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Performance Evaluation of Hybrid Chaotic and Permutation Schemes for Image Transmission Based MC-CDMA

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ABSTRACT- The demand for more reliable and efficient multimedia data transfer through wireless communications channels is escalating. However, multimedia data, such as images, suffers significantly from wireless channel effects, including interference, fading, and burst errors. The Multi-Carrier Code Division Multiple Access (MC-CDMA) technology is regarded as the most efficient method for data transfer across wireless networks, supporting multiple users simultaneously without requiring an expansion of the frequency band. This paper employs permutation and hybrid chaotic techniques to demonstrate image transmission performance over the MC-CDMA network. Based on Peak Signal-to-Noise Ratio (PSNR), Bit Error Rate (BER), and Root Mean Square Error (RMSE) parameters, this paper analyzes, compares, and discusses the image transmission performance over the MC-CDMA network. Moreover, the hybrid chaotic and permutation techniques enhance the encryption degree of the image transmission. The performance outcomes demonstrate that the MC-CDMA image transceiver system based on a permutation scheme achieves more effective and better results in terms of BER, RMSE, and PSNR than the one based on a hybrid chaotic scheme over the Rayleigh channel. However, the BER performance is almost identical to that of increasing the number of users in the MC-CDMA model for both schemes.

Keywords: MC-CDMA, permutation, Henon map, logistic map, BER, PSNR.

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1. INTRODUCTION

The multimedia transmission of signals over wireless channels is one of the best demands of modern and future communication systems. Images transmission with minimum error is the demanding aim of current and future communication because of the difficulties of wireless communication channels, such as multipath propagation and fading. Multi-Carrier Code Division Multiple Access (MC-CDMA), which is the combination of Orthogonal Frequency Division Multiplexing (OFDM) and Code Division Multiple Access) CDMA, is an excellent technology concerned with the multipath fading effects [1]. The expansion of multimedia applications has boosted the information storage and transmission requirement. Encryption and digital watermarking are the two main methods utilized for multimedia information security [2]. The chaos and permutation techniques are designed to boost security and increase the efficiency of image transmission. Burst errors can be avoided by employing these approaches in communication systems in addition to detecting and correcting the random errors in wireless networks [3].

Various scientific works have been described as transmitting multimedia signals over MC-CDMA. In 2013, [4] used frequency domain equalizers and chaotic interleaving for efficacious image transmission. The achieved results represented a considerable performance enhancement in terms of the Peak Signal to Noise Ratio (PSNR) and Root Mean Square Error (RMSE), especially when collecting the Least Minimum Mean Square Error (LMMSE) equalization with the chaotic interleaving. Additionally, the chaotic interleaving technique adds encryption to the transmitted image.

In 2015, [5] employed the achievement of Multi Group Space-Time Codes Bell Laboratory layered Space-Time (MGSTC BLAST) spatial multiplexing system combined with MC-CDMA system for color image transmission using Forward Error Correction) FEC) channel encoded. It also facilitates different signal detection systems. The results presented the strength of system achievement in receiving transmitted color images over Rayleigh fading channels and contaminated Gaussian noise.

In 2017, [6] discussed the Discrete Wavelet Transform (DWT) method combined with the Set Partitioning in Hierarchical Trees) SPIHT) coder for compressing the image. The MC-CDMA technique is implemented to transmit the compressed image over a noisy channel. The results showed that image transmission achieved over MC-CDMA utilizing the SPIHT model is better than the classic approach, such as MC-CDMA through the AWGN channel.

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In 2019, [7] analyzed Peak Average Power Ratio (PAPR) and Bit Error Rate (BER) of a hybrid scheme (clipping-based MC-CDMA and Selective Mapping (SLM)) without and with the Multiple-Input Multiple-Output (MIMO) technique. Results showed that this hybrid system substantially reduces PAPR. The MIMO technique has been utilized to improve the performance of BER while maintaining PAPR.

This paper aims to demonstrate image transmission performance through an MC-CDMA system that allows transmission for multiple users simultaneously without expanding the frequency band. Interleaving and scrambling techniques have been used for decades to mitigate the effect of burst errors. Permutation and hybrid chaos are applied to the image data to transmit it over communication networks sufficiently to support more security and reduce the impact of burst errors. MC-CDMA performance based on the permutation scheme is superior in terms of BER and PSNR compared to that based on hybrid chaos. This highlights the effectiveness of the permutation scheme in implementing robust and high-quality image transmission over the MC-CDMA system.

