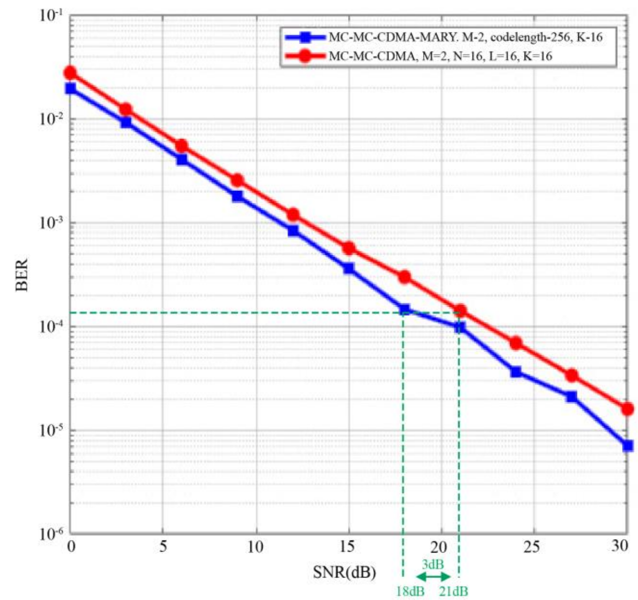


(b)

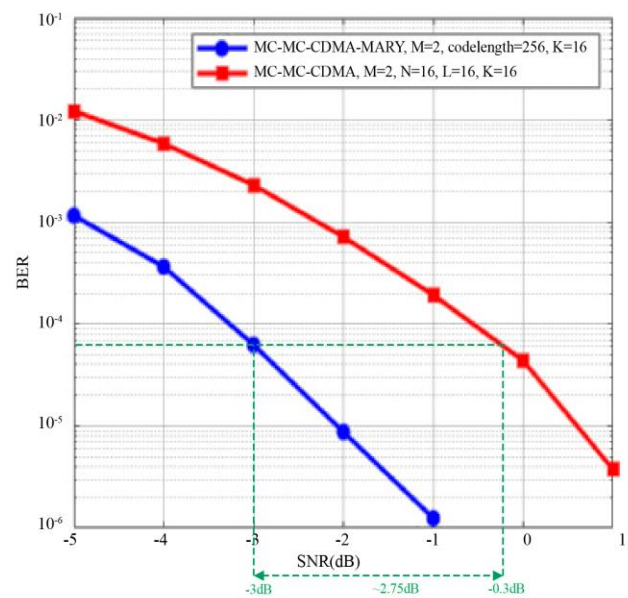
Fig. 13 Comparison of MC-MC-CDMA and the enhanced MC-MC-CDMA for M=4 and 16 users in (a) Fading channel (b) AWGN channel

For M=2, and a spreading code length of 256 is used, figure 14 below shows the BER behaviour with the change of SNR of the two systems. The outcomes proved that the enhanced MC-MC-CDMA introduces better BER values than the conventional MC-MC-CDMA in the case of M=2. From Figure 14 (a), the BER of the conventional MC-MC-CDMA was 1.5x10^(-4) at SNR=21 dB, while for the enhanced MC-MC-CDMA, the same BER was obtained at 18dB. As a result, there are about 3 dB were gained through using the enhanced MC-MC-CDMA system. For fading channel in Figure 14 (b), the BER of the conventional MC-MC-CDMA was 6x10^(-5) at SNR=-0.3 dB, while for the enhanced MC-MC-CDMA, the same BER was obtained at -3dB. As a result, about 2.7 dB was gained through using the enhanced MC-MC-CDMA system.

The developed MC-MC-CDMA provides a larger number of customers compared to the conventional MC-MC-CDMA for the same spreading code length. For an orthogonal spreading code with a length of 256 and a 16-ary mapping scheme, there are 256 orthogonal Walsh-Hadamard spreading codes. The developed MC-MC-CDMA uses 8 codes for each user; as mentioned in Table 3, these codes are used for spreading the eight chips of the constellation points so that it can permit up to 256/8=32 users to be accessed. At the same time, the conventional MC-MC-CDMA permits up to 16 users to access for M =2,4,8,16, which are equal to the length of user-specific sequences (L=16). On the other hand, the maximum number of users for 8,4 and 2-ary of the developed system are 64, 128, and 128, respectively, which is larger than that of the classical system.



