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IMPROVING RELIABILITY, CAPACITY, AND SECURITY OF AUDIO TRANSMISSION BASED ON MULTIPLE ANTENNAS USING MGSTC TECHNOLOGIES

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Abstract

Due to of the importance and increase of security requirements in the transmission of data, the process of hiding information is considered one of the contemporary and appropriate technologies for these requirements. We demonstrate an audio hiding based on multiple input multiple output antennas (MIMO) communication systems. The MIMO communication system is one of the modern technologies used in wireless communication systems which comprises several technologies, including Multi Group Space Time Codes (MGSTC) that is implementing in this paper. Moreover, three different types of MGSTC methods are proposed using OSTBC and NON-OSTBC depending on their code rate in order to least complexity, full diversity and simple decoding. The proposed system is investigated and carried out by evaluating in terms of security, data rate, bit error rate, as well as the Peak signal to noise ratio (PSNR). The Proposed system is employed by Matlab simulation. The results show the significant improvements in BER and PSNR of the stego transmitted signal in the first case of our proposed system that leads to the best case of extracting secret signal. While the channel capacity performance is the best for the third case of our proposed system.

Keywords: Audio transmission, MGSTC, NOSTBC, OSTBC, PSNR.

1.Introduction

Due to the increasing in the demands for security in the global, hiding data could be a significant technology in such afield. Data hiding has widespread with the security of communication and protection. As known, the carrier signal that convey the hidden data, it could be audio, image, text and video. Due to the data hiding, the statistical properties of these carriers were modified [1, 2]. Moreover, the most significant challenge facing the system is increasing frequency spectrum efficiency in order to increase the system capacity [3]. Hence, multiple antennas system, present effective technologies, are used to mitigate these challenges, by implementing the space time code (STC), to improve wireless spectrum efficiency [4]. Moreover, the channel coding is utilized to enhance the reliability of transmitted data. Besides, data rate and quality of wireless communications system were improved, without effect on the transmitted power and the bandwidth of the channel, are some of the advantages of multiple antenna technology [5].

For MIMO systems the spatial multiplexing (SM) and space time coding (STC) are two types of transmission technique. With SM systems, encoded data are transmitted separately meaning different streams of data. STC technique is used to transmit redundant information and multiple copies of data over MIMO. Those techniques are achieved an improvement in transmission rate and reliability. STC for multiple antennas system is contained two categories: space-time block codes (STBC) and space-time trellis codes (STTC) and both are achieving full diversity. The input symbols are arranged as block with STBC to produce matrix output, with that matrix the rows represent antennas, and the columns represent the time. STBC is presented with this work due to least complexity, full diversity, and simple decoding, STBC is divided into two subcategories: orthogonal space-time block codes (OSTBC), and non-orthogonal space-time block codes (NOSTBC) [6].

There are many research works are presented for transmitting multimedia signals with multiple antenna techniques. Alamouti coding, was utilized with Data hiding technology in MIMO system, where it derives and analyses of the capacity of data hiding. This is confirmed by Chen and Lu [3]. The researchers have evaluated the suggested system, which is wireless steganography by the MIMO system through the E-DSM transmission by the simulation. They are found an improvement in the performance of the BER of the stego signal comparison with employing SISO [7]. Furthermore, there was studying the equitability of the transmitted audio signal by using MGSTC channel coding with various Channel equalization conception. The results have shown that the system is effective and robust in receiving the audio signal and that through utilizing Turbo channel coding, MMSE-SIC signal detection technique and 16-QAM digital modulation [8]. In addition, this paper investigates the effectiveness of MGSTC BLAST spatial multiplexing scheme on transmitting colour image in MC-CDMA wireless communication. Results explain the robustness in receiving transmitted signals by MMSE-SIC signal detection [9].

Chen et al. [10] proposed hiding information systems employing MIMO-OFDM system and applied the principle of error correction in the channel coding as well as the evaluation and analysis are carried out for the proposed system. The authors were proposed MGISAP algorithm with MGSTC in MIMO system and the results illustration the improving in resistance to fading and reducing BER [11]. Moreover, Hamidian and Mohamed [12] investigated and improved the performance of MGSTC by using parallel decoding algorithm. This new algorithm reduces the total time of signal detection. While Wang et al. [13] proposed a steganography method with high capacity based on hamming code and LSB so the results have shown that system has high image equality and high capacity.

This paper presents a data hiding system using Multi Group Space-Time Codes channel coding, MGSTC is a method of MIMO communication system. Additionally, STBC is used with this work. STBC includes two subcategories: orthogonal space-time block codes (OSTBC), and non-orthogonal space-time block codes (NOSTBC). The system presented with this work is implemented and evaluated in terms of bit error rate, security, data rate, as well as the Peak signal to noise ratio (PSNR), which resulting in, an enhancement with data rate, diversity, bit error rate (BER) as well as the Peak signal to noise ratio (PSNR). Moreover, the paper is proposed and discussed three different code rates of STC by transmitting k=3, 4, and 5 symbols which is number of symbols in each STC block of the MGSTC system. The signal is transmitted over a Rayleigh flat fading channel, with additive white Gaussian noise (AWGN) matrix.

This paper is organised into seven sections. Section 1 is introduction; Section 2 has been proposed system model of data hiding and MGSTCS then theoretical analysis for MGSTC method has been introduced in Section 3. In addition, Section 4 deals with channel capacity of MGSTC system. Diversity of MGSTC system is explained in Section 5. While section 6 is discussed and analysed the results. Lastly, the conclusion of this paper is listed in Section 7.