The remnant of the paper is arranged as follows. *Section II* describes the encryption methods, which are permutation and hybrid chaos. *Section III* states and analyzes the MC-CDMA transmission model, while *section IV* discusses and compares the simulated results of the models. *Section V* summarizes the performance of the models.

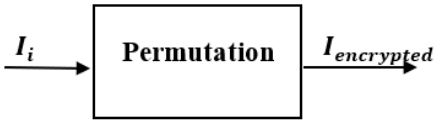
2. ENCRYPTION SCHEMES

Since the effectiveness of fading and channel errors on wireless channels in data transmission, error correction codes are assigned to protect the transmitted data from random errors in the wireless communication channels.

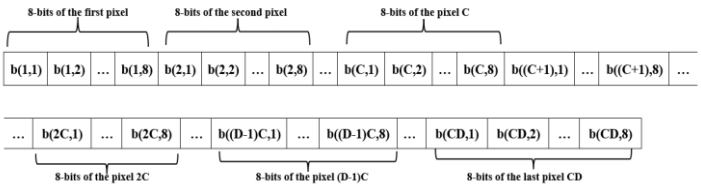
Encryption is the process of reordering the data symbols to be transmitted based on a predetermined rule to spread error bursts over multiple symbols instead of affecting sequential symbols. At the receiver, the original data symbols are returned based on the inversed rule. Different encryption techniques [8, 9, 10] were found. Most of these techniques were considered simple and effective, but they could still suffer from some burst errors. This paper describes and simulates the most straightforward permutation and hybrid chaotic schemes using MATLAB code.

2.1. Proposed Permutation Scheme

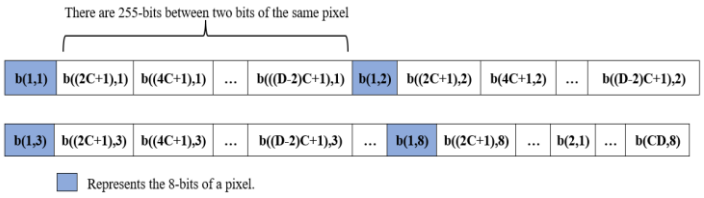
The transmitted signals suffer from fading and impose channel errors. Most error correction codes are assigned to protect the transmitted data from random errors in the wireless communication channels. However, burst error, a contiguous sequence of errors, could not be figured out [3]. Permutation is one method of randomizing burst errors, which is used to enhance error-correcting codes performance. Generally, a permutation scheme reorganizes the ordering of data signals to be transmitted based on a predetermined rule. This process spreads error bursts over several symbols of such a signal instead of affecting consecutive symbols. However, several permutation techniques, interleaving techniques, were considered, such as block interleaving, 1-D interleaving, and 2-D interleaving [10], and others. This paper describes and simulates the most straightforward permutation scheme using MATLAB code. It is applied to a binary image. The quality of an image is significantly harmed by burst error. Consequently, to diminish the effects of burst error on image transmission, the permutation scheme procedure is performed as shown in *Fig. 1*. First, a gray image is converted to a binary image. Moreover, each pixel in an image is represented by eight bits, which corresponds to the grayscale level of the image. Then, it is converted to a vector as shown in *Fig. 1b*.



(a) Permutation scheme



(b) Bit stream of the original image.



(c) Bit stream of the encrypted image.

Fig. 1. Permutation process.

Where I_i is the bit stream of the original image as shown in *Fig.1(a)*, which is demonstrated in *Fig.1(b)* while *Fig.1(c)* demonstrates I_encrypted. It is the output bit stream of the permutation process. Where C and D present the total pixel numbers in the row and column of the original image, respectively. As shown in *Fig1*., this proposed permutation scheme significantly diminishes the burst error.

