

# A Novel Chaotic MIMO-OFDM System for Improved Performance in Future Cellular Wireless Networks

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*Abstract:* - In recent years, the explosive growth of new generation wireless networks has spurred lot of research thrust particularly looking for a bandwidth efficient modulation and coding scheme. In this connection, researchers have recently turned up their attention towards chaotic communication systems and golden codes for its attractive benefits. This consequently had motivated us for two new proposals namely: code shifted-quadrature chaos shift keying (CS-QCSK) and modified golden codes with low complex decoder. The Code Shifted-Quadrature Chaos shift Keying (CS-QCSK) modulation technique with its code domain approach has proven to be the best among the conventional chaotic modulation schemes [4]. Similarly, in the coding scenario, modified Golden codes had been proven to exhibit better error performance than any other space time block codes through our earlier investigation in [14]. The aforementioned modulation scheme (CS-QCSK) and coding scheme (modified golden code) can be concatenated in an OFDM system to harvest an enhanced performance. The suitability of the proposed chaos based logic is tested in a multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) system. The performance parameters like spectral efficiency, capacity and BER analysis is computed through simulation analysis. The obtained results were found very satisfactory, of course with a marginal increase in the process complexity.

*Key-Words:* - Chaotic MIMO-OFDM, modified golden codes, Code shifted quadrature chaos shift keying (CS-QCSK), multiple input multiple output (MIMO), Orthogonal frequency division multiplexing (OFDM), low complex sphere decoder, Bit error rate, spectral efficiency

## 1 Introduction

The future broadband communication technology is persuaded by the enormous demands for fast and unswerving communications over an error prone fading environment. This physical layer challenge remains as an important bottleneck to find a suitable bandwidth efficient channel coding and modulation scheme in one side. On the other side, the amelioration of MIMO wireless technology with OFDM technique called MIMO-OFDM had been proven to support higher data rate and improved performance against multipath fading and other channel impairments. Because of this fact, it captures a widespread attention in the literature [15-30]. In [1], the authors discussed the basic concepts of chaotic modulation schemes and introduces DCSK scheme as a robust non-coherent scheme, where the chaotic basis function details are not required at the receiver. In [2], the authors discuss Quadrature CSK (QCSK) as a multilevel version of DCSK, based on the generation of orthogonal

chaotic functions and allow an increase in data rate by occupying same bandwidth with respect to DCSK. To improve the DCSK scheme, Code shifted differential chaos shift keying (CS-DCSK) has been proposed. It uses code domain approach in which the reference and the information bearing signals are transmitted in the same time slots and exhibit similar BER performance and bandwidth efficiency, as described in [3]. To overcome the drawbacks of CS-DCSK and QCSK, a novel chaos based modulation scheme CS-QCSK which is the blend of CS-DCSK and QCSK modulation schemes with superior performance has been proposed by us for a single user scenario with the analytical model in [4]. The analytical modelling of a novel CS-QCSK modulation scheme under multiuser environment was done and its performance analysis has been discussed in [5]. The performance of the combinational approach of CS-QCSK and reduced golden ratio-golden code (RGR-GC) called (CS-QCSK\_RGR-GC) scheme has been analyzed with

various parameters and compared with the conventional schemes in [6]. The performance analysis of various chaotic modulation techniques has been analyzed and examined to be suitable for future generation standards.

In addition to the modulation schemes, some of the researchers have taken initiatives to focus at space time block coding approaches for exploiting its supremacy. The techniques for constructing STBC's with full-rank, minimal-delay using commutative division algebras, noncommutative division algebras and the performance of the codes were exhaustively analyzed in [7]. In [8], the authors discuss the substantial STBC called golden code as a full rate and full diversity code with Non-vanishing minimum determinant (NVD) for a 2x2 MIMO system. In [9], the performance analysis of the Golden code in a Bit Interleaved Coded Modulation-MIMO (BICM-MIMO) system and its comparison with the uncoded MIMO scheme was discussed. The authors in [10] discussed, a method to develop the suboptimal decoders for the golden code with reduced complexity and near -ML performance, as the ML- decoding of the golden code have higher complexity. Concatenating the golden code by set partitioning of the inner code and labelling the branches with outer trellis code and its higher trellis complexity has been discussed in [11]. From the discussion, it is obvious that the decoding logic for golden codes are quite complex. This triggered to discuss, the design of low complex Maximum likelihood (ML) decoder for Space Time Block Codes (STBC) and embedded orthogonal STBC with symmetric and asymmetric coding conditions .Different STBCs with its key properties and the ideas to reduce the decoding complexity has been analyzed in [12]. Multigroup maximum-likelihood (ML) decoding for collocated and distributed space-time block codes (DSTBCs) and OFDM based alamouti space-time coded scheme application in synchronous wireless relay networks has also been discussed in [13]. The design of modified golden code and the reduction in decoding complexity through low complex sphere decoder has been presented in [14]. To deal with the other physical layer techniques, the OFDM and MIMO-OFDM has been investigated further.