2. The System Model of Data Hiding and MGSTCS

The structure of the proposed system summarizing the audio steganography based on MIMO system depicted with Fig. 1. In the first step, the system presents information hiding technology. The secret data (audio signal) are embedded in the carrier data (image signal) by using a least significant bit (LSB) algorithm [14, 15]. The modulated signal is modulating by QPSK modulation. These symbols moved as input to the encoder after passing the serial to parallel converter (S/P) which is divided the symbols into two groups. MGSTCs technique is used, then each group is fed to the space-time codes (STC), and it has three antennas $n = 3$. In this work two proposed techniques of STC were suggested, non-square OSTBC and non-square NON-OSTBC techniques. Then, the signal is transmitted over Rayleigh flat fading channel. Finally, at the receiver, the MGSTC decoder has received the signal by N_r antennas. The Basic MIMO signal transmission and detection in Matrix form can be described as [16, 17]:

$$Y = HX + Z \tag{1}$$

where $Y, and\ X$ received and transmitted signal matrix, respectively; while H, Z are transmission channel matrix and (AWGN) matrix correspondingly. The stego transmitted data was decoded using MGSTCs technique and demodulated at the receiver. By the extraction algorithm, the secret information is extracted from the carrier information at the destination.

However, Fig. 2 shows the procedure of hiding secret data and the relation between the bit length of carrier signal M and the position of data hiding in carrier signal $i(I)$ depending on LSB algorithm, where the LSB algorithm steps could explain briefly below:

i. Transform 2-D grey image (carrier signal) with (512×348) into 1-D image (178176).
ii. Each pixel in grey image is denoted by (8-bits/pixel), so M = 512×348×8 = 157864 bits where M represent bit length of carrier signal.
iii. Transform audio signal (secret signal) with (13129×1) into audio signal (105032) bits.
iv. Replace the value of eighth bit in carrier signal (BBI8), by the value of first bits from secret signal (BBA1) and continue the process of replacing all audio bits into the image.
v. Convert back from binary to decimal and then from 1-D to 2-D to get stego- image.

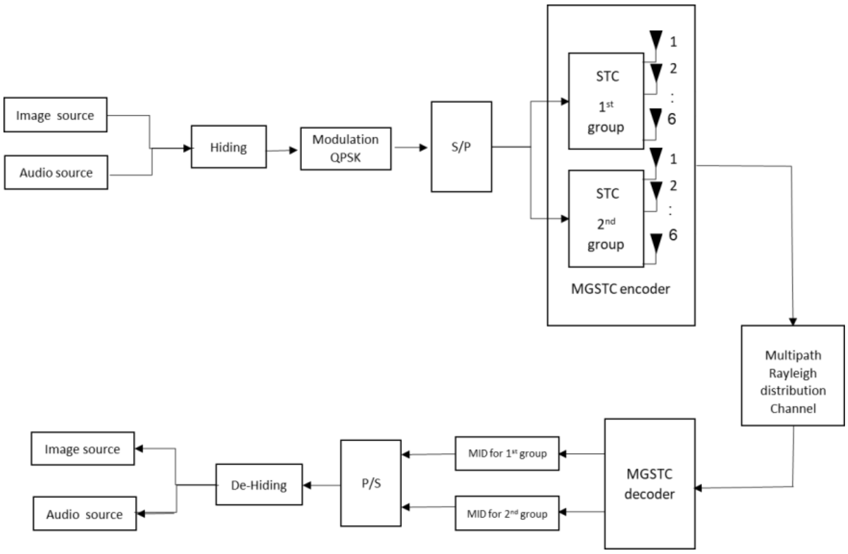
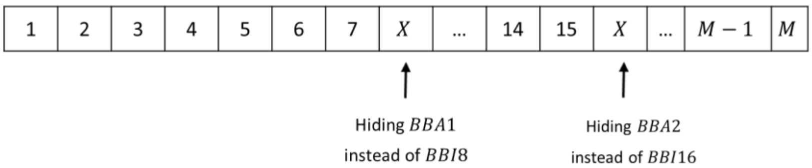
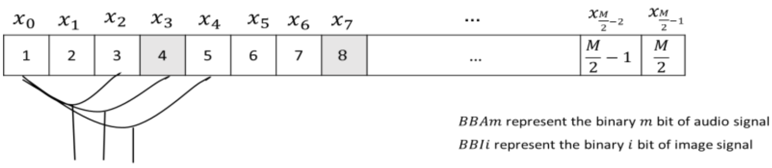


Fig. 1. Proposed system model.



(a) Audio hiding using LSB.



(b) Modulated Audio hiding using LSB.

Fig. 2. Hiding procedure.

Each code matrix of non-square non-OSTBC and non-square OSTBC have own code rate r_s

$$r_s = k/p \tag{2}$$

The k represents the number of symbols transmitted in such block and p denotes the number of symbol periods that are required to transmit all this STC block. Therefore, this research is stated and discussed three different code rates of STC by transmitting k =3, 4, and 5 symbols in each STC block of the MGSTC system.

3.Theoretical Analysis for MGSTC Method

The main idea of MGSTC is achieving spatial diversity and spatial multiplexing together simultaneously in MIMO communication technology [12]. With this section the idea of MGSTC, which represents the contribution of this work, will be present. Therefore, it is divided into two subsections, the first covers the design of the MGSTC encoder matrix for three proposed cases depending on the number of symbols transmitted (k), whilst the second represents the analysis of MGSTC decoder.

3.1. Analysis of MGSTC encoder

The encoder algorithm of MGSTC has been analysed in detail in this section. The number of independent data streams, which are transmitted simultaneously, must be equal to the minimum number of transmit and receive antenna. Although, receiving antennas number must be greater or equal to the transmitted antennas to allow the receiving antennas from detecting all independent data streams that have been sent. Hence, the highest number of streaming data that could be sent and they must be equal to:

$$N_{stream} = Nt = 6 \tag{3}$$

where N_{stream} is data streams and Nt is transmitted antenna. The main idea of the MGSTC is splitting the sequence of bits into q groups where each one of q contains $B1, B2, \dots, Bq$ bits, respectively. These groups of bits' feds to the particular group of the transmitting antennas by STC encoder and that is known as a component code. Where the $X_{C1}, X_{C2}, \dots, X_{Cq}$, is denoted the outputs of the component code. Thus, the matrix X is indicated to the transmitted signal and expressed as [3, 5]:

$$X = \begin{bmatrix} X_{C1} \\ X_{C2} \\ \vdots \\ X_{Cq} \end{bmatrix} \tag{4}$$

where the component (X_{C1}) could be shown as

$$X_{c1} = \begin{bmatrix} X_1 & \cdots & X_1 \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{n1} \end{bmatrix} \tag{5}$$