2.2. Proposed Hybrid Scheme

The encryption techniques based on chaos are an efficient method for securing and scrambling the data because of the behavior and performance of a chaotic system, which is unpredictable and sensitive to initial conditions, as the non-periodicity and the randomness [11, 12]. These chaos characteristics have made the close relationship between the encryption and the chaos itself for securing the transmission of multimedia data, such as audio, image, and video, and preventing a widespread error, "burst error" in a wireless channel [3]. The main issues of using chaos with the image encryption process are the diffusion and confusion processes of the position and value of the pixel, respectively, by using the randomness generated by chaos [13]. In this paper, the 2D chaotic map will be used to add two levels of security: the first

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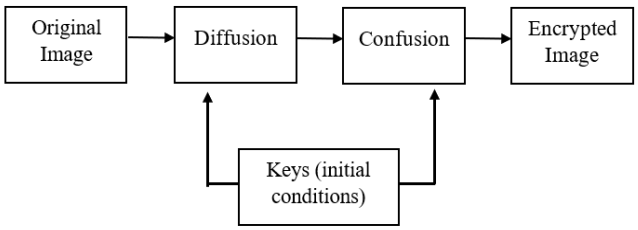
level is pixel diffusion or permutation, and the second level is pixel value confusion or transformation, as shown in *Fig.2*. The keys to this process are the initial conditions of the chaotic maps.



(a) Hybrid chaotic scheme

	1	2	3	4	.	.	C
1	254	255	255	254			
2	254	218	188	192			
3	255	186	116	126			
4	255	191	126	143			
.							
.							
D							C*D

(b) Original analog image matrix

	1	2	3	4	.	.	C
1	254	255	255	255			
2	255	51	57	104			
3	255	79	61	126			
4	255	96	205	118			
.							
.							
D							C*D

(c) Diffused image matrix

	1	2	3	4	.	.	C
1	187	199	190	193			
2	203	210	194	197			
3	193	205	198	202			
4	194	205	201	203			
.							
.							
D							C*D

(d) Key generated matrix by Hennon map

	1	2	3	4	.	.	C
1	69	56	65	62			
2	52	225	251	173			
3	62	130	251	180			
4	61	173	4	189			
.							
.							
D							C*D

(e) Confused image matrix

Fig.2. Hybrid chaotic process.

To describe and illustrate the process, the hybrid chaotic scheme is applied to the original analog image as shown in the *Fig.2a* which includes: Diffusion, and Confusion process. Diffusion Process is used to get position permutation using the logistic map as shown in *equation (1)*.

$$x_{n+1} = r\, x_n\,(1 - x_n) \quad (1)$$

Where x_n is the chaotic value at step n and it is a sequence from 1 to the total pixel number of the original image. r is the chaotic parameter (3.99 for strong chaos) with x_0 being the initial condition. The pixel position in the original image is permuted by using the logistic equation for both row and column [14] as shown in *eq. (2) and (3)*.

$$c_{new} = \lfloor (r\, c\, (1-c) \ mod\ C) + 1 \rfloor \quad (2)$$

$$d_{new} = \lfloor (r\, d\, (1-d) \ mod\ D) + 1 \rfloor \quad (3)$$

*w*here c and d present the row and column index of the original analog image as shown in *Fig. 2b,* respectively. c_{new} and d_{new} present the row and column index of the diffused analog image as shown in *Fig. 2c,* respectively. Also, $\lfloor * \rfloor$ present the floor function.

The confusion process is value modification using the Hennon map as demonstrated in *eq. (4) and (5).*

$$y_{n+1} = 1 - a\, y_n^{\,2} + z_n \quad (4)$$

$$z_{n+1} = b\, y_n \quad (5)$$

Where $a = 1.4$ and $b = 0.3$ Henon parameters are for generating chaos. The y and z vectors are reshaped to generate Y and Z matrices with the equivalent dimension of the original image. Then, the Key matrix K is generated by *eq. (6)* and it is shown in *Fig. 2d.*

$$K = \left\lceil f \frac{YZ}{\overline{YZ}} \right\rceil \quad (6)$$

Where f is the confusion factor. $\lceil * \rceil$ present the ceiling function and $\bar{*}$ present the mean of the variable. K used in the confusion process [15], [16], [17] to get the confused matrix shown in *Fig.2(e)* by bit-wise exclusive or between the diffused matrix and the key generated matrix.