In [15], the authors presented a comprehensive survey of OFDM, OFDM related modulations and introduced MIMO techniques for OFDM in current systems and standards. In [16&17], the authors discuss the MIMO-OFDM an ideal solution not only for wireless LAN, but also for 4G networks with the improved performance. The different physical layer issues in MIMO-OFDM systems such as space time

techniques, physical channel measurements and modeling, error control coding techniques and a software radio implementation had been studied in [18]. In [19], the authors described about space frequency coding, space-time coding and space-time-frequency coding for MIMO-OFDM systems and orthogonal frequency division multiple accesses (OFDMA) for achieving the maximum diversity while minimizing the interference. In [20], the STF Block Codes had been discussed for MIMO-OFDM transmissions over the Rayleigh fading channels without compromising the performance. The design issues pertaining to iterative receivers for STBC-OFDM systems with outer channel coding in unknown realistic channels has been presented in [21]. To enhance the system performance, an improved space-time coding for MIMO-OFDM for 2X2 and 4X4 antennas systems using QPSK modulation had been elaborated in [22&23]. The challenging issues of MIMO-OFDM systems like achieving the channel synchronization with channel state information and coherent detection of information symbols had been broadly analyzed in [24]. In [25], the authors had described about the drawbacks of MIMO-OFDM system and examined the use of genetic algorithms as a tool for next-generation wireless systems to handle large numbers of users.

In [26], the authors discussed the 4G systems and other 4G systems like Long Term Evolution (LTE) had predominately employs MIMO-OFDM physical layer, thereby ratifying its performance has been analyzed. The MIMO and MIMO-OFDM concepts has been exhaustively analyzed and elaborated in [27]. In [28] the authors discuss the MIMO-OFDM system concepts and particle swarm optimization (PSO) method to optimize the power of pilot tones. Reducing the peak-to-average power ratio (PAPR) and provisioning of channel state information of MIMO-OFDM system concepts has been presented in [29]. The performance of MIMO-OFDM system technology has been examined through the ergodic capacity and validated by fully dynamic 3GPP LTE network simulations under realistic mobility scenarios in [30].To enhance the system performance under realistic channel conditions, MIMO-OFDM has been preferred by many of the researchers.

### 1.1 Our contribution and organization of the paper

Recently, research has been focused on various aspects of improving the physical layer techniques

and stated that MIMO-OFDM scheme offers better performance compared to the conventional physical layer mechanisms. In this paper, a modified version of golden code called RGR-GC scheme, described in [14] has been used. Following the work quoted in the references [4 & 14], an attempt is made to propose the concatenation of chaotic modulation (CS-QCSK) scheme and the most efficient code namely “modified golden code” with the OFDM. This work elaborates about the schemes involved in physical layer and to overcome the issues that arise in communication under realistic channel condition. It was analyzed with the chaotic modulation schemes, Space time block codes, and OFDM techniques. Moreover, the potential benefit of MIMO schemes is eroded when it is combined with the vulnerable modulation schemes. This has served as a motivation to investigate on MIMO-OFDM system and proposed a novel chaotic MIMO-OFDM scheme. Intuitively, from the above discussions, significant improvement in wireless system performance could be achieved even in a highly hostile environment by the mere concatenation of both of our proposals namely: CS-QCSK and modified golden code with OFDM has been discussed in [4&14] and the same has been proved through simulation analysis in this paper. The major highlight of this paper is emphasized that the considerable performance improvement is certainly possible through the usage of CS-QCSK and modified golden codes with OFDM system. The readers are advised to refer the [4&14] references for detailed analytical modeling of them. Therefore, the so called proposed scheme namely chaos based MIMO-OFDM, the concatenation of chaotic modulation scheme (CS-QCSK) and modified golden STBC with OFDM technique as a single entity is truly novel and unique of its kind.

The persisting part of the paper is systemized as follows: In section 2, the system model of the proposed chaos based MIMO-OFDM scheme, the code shifted quadrature chaos shift keying scheme modified golden code and OFDM system are elaborated. Simulation results are analyzed in Section 3. Conclusion of the paper is dealt in section 4.