In this work, the proposed system contains $N_{stream} = 6$, as shown in Eq. (3), and two groups in each group $n = 3$ antennas. Therefore, the transmitted matrix will equal to

$$X = \begin{bmatrix} X_{C1} \\ X_{C2} \end{bmatrix} \tag{6}$$

These transmitted signals Matrix X is different depending on STBC type as follows:

3.1.1. Non-orthogonal space time block coding (NON-OSTBC)

Non-square non-OSTBC is discussed and designed using two different STC matrix depending on its size. For simplicity, the p value is 4 for both cases while value of k is different as follow:

For $k = 4$, in this case, the code rate r_s = 1 where the number of transmitted symbols k is equal to the number of symbols (time) period p and the STC matrix of this scenario become as:

$$X_{cjj} = \begin{bmatrix} x_{j} & -x_{j+1}^{*} & -x_{j+2}^{*} & -x_{j+3}^{*} \\ x_{j+1} & x_{j}^{*} & x_{j+3} & x_{j+2}^{*} \\ x_{j+2} & x_{j+3}^{*} & x_{j}^{*} & x_{j+1}^{*} \end{bmatrix} \tag{7}$$

Where jj refers to any STC matrix in each case, and j refers to the numbering of the modulated symbols. In addition, the columns number represents $p = 4$, while the rows number represents $N = 3$ antennas of such STC group. These imply that each row will be transmitted through a corresponding antenna by mapping these four independent symbols during four symbols (time) periods.

While for $k = 5$, the second scenario, the code rate $r_s = \frac{5}{4}$, therefore, the general STC matrix in this case becomes:

$$X_{cjj} = \begin{bmatrix} x_{j} & -x_{j+1}^{*} & -x_{j+2}^{*} & -x_{j+3}^{*} \\ x_{j+4} & x_{j}^{*} & x_{j+3} & x_{j+2}^{*} \\ x_{j+2} & x_{j+3}^{*} & -x_{j+4}^{*} & x_{j+1} \end{bmatrix} \tag{8}$$

3.1.2. Orthogonal space time block coding (OSTBC)

This section presents the last proposed scenarios, the full code rate is 1, and it is achieved by utilizing the Alamouti code. However, in this proposed system, there is an $n = 3$ antennas in each STC block and $p = 4$ for good compression. Due to orthogonality, where $k = 3$, STC matrix become as:

$$X_{cjj} = \begin{bmatrix} x_{j} & -x_{j+1}^{*} & x_{j+2}^{*} & 0 \\ x_{j+1} & x_{j}^{*} & 0 & x_{j+2}^{*} \\ x_{j+2} & 0 & -x_{j}^{*} & -x_{j+1}^{*} \end{bmatrix} \tag{9}$$

The orthogonal STC means that the multiplication result of each row by the Hermitian of any other row is zero [16]. Therefore, the code rate for this scenario is $r_s = \frac{3}{4} = 0.75$. This implies that this system can be transmitted three independent symbols in each STC block during four symbols periods.

3.2. Analysis of MGSTC decoder

At the receiver, MGSTC decoder, the main problem appearing is the intergroup interference. Because the component code for each receiver has interferences from all other component codes. Therefore, MGSTC decoder provides a significant solution to mitigate Inter-group interference. Therefore, H is referred to the channel matrix and it is decomposed into the following Eqs. as appearing below [2, 3]

$$H = \begin{bmatrix} h_{1,1} & \dots & h_{1,3} & h_{1,4} & \cdots & h_{1,6} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ h_{6,1} & \dots & h_{6,3} & h_{6,4} & \cdots & h_{6,6} \end{bmatrix} \quad (10)$$

$$H = \begin{bmatrix} H_{C_1} & H_{C_2} \end{bmatrix} \quad (11)$$

Hence, the H_{C1} denotes the channel section dealing with the X_{C1}that refers to the transmitting the first STC group of a MGSTCs system $n = 3$. while $H\_C2(N\_t \times (N\_r - n)$ channel section is associated with transmitting the second STC group of a system.

For decoding the (X_{C1}), it is important to be the number of receiving antenna Nr satisfies the formula of $Nr \geq Nt - n + 1$. Also, for suppressing all the interference of the remaining signals which are related to H_{C2} and that could occur through pre-multiplying of Y by the matrix as shown in the Eq. below:

$$\widetilde{Y_{c_1}} \triangleq \Theta_{C2}\, Y \quad (12)$$

The Y denotes the received signal Matrix, $Y = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}$ while $\widetilde{Y_{c_1}}$denotes to estimate received signal matrix once interference suppression occurred and Θ_{C2} includes the set of null space vectors of H_{C2}, where each row is an orthonormal basis vector of the null space of H_{C2} as shown below:

$$\Theta_{C2}\, H_{C2} = 0_{(\mathrm{Nr-Nt+n})\times(\mathrm{Nt-n})]} \quad (13)$$

The received matrix clarifies in Eq. (13) with assuming of the Rayleigh distributions

$$Y = \sqrt{\rho}\, HX + Z \quad (14)$$

Substitute Eqs. (14), (11), and (6) in Eq. (12), the $\widetilde{Y_{c_1}}$ could be written as:

$$\widetilde{Y_{c1}} = \sqrt{\rho}\, \Theta_{C2}\, H_{C_1}\, X_{C_1} + \Theta_{C2}\, Z \quad (15)$$