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3. MC-CDMA IMAGE TRANSMISSION MODEL

Code Division Multiple Access is a digital method of sharing the frequency spectrum. Multi-carrier users are transmitting in the same frequency band, in which each user is separated from the others via the employ of the spreading code, which is an orthogonal code [3]. This section represents the three-user transmitter and receiver model of the MC-CDMA system implementing two different encryption schemes. One implements a permutation scheme as described in *2.1* subsection, and the other implements a hybrid Chaotic scheme as described in *2.2* subsection. The three-user transmitter model is shown in *Fig. 3*. It is proposed that three users are active in the MC-CDMA system.

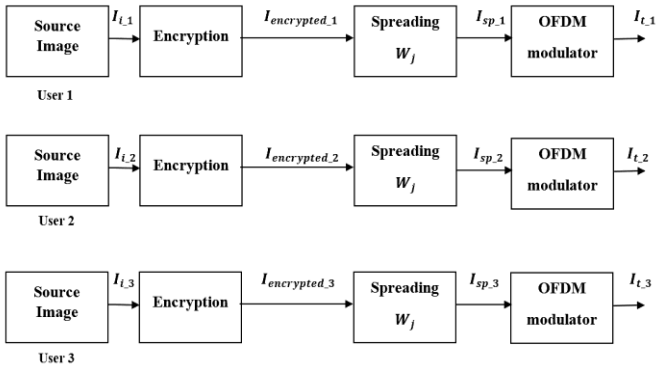

Fig. 3. Transmitter model of image transmission-based MC-CDMA

Three users' signals are encrypted by permutation and hybrid chaotic. $I_{encrypted}$ is the bit sequence of the encrypted image, which is the output of either the permutation or the hybrid chaotic scheme, corresponds to each user. It is noted that the output of the hybrid chaotic scheme, the confused matrix, is converted to a vector and then digitized.

In the spreading stage, each symbol of $I_{encrypted}$ is multiplied by the unique spreading code, W_j [3] as given in (7) to get the spreading sequence.

$$W = [W_0, W_{1,} \dots W_{m-1}]^T \quad (7)$$

Where W is a Walsh–Hadamard matrix with length m.

$$I_{sp} = I_{encrypted} * W_j \quad (8)$$

Where I_{sp} is the spreading sequence that corresponds to each user. Next, the OFDM modulator is applied to each user separately, which consists of an IFFT block then the cyclic prefix is added to the transmitting data to minimize the effect of Inter-Symbol Interference (ISI) and delay spread as in OFDM. Where I_{t_1}, I_{t_2}, and I_{t_3} are the sequences of the transmitted symbols, which are transmitted on the same Rayleigh channel, frequency, and time.

On the other hand, the opposite operations are performed at the receiver as shown in *Fig. 4* to extract all three different images transmitted from three different users at the same time, frequency, and channel. At the receiver side, the received vectors as *eq. (9)*.

$$I_r = (I_{t\_1} + I_{t\_2} + I_{t\_3})h + n \quad (9)$$

Where I_r is the received vector after combining the three different users. h and n present the Rayleigh channel and AWGN noise, respectively.

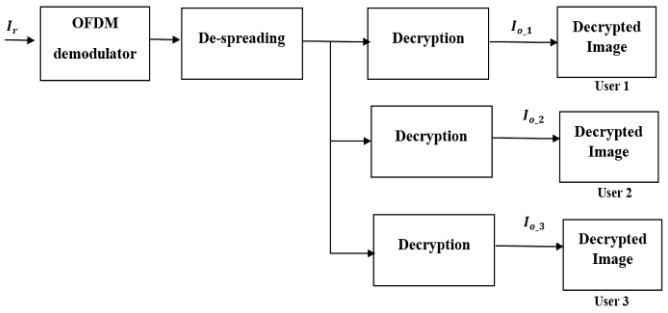

Fig. 4. Receiver model of image transmission-based MC-CDMA

4. RESULTS

This section introduces and discusses the MATLAB simulations' obtained results. Two scenarios have been utilized for programming. The first scenario implements a permutation scheme for different user numbers, while the second uses a hybrid chaotic scheme for different user numbers in the MC-CDMA model. The simulation parameters are tabulated in *Table I.* Regarding BER, it compares the performance of BER for multiuser cases in the Rayleigh channel with the MC-CDMA model. The Bit Error Rate (BER) is determined by analyzing the decrypted image for each user. The performance of the two scenarios for a single user is presented in *Fig. 5.*

Table I. Compares the performance of BER for multiuser cases in the Rayleigh channel with the MC-CDMA model.