(a)



(b)

Fig. 14 Comparison of MC-MC-CDMA and the enhanced MC-MC-CDMA for M=2 and 16 users in (a) Fading channel (b) AWGN channel

3.4. FPGA Results of the Enhanced MC-MC-CDMA

The FPGA results of the enhanced MC-MC-CDMA using VIVADO 2017.4 are shown in Figure 15 below. It explains the transmitted and received data for two users. A Walsh Hadamard spreading code with a code length of 256 is utilized for 16-ary mapping. The figure includes 4 bits of transmitted parallel data for each user and the corresponding 4 bits of received parallel data. The results proved that the system works well and that the transmitted signal can be corrected and retrieved properly.

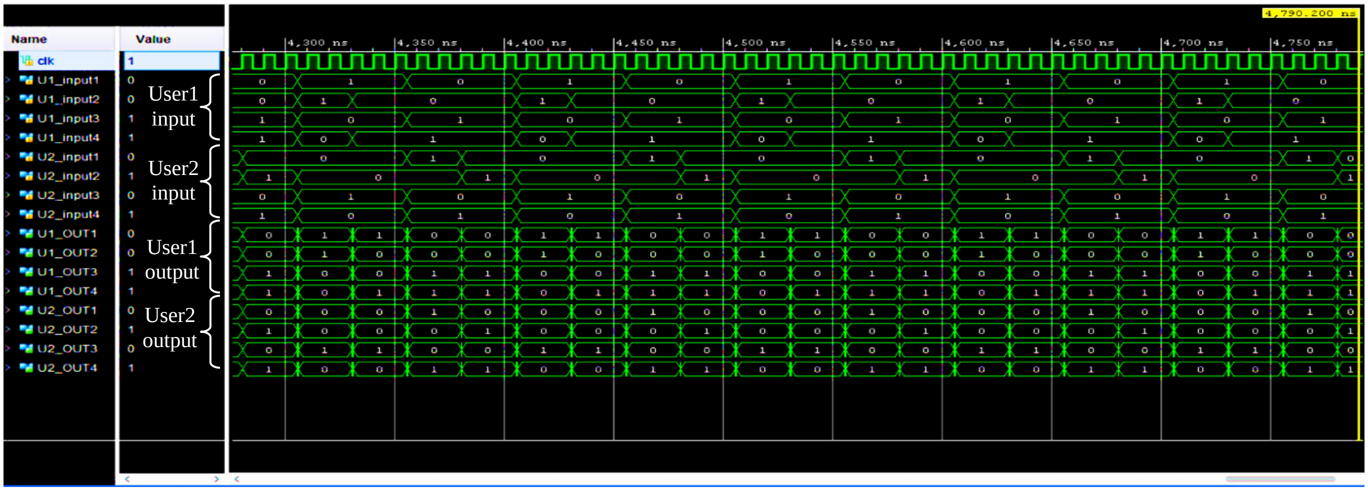


Fig. 15 VIVADO Simulation results of the enhanced MC-MC-CDMA for 16-ary mapping scheme

4. Conclusion and Future Works

The enhanced MC-MC-CDMA is designed and simulated in the Gaussian noise and multipath fading channels. It is based on the proposed M-ary-BPSK Multicode system, where new constellation points have been proposed to enhance the system. The enhanced MC-MC-CDMA technique is designed and implemented in the Kintex-7 KC705 FPGA board, then compared with the classical MC-MC-CDMA. The outcomes proved that the developed MC-MC-CDMA outperforms the classical MC-MC-CDMA for M=2 and M=4, and they have almost the same performance for M=8 and 16. For the enhanced MC-MC-CDMA, the maximum number of subscribers that can be connected is larger than that of the MC-MC-CDMA at the same code length and data rate (bit per symbol).

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