## 2 The Proposed System Model

The combination of MIMO technology with OFDM technique has the capability to meet out the requirements of future generation wireless networks, which are expected to offer high data rate and robust communication. A considerable performance

improvement can be evinced definitely, through suitable efficient physical layer mechanisms. This is achieved by employing the combination of a CS-QCSK modulation scheme and a modified golden code with the OFDM technique.

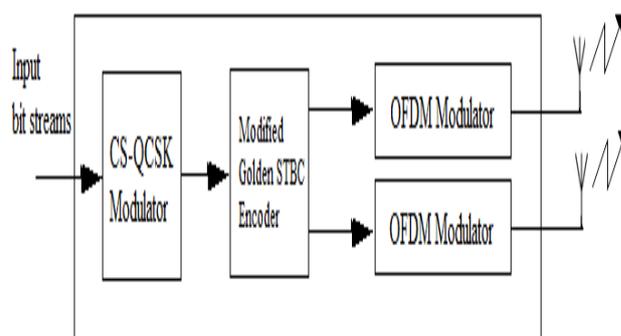


Fig. 1. Transmitter block diagram of the proposed scheme

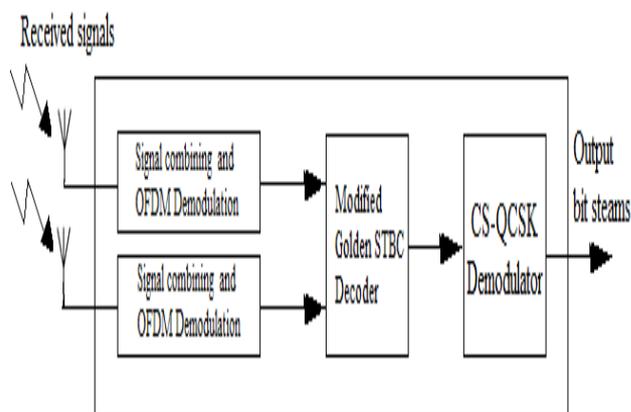


Fig. 2. Receiver block diagram of the proposed scheme

The system model is of 2x2 MIMO type with transmitter comprising of a CS-QCSK modulator, modified golden code encoder and OFDM modulator. The process involved is briefed as follows: The input bit streams are given as input to the CS-QCSK modulator. In modulator, the input bit streams are mapped into data symbols. The mapped data symbols are then fed to the modified golden STBC encoder, where the block of  $M_s$  symbols  $S = [S_1, S_2, \dots, S_{M_s}]$  were encoded as codeword matrix ‘C’ of  $M_T \times N_t$  size. The encoded output is later fed to the OFDM modulator and launched through the ‘ $N_t$ ’ antennas in ‘T’ OFDM blocks each having ‘M’ sub channels. The code words  $[C_i^1, C_i^2, \dots, C_i^T]$  are transmitted from  $i^{\text{th}}$  transmit antenna in OFDM blocks 1,2,.....,T respectively, where  $C_i^n$  has the

vector length  $N$ , for all  $i=1,2,\dots,N_t, n=1,2,\dots,T$ . The codeword matrix ‘ $C$ ’ can be designated as,

$$C = \begin{bmatrix} C_1^1 & \dots & C_{N_t}^1 \\ \dots & \dots & \dots \\ C_1^T & \dots & C_{N_t}^T \end{bmatrix}$$

The transmitted signals propagate through the MIMO channels and are received by the receiver unit. The receiver consists of OFDM demodulator, modified golden STBC decoder and CS-QCSK demodulator. The received OFDM symbols are then recovered through a sequence of reverse operation performed by the demodulator and decoder, subsequently to extract the transmitted bit streams. Further, the capacity, code rate and the data rate expression were discussed. In general, capacity can be achieved by transmitting a codeword over a huge number of independently fading blocks. Therefore, the capacity of the MIMO-OFDM system is obtained as,

$$C = \sum \left\{ \log \det \left[ I_{N_R} + \rho \lambda H_{\omega} H_{\omega}^H \right] \right\} \text{ bps/Hz} \quad (1)$$

$$\lambda = \text{diag} \left\{ \lambda_i(R) \right\}_{i=0}^{N_{R-1}} \quad (2)$$

where ‘ $\lambda_i(R)$ ’ denotes the non zero Eigen values of  $R$ . The rank and Eigen value spread of the sum correlation matrix,  $R = \sum_{l=0}^{L-1} \sigma_l^2 R_l$ , where ‘ $R_l$ ’ is the Rayleigh