Parameters	Description
Spreading codes	Walsh–Hadamard Code
Cyclic prefix	3
IFFT points	8 points
Channel	Rayleigh flat fading channel
Noise	Additive White Gaussian Noise AWGN
No. of users	1, 2, and 3

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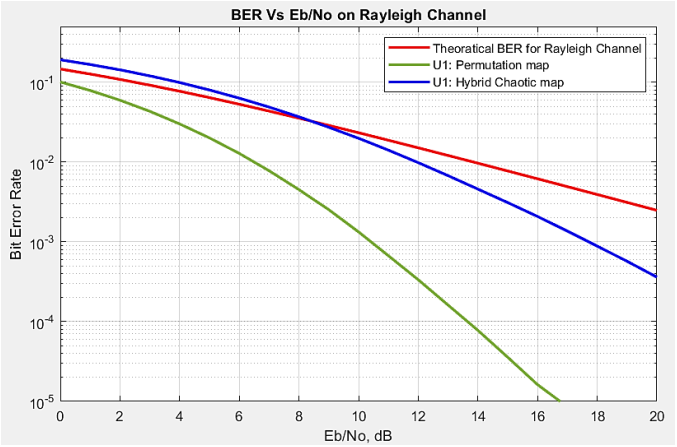


Fig. 5 BER performance of two scenarios for a single user

It is observed that the BER of the proposed permutation scheme is the best for single-user CDMA. BER of the proposed permutation scheme is better than the hybrid chaotic scheme at the second user of MC-CDAM as shown in *Fig.6.* However, the BER performance is almost the same, with increased users for both the proposed permutation scheme and the hybrid chaotic scheme as shown in *Fig.7*. It is observed that BER will be worse for both scenarios if the number of users increases.

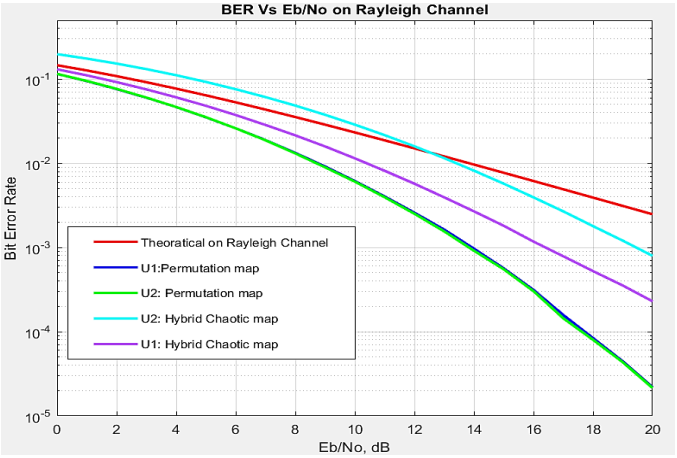


Fig. 6 BER performance of two scenarios for two users

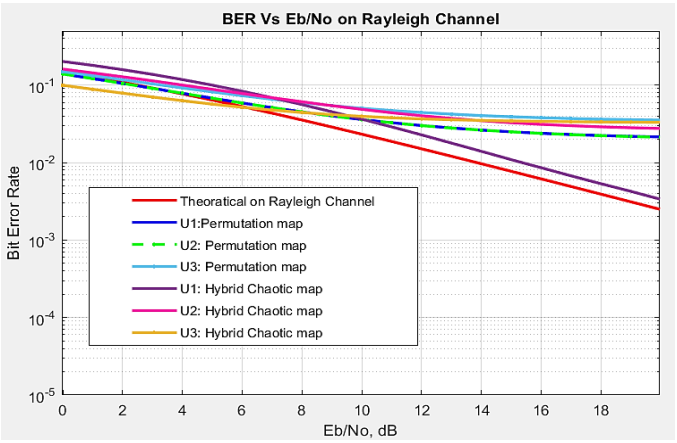
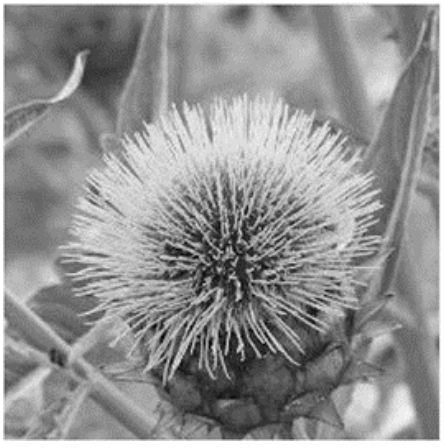