Eq. (15) indicates that the energy of the estimated received signal $\widetilde{Y_{c_1}}$ is only from X_{c1}. Therefore, the interferences from all other STC block have disappeared. So, Eq. (16) is written as below:

$$\widetilde{Y_{c1}} = \sqrt{\rho} H_1^{eff} X_{C_1} + \tilde{Z}_{C2} \quad (16)$$

where each H_1^{eff} and $\tilde{Z}_{C2}$ denote to the effective channel matrix and noise respectively and both are related to the first component code, Eqs. (17) and (18) are written for expressing them

$$H_1^{eff} = \Theta_{C2}\, H_{C_1} \quad (17)$$

$$\tilde{Z}_{C-C_1} = \Theta_{C2}\, Z \quad (18)$$

To estimate and compute X_{C_1}, Maximum likelihood is used, and that carried out by applying it to the Eq. (16). So, the formula becomes as:

$$\widehat{X_{C_1}} = (arg\ min\ _{X_{C_1}}) \left\{ \left\| \widetilde{Y_{C_1}} - \sqrt{\rho}\, H_1^{eff} X_{C_1} \right\|_F^2 \right\} \quad (19)$$

where $\widehat{X_{C_1}}$ denotes the estimated value of X_{C_1}, it could apply the same procedure of decoding the first STC block to decode the remaining of the other STC block after extracting the previously decoded STC block from the main receiving signal. For more explanation, after obtaining $\widehat{X_{C_1}}$, it could use it to cancel the interference associated with X_{C_2} by subtracting it from the main receiving signal. As a result, the following Eq. becomes as:

$$\widetilde{Y_{C_2}} \triangleq Y - \sqrt{\rho}\, H_{C_1} \widehat{X_{C_1}} \tag{20}$$

The decoding method is achieved in a serial way which providing an excellent method to detect the remaining of the STC blocks. Also, this method is improving the diversity order and increasing the transmission data rate simultaneously.

It is important to notice that applying (MLD) differs for each STC techniques. It is not only dependent on modulation types of a system but also on the number of symbols (k) in each STC block technique. The number of possible symbols is 2^2 cases using QPSK modulation. Therefore, the number of possible STC blocks is ^{k} cases. Hence, increasing k leads to increase the MLD complexity. On the other words, there is a trade-off between the complexity of a system and its data rate. Table 1. could explain the iteration of the possible cases.

Table 1. Possible cases of iteration.

k	^{k}**p**OSSIBLE CASES
3	64
4	256
5	1024

4. Channel Capacity of MGSTC System

Generally, the data rate of the MGSTC system depends on not only the number of transmitting and receiving antennas but also, it is depending on the number of modulated symbols that are transmitted in a given symbol (time) period. In this paper, (6×6) MIMO employing the MGSTC method with three different STC matrices, in which each of them can be transmitted a different number of individual modulated symbols depending on the code rate of each STC matrix as follows. When the code rate $r_s = 1$ as stated previously in section 3.1.1 ($k = 4$), this system can be sent four modulated symbols during four symbol periods in each group of MGSTC. Therefore, this system sends eight independent modulated symbols $(X\_(c(jj))\ \ and\ X\_(c(jj+1)))$ during four symbols periods. This implies that the data rate of this system is twice of the SISO system. On the other words, the number of symbol periods that need to transmit this stego signal can be:

$$N_{period} = \frac{Total\ number\ of\ modulated\ symbols}{\begin{matrix} number\ of\ modulated\ symbols \\ that\ are\ transmitted\ during\ 4\ symbol\ periods \end{matrix}} \times 4 \tag{21}$$

where the total number of modulated symbols equals to the half of the carrier data length (M) due to applying QPSK type of modulation.

$$N_{period} = \frac{M/2}{8} \times 4 = 393216 \tag{22}$$

When the code rate $r_s = \frac{5}{4}$ as stated previously in section 3.1.1 (k=5), this system can be sent five independent modulated symbols during four symbol periods in each group of MGSTC. Therefore, this system sends ten independent modulated symbols ($X\_(c(jj))$ and $X\_(c(jj+1))$) during four symbols periods. This imply the data rate of this system is twice and half of the SISO system (2.5 times SISO system). On the other words, the number of symbol periods that need to transmit this stego signal can be calculated from (23) as:

$$N_{period} = \frac{M/2}{10} \times 4 = 314572.8 \quad (23)$$

When the code rate r_s=3/4 as stated previously in Section 3.1.2, this system can be sent three independent modulated symbols during four symbol periods in each group of MGSTC. Thus, this system sends six independent modulated symbols ($X\_(c(jj))$ and $X\_(c(jj+1))$) during four symbols periods. This implies that the data rate of system is one and half of the SISO system (1.5 times SISO system). On the other words, the number of symbol periods that need to transmit this stego signal can be calculated from Eq. (24) as:

$$N_{period} = \frac{M/2}{6} \times 4 = 524288 \quad (24)$$

It is concluded from Eqs. (22) to (24) that the system having smallest value of k has the largest number of symbol periods N_{period} required to transmit the stego signal. In another word, the capacity of the system r_s=5/4 is the largest among the other.

5. Diversity of MGSTC System

The diversity concept is transmitting copies from the original signal over the fading channel where each one of the copies is faded separately from the other and at different times. Thus, the probability of fading the copies is decreasing when the number of them increased. Therefore, diversity is the solution to mitigate the fading affecting [12]. Besides, according to MGSTC, the relation between diversity order and group i depending on the following equation:

$$n_i(N_r - N_t + \sum_{k=1}^{i} n_k) \quad (25)$$

$i = 1, \ldots, q$, the diversity is rising as going from the first group up to q group. As a result, the bit error probability of MGSTC is controlled by the worst group that is associated with the minimum value of the diversity order [12]. Table 2 summarizes the diversity order for each group. It was shown that the diversity order of the higher group is more than the lower one. However; it is increased by increasing the number of antennas in each group. Thus, (6×6) MGSTC system grouped to two is much better than grouped into three groups of STC block.

Table 2. Diversity order of each group of MGSTC system.

GROUP NUMBER	DIVERSITY ORDER
1	$n\ (N_r - N_t + n)$
	$= 3 \times (6 - 6 + 3) = 9$
2	$n\ (N_r - N_t + n + n)$
	$= 3 \times (6 - 6 + 3 + 3) = 18$

6. Results and Discussion

This section discusses, analyses, and presents the simulation results that are employed using MATLAB simulation. The computations have resulted via employed three systems. In each system, the BER performance between the original stego signal and stego received signal with different SNRs are simulated and analysed. The simulation parameters are tabulated in a Table 3. and the simulated results are shown in Fig. 3.