Fig. 7 BER performance of two scenarios for three users

However, these performances have improved compared to [7] which used a more complicated system with and without MIMO techniques. To demonstrate the efficiency and performance of the two proposed encryption schemes, three different grayscale images have been used as inputs corresponding to each user, as shown *Fig.8.*

(a) User1

(b) User2



(c) User3

Fig. 8 Original images of three different users.

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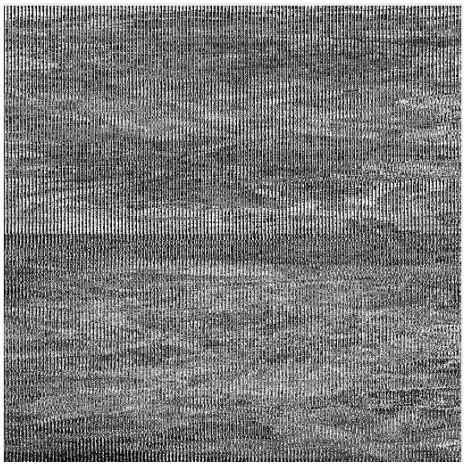
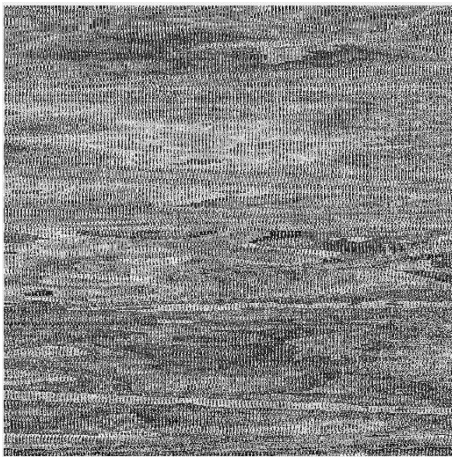
Fig.9 shows the encrypted images of both scenarios for three different users. *Fig.10* shows the decrypted, received, images of both sceneries for different numbers of users in the MC-CDMA model at SNR=20 dB.