Table 3. Simulation parameters.

Parameters	Description
Data transmitted	Hiding audio
Configuration of antenna	6 × 6
MIMO technique	MGSTC
STC technique	Non square OSTBC Non square NON OSTBC
Date type of carrier	GRAY IMAGE
Modulation and demodulation type	QPSK
Noise type	Gaussian noise or AWGN
SNR (dB)	-5 to 5
Channel type	Flat Rayleigh distribution

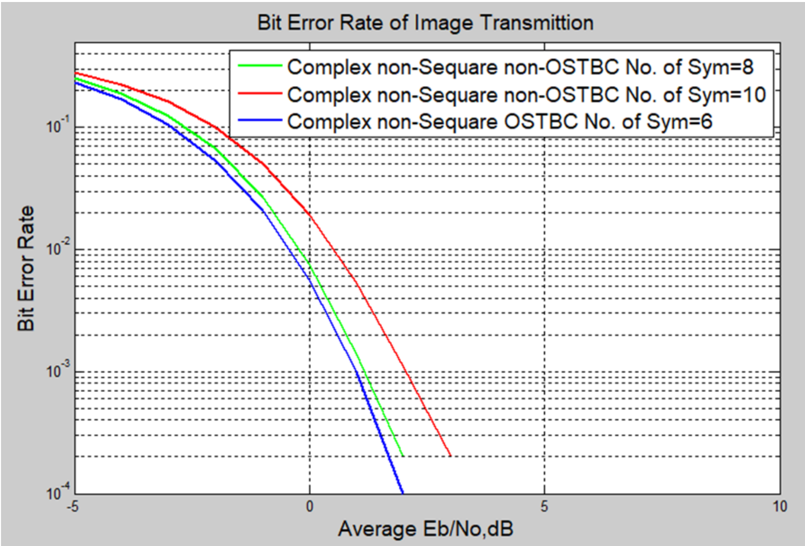
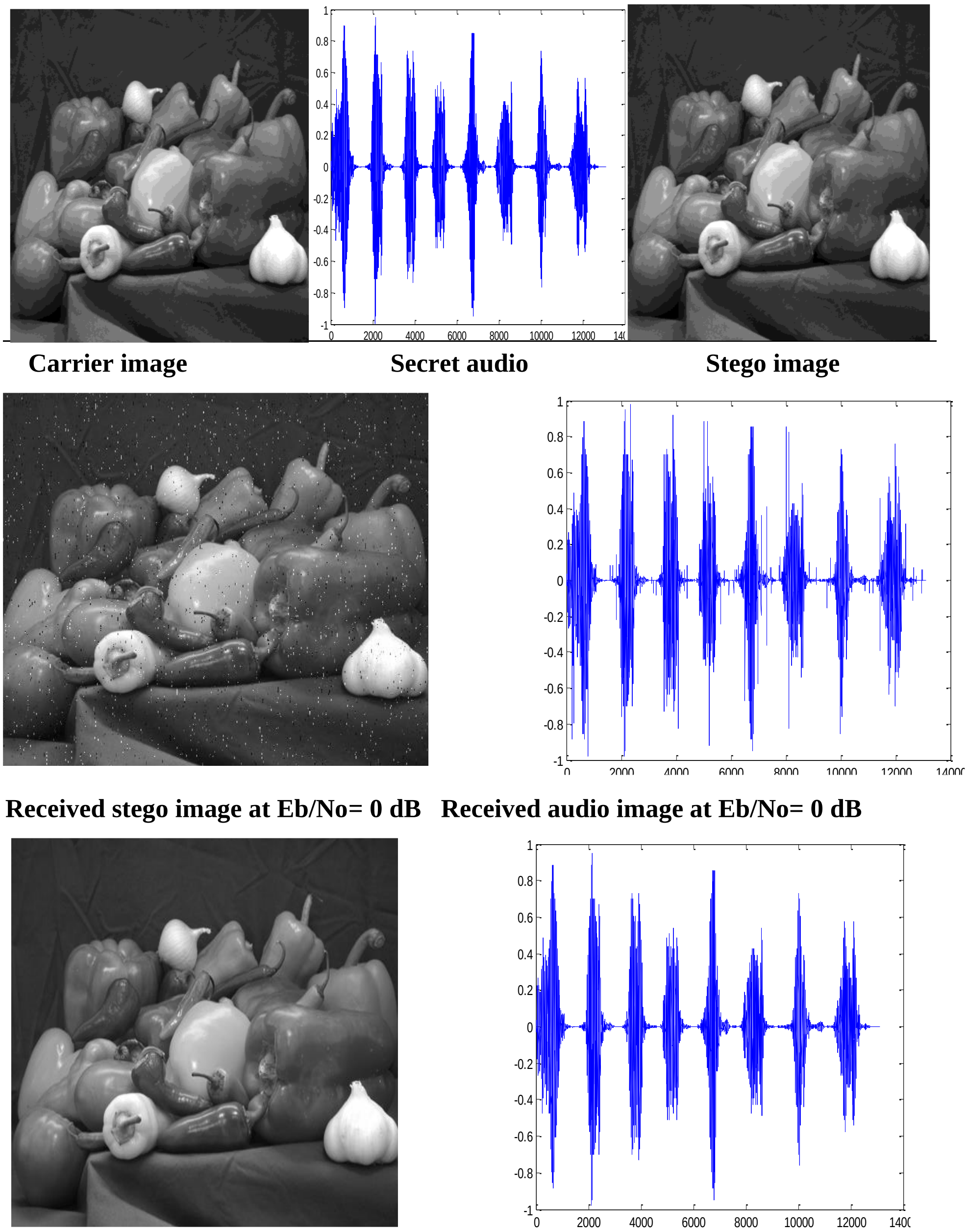


Fig. 3. BER of stego transmitted data.