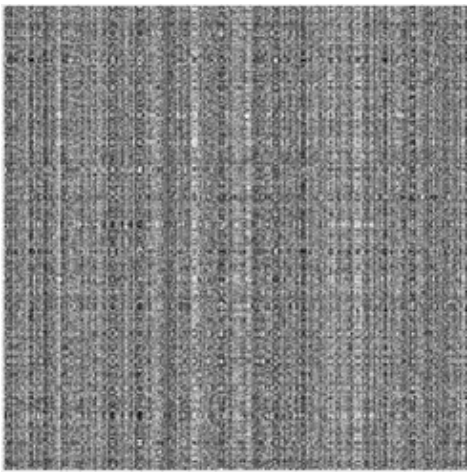
(a) User1: Permutation



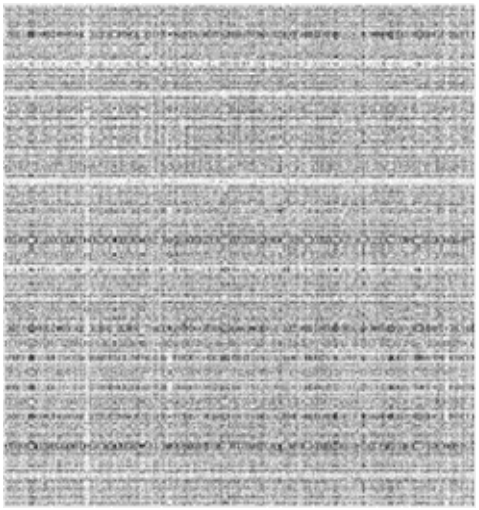
(b) User2: Permutation



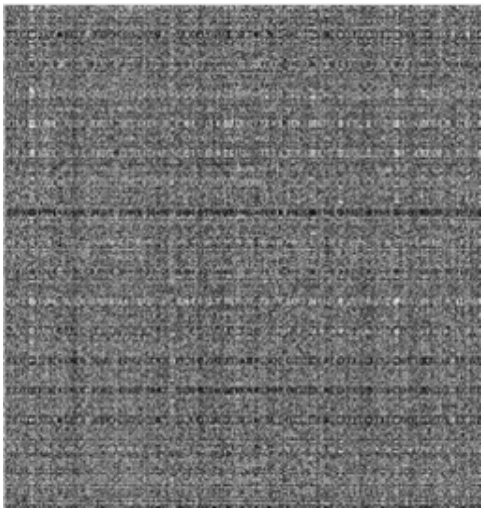
(c) User3: Permutation



(d) User1: Hybrid Chaotic



(e) User2: Hybrid Chaotic



(f) User3: Hybrid Chaotic

Fig. 9 Encrypted images of both scenarios for three different users.

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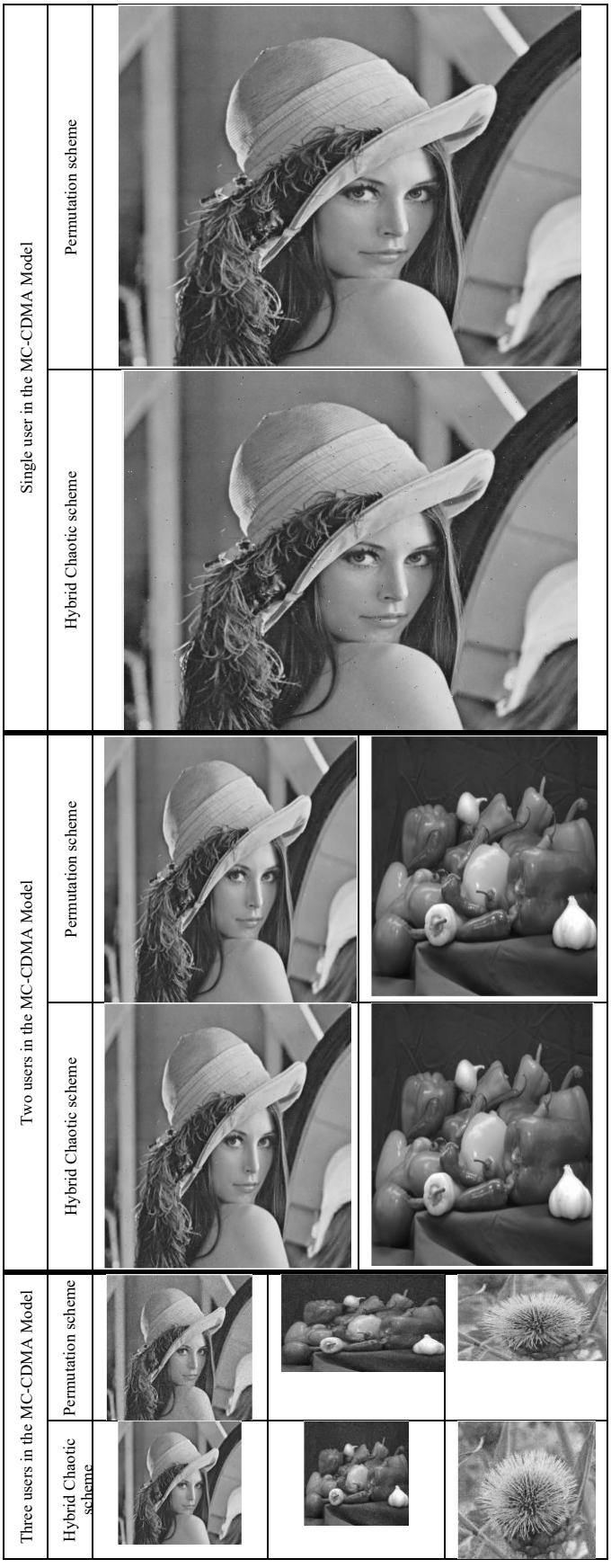

Fig. 10 Decrypted images of both scenarios for three different numbers of users.

From *Fig.10*, the MC-CDMA image transmission system employing a permutation scheme transmits images more efficiently. Additionally, this paper includes two parameters to determine the quality of the reconstructed image and compare the received image with the source image.