Depending on STC matrix, three cases of STC are carried out and depicted in Fig. 3, which shows the improvement in the performance of the systems in terms of BER. When our proposed systems are compared with the simulated results in [10, 12], their BER are significantly reduced. Additionally, the results show that for the case of complex non square OSTBC, the BER of the stego transmitted data will be the best among three cases, which leads to recovering the secret data correctly. Figures 4, 5, and 6 represent the performance of proposed work in hiding data over MIMO channel for three proposed cases depending on the code rate.

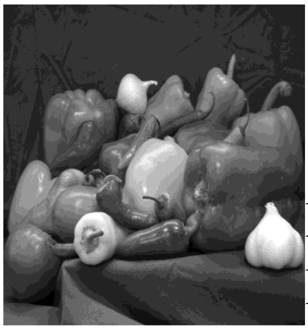


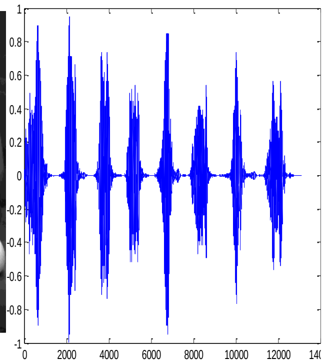
Carrier image **Secret audio** **Stego image**

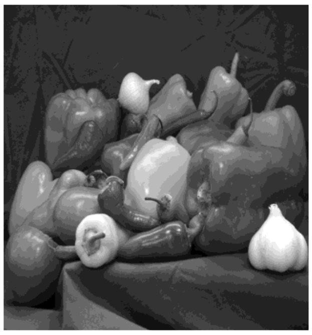
Received stego image at Eb/No= 0 dB **Received audio image at Eb/No= 0 dB**

Received stego image at Eb/No= 5 dB **Received audio image at Eb/No= 5 dB**

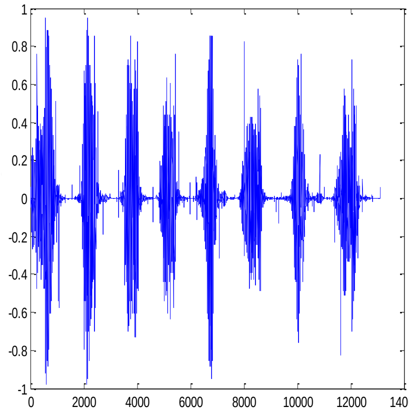
Fig. 4. Complex non square non OSTBC when the number of symbols =4 in each block of MGSTC.



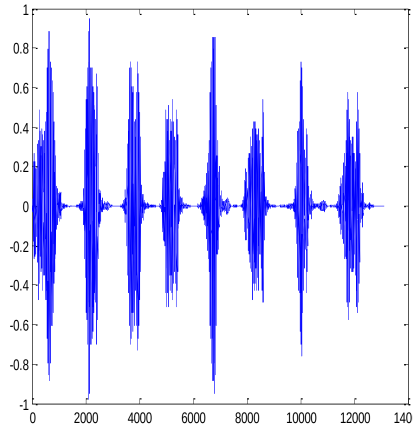




Carrier image **Secret audio** **Stego image**



Received stego image at Eb/No= 0 dB **Received audio image at Eb/No= 0 dB**



Received stego image at Eb/No= 5 dB **Received audio image at Eb/No= 5 dB**

Fig. 5. Complex non square non OSTBC when the number of symbols=5 in each block of MGSTC.

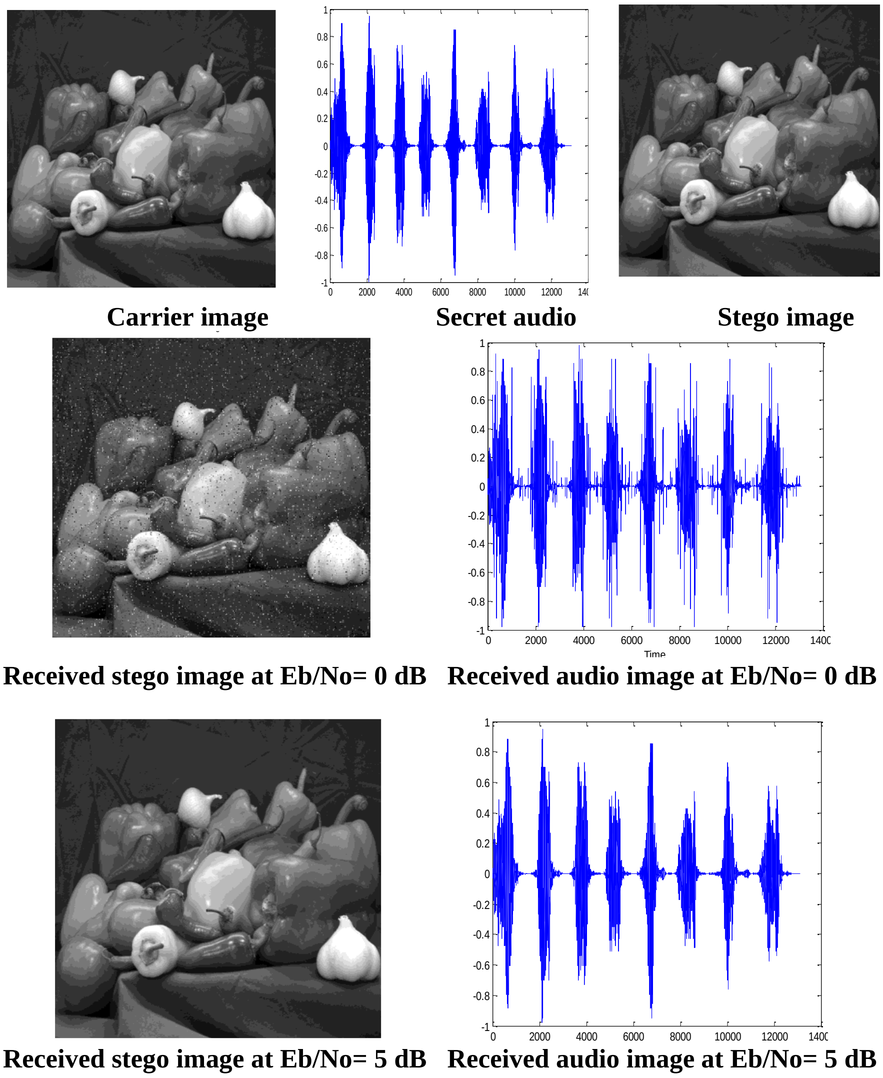


Fig. 6. Complex non square OSTBC when number of symbols=3 in each block of MGSTC.

These figures represent the effect of hiding on the original image before the steps of transmitting the stego image on MIMO channel and comparison between the received stego carrier image and the received secret audio for the various value of SNRs. Even with increasing the SNR, the obtained errors in the received stego images and the received secret data (audio) is small value comparing to the original carrier image and original secret (audio) respectively. This leads to this proposed system is normal communication and the procedure of data hiding can be realized in the MIMO channel system.

Moreover, another parameter is utilized in this paper to test the strength of the proposed work which is the Peak signal-to-noise ratio (PSNR). PSNR is calculated as the error between the original and the received images. However, the calculation of PSNR requires source signals as in [18]

$$PSNR = 10\,log_{10}\frac{L-1}{\frac{1}{A\times B}\sum_{a=1}^{A}\sum_{b=1}^{B}[O(a,b)-C]^2} \quad (26)$$

where, A, B are representing the height and width of the two images, respectively. While the a and b are the rows and the column numbers respectively finally the L is the number of the gray scale level in the two images where $O(a,b)$ and C are the original source image and another compared image.

Table 4. represents the relation between SNR value and PSNR for three proposed cases. The comparison is achieved between the original carrier image and stego image, original carrier image and received stego image, and stego image and received stego image. From the table, we noted that when SNR increases, the values of PSNR also increase and all proposed systems having PSNR better than [10].

Table 4. the relation between SNR value and PSNR for three proposed cases.

PSNR System Type	O&H	O&R			H&R		
		At -5 dB	At 0 dB	At 5 dB	At -5 dB	At 0 dB	At 5 dB
Complex non Square non OSTBC # symbols=4 in each block of MGSTC	53.9145	11.0268	25.9449	53.9144	11.0287	25.9528	101.1008
Complex non square non OSTBC #symbols=5 in each block of MGSTC	53.9145	10.5562	21.9116	53.5674	10.5580	21.9152	64.7129
Complex non square OSTBC # symbols=3 in each block of MGSTC	53.9145	11.3689	27.4989	53.9144	11.3705	27.5099	101.1008

Moreover, the PSNR values between the original image and the received image for three proposed systems are presented in Fig.7.

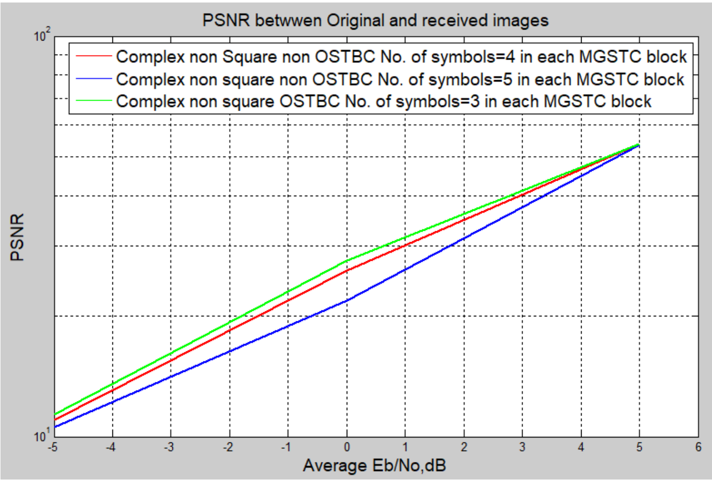


Fig. 7. PSNR between original and received images.

For three proposed systems, the PSNR values are closed to each other and directly proportional with SNR. They are within acceptable limit even though the comparison is computed between the original image without audio signal and the received image with audio signal. That means the received image is not impacted with the hiding process.

7. Conclusion

In this work, the data hiding system in the MIMO channel is presented first. Then, according to the principle of data hiding in the channel, the data hiding will be changed therefore MGSTC is utilized to increase data rates and resist fading without expanding the spectral footprint in MIMO technology. Proposed systems are presented in this work by depending on the code rate. From the simulation results, the BER and the PSNR of the stego transmitted signal for the case of $r_s = \frac{3}{4}$ (Complex non-square OSTBC) is the best among the three proposed systems and that leads to the best case of extracting secret signal. The effect of MGSTC diversity was also analyzed. Finally, the performance of the channel capacity for the three proposed cases are tested and the case of $r_s = \frac{5}{4}$ is the best because it has the minimum number of symbol periods that need to transmit this stego signal.

Nomenclatures

a	Rows numbers
A	Height of the two images
b	Column numbers
B	Width of the two images
Bq	Bit in each q
C	Compared image
H_1^{eff}	Effective channel matrix
H_{C1}	Channel section dealing with the X_{C1}
H	Transmission channel matrix
i	$1, \ldots, q$,
i	Position of data hiding in carrier signal
I	Bit length of secret data
jj	Any STC matrix in each case,
j	Numbering of the modulated symbols
K	Number of symbols transmitted in such block
L	Number of the gray scale level in the two images
M	Bit length of carrier signal
N_{period}	Symbol periods number to transmit the stego signal
N_r	Received antenna
N_{stream}	Data streams
N_t	Transmitted antenna
n	Antenna number
$O(i, j)$	Original source image
p	Number of symbol periods
q	Groups of splitting the sequence of bits
r_s	Code rate