5.1. Root Mean Square Error (RMSE)

The parameter RMSE can be defined as the square root of the mean squared error of the entire image. It is defined as [4]:

$$\text{RMSE} = \sqrt{\frac{\sum_{c=1}^{C}\sum_{d=1}^{D}\left((\mathrm{I_i}(c,d)-(\mathrm{I_o}(c,d)\right)^2}{CD}} \quad (10)$$

Where CD indicates the total number of pixels in the transmitted image.

5.2 Peak Signal-to-Noise Ratio (PSNR)

It is utilized to measure the reconstructed image quality at the receiver [18],[19].

$$PSNR = 10\log_{10}\frac{k-1}{\frac{1}{CD}\sum_{c=1}^{C}\sum_{d=1}^{D}[\mathrm{I_i}(c,d)-\mathrm{I_o}(c,d)]^2} \quad (11)$$

Where k is the number of the grayscale level in the two images. *Table 2* and *Table 3* represent the performance of the MC-CDMA model for both scenarios in terms of RMSE and PSNR at $SNR = 20\ dB$, respectively.

Table 2. Root Mean Square Error for hybrid chaotic and permutation systems

System models	User's number	RMSE hybrid chaotic system		RMSE for permutation	
		RMSE between original & encrypte	RMSE between original & decrypted	RMSE between original & encrypted	RMSE between original & decrypted
Single user – CDMA	1	83.9983	2.8128	91.3536	0.0313
Two users-MC-CDMA	1	83.9983	4.3098	91.3536	0.7730
	2	129.0328	2.2089	100.0210	0.6871
Three users-MC-CDMA	1	83.9983	8.4529	91.3536	21.3297
	2	129.0328	24.0452	100.0210	21.5979
	3	81.4870	26.8722	85.1912	27.3492

A comparison is made between the original image and the encrypted image, followed by the original image and the decrypted, received, image for hybrid chaotic and permutation scenarios.

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From *Table 2*, RMSE values between the original and encrypted images are high for both schemes to provide security of image transmission. RMSE between the original and decrypted images increased with the number of users. RMSE for permutation is better than for a hybrid chaotic system.

System models	User's number	PSNR for hybrid chaotic system		PSNR for permutation	
		PSNR between original & encrypted	PSNR between original & decrypted	PSNR between original & encrypted	PSNR between original & decrypted
Single user – CDMA	1	9.6454	39.1481	8.9163	78.2338
Two users-MC-CDMA	1	9.6454	35.4417	8.9163	50.3670
	2	5.9168	41.2472	8.1290	51.3906
Three users-MC-CDMA	1	9.6454	29.5907	8.9163	21.5511
	2	5.9168	20.5102	8.1290	21.4462
	3	9.9090	19.5447	9.5229	19.3919

Table 3 shows that the quality of the extracted image will be low with an increasing number of users. The PSNR values of the permutation scheme are more efficient and acceptable than those of a hybrid chaotic system. These performances for both schemes are better than the simulated results of [3] because of utilizing a hybrid chaotic scheme instead of a chaotic Baker map. Also, our proposed interleaving procedure is more efficient than [3] due to randomizing the sequential bits of the signal, increasing the PSNR, and minimizing BER. The performance of this work is also compared with [20], From comparison, the BER in this work when using the permutation scheme as an encryption method for single user and two users is better than [20], which used DS-CDMA, with an MSE equalizer, Proakis B channel, Nfft=16 and Nuser=1,4,6 and 8.

5. CONCLUSION

MC-CDMA system supports multiple users simultaneously without expanding the frequency band over the same network. The article aims to analyze, discuss, and compare the image transmission performance via the MC-CDMA system using permutation and hybrid chaos. Moreover, using MATLAB coding, a different number of users is applied via the MC-CDMA model for both scenarios. One scenario is image transmission via MC-CDMA employing a permutation scheme for three steps: single user, two users, and then three users. The other scenario employed a hybrid chaotic scheme for a similar procedure of three steps. Each user transmits a different independent image. From the simulated results, it has been concluded that the MC-CDMA image transmission system employing a permutation scheme transmits images more effectively and better in terms of BER, RMSE, and PSNR than using a hybrid chaotic scheme over the Rayleigh channel. However, the performance of both scenarios is almost the same when the number of users in the MC-CDMA model is increased. It will be worse with increasing the number of users. It can be solved for future work.

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