X_{C1}	Transmitting the first STC group of a MGSTCs system
X_{Cq}	Component code outputs
X_c	Independent modulated symbols
X_c	Independent modulated symbols
X	Transmitted signal matrix
$\widehat{X_{C_1}}$	Estimated value of X_{C_1}
Y	Received signal matrix
Z	AWGN matrix
$\tilde{Z}_{C2}$	Noise
Greek Symbols	
$\widehat{Y_{C_1}}$	Estimate received signal matrix once interference suppression occurred
Θ_{C2}	Includes the set of null space vectors of H_{C2},
Abbreviations	
16-QAM	16- Quadrature amplitude modulation
AWGN	Additive White Gaussian Noise
BBA1	binary bit of audio signal
BBI8	binary bit of image signal
BER	Bit error rate
E-DSM	Eigen beam-Space Division Multiplexing
LBC	Linear block code
LSB	Least significant bit
MC-CDMA	Multi carrier -Code Division Multiple Access
MGSTC	Multi Group Space Time Codes
MGSTC BLAST	Multi Group Space Time Codes Bell Laboratory layered space – time
ZMIMO	Multiple input multiple output
MIMO-OFDM	Multiple input multiple output- orthogonal frequency-division multiplexing
MLD	Maximum Likelihood Detector
MMSE-SIC	Minimum mean square error successive interference cancellation
NON-OSTBC	Non-Orthogonal space-time block codes
NON-STBC	Non square space-time block codes
NOSTBC	Non-orthogonal space-time block codes
OSTBC	Orthogonal space-time block codes
PSNR	Peak signal to noise ratio
QPSK	Quadrature phase-shift keying
S/P	Serial to parallel converter
SISO	Single input single output
SM	Spatial multiplexing
SNR	Signal to noise ratio
STBC	Space-time block codes
STC	Space time codes
STTC	Space-time trellis codes

References

1. AlSabhany, A.A.; Ali, A.H.; Ridzuan, F.; Azni, A.H.; and Mokhtar, M.R. (2020). Digital audio steganography: Systematic review, classification, and analysis of the current state of the art. *Computer Science Review*, 38, 100316.
2. Tew, Y.; and Wong, K. (2013). An overview of information hiding in H. 264/AVC compressed video. *IEEE Transactions on Circuits and Systems for Video Technology*, 24(2), 305-319.
3. Chen, L.; and Lu, M. (2011). Information hiding capacities in multiple antennas channel coding system. *Procedia Engineering*, 15, 1848-1853.
4. Al-Sultani, M.; Mohamed, W.Q.; and Huiyi, M. (2018). Study on various antenna configurations. 2*nd International Symposium on Multidisciplinary Studies and Innovative Technologies* (*ISMSIT*). Ankara, Turkey, 1-5.
5. Chen, L.Q.; Fan, Z.J.; Lu, M.; and Hu, A.Q. (2015). Information hiding capacities in different multiple antenna systems. *Journal of Information Hiding and Multimedia Signal Processing*, 7(4), 714- 728.
6. Halmi, M.H.; Abdellatif, M.; and Nooridin, N. (2015). Orthogonal space-time block codes for large MIMO systems. *International Conference on Communications, Management and Telecommunications* (*ComManTel*). Danang, Vietnam, 78-82.
7. Hokai, K.; Sasaoka, H.; and Iwai, H. (2014). Wireless steganography using MIMO system. *IEEE Fifth International Conference on Communications and Electronics* (*ICCE*). Danang, Vietnam, 560-565.
8. Kafi, M.H.; Islam, S.S.; and Rahman, M.M. (2015). Performance analysis of MGSTC BLAST spatial multiplexing scheme aided dual polarized OFDM system on secure voice frequency signal transmission. *Journal of Multidisciplinary Engineering Science and Technology*, 2(7), 1964- 1971.
9. Hosain, M.; and Ullah, S. (2015). Impact of MGSTC BLAST spatial multiplexing scheme on performance assessment of MCCDMA wireless communication system. *International Journal of Emerging Technologies in Computational and Applied Sciences*, 12(1), 8-14.
10. Chen, L.; Fan, Z.; and Huang, J. (2016). Data hiding capacity of spatial domain bit replacement steganography in a MIMO-OFDM coding channel. *AEU-International Journal of Electronics and Communications*, 70(9), 1295-1303.
11. Kang, R.; Zhang, J.; Zhang, Z.; and Ge, L. (2017). Multi-group independent sub-channels allocation precoding for MGSTC systems in correlated HF-MIMO channels. *IEEE* 2*nd Advanced Information Technology, Electronic and Automation Control Conference* (*IAEAC*). Chongqing, China, 1799-1804.
12. Hamidian, K.; and Mohamed, W.Q. (2018). Performance enhancement of MIMO–MGSTC using a new detection and decoding technique. Future of Information and Communication Conference. Springer, Cham, 12-25.
13. Wang, Y.; Tang, M.; and Wang, Z. (2020). High-capacity adaptive steganography based on LSB and Hamming code. *Optik*, 164685.
14. Bhuiyan, T.; Sarower, A.H.; Karim, M.R.; and Hassan, M.M. (2019). An image steganography algorithm using LSB replacement through XOR substitution. *International Conference on Information and Communications Technology* (*ICOIACT*). Yogyakarta, Indonesia, 44-49.

15. Jiang, S.; Ye, D.; Huang, J.; Shang, Y.; and Zheng, Z. (2020). Smart steganography: Light-weight generative audio steganography model for smart embedding application. *Journal of Network and Computer Applications*, 102689.
16. Hampton, J.R. (2014). *Introduction to MIMO communications*. New York: Cambridge university press.
17. Hosany, M.A.; and Ramanna, G. (2020). Design and implementation of a novel unequal error protection scheme for coded MIMO systems. *AEU-International Journal of Electronics and Communications*,122, 153257.
18. Al-Rawi, Z.N.A.; Hatem, H.R.; and Ali, I.H. (2018). Image compression using contourlet transform. 1*st Annual International Conference on Information and Sciences* (*AiCIS*). Fallujah, Iraq, 254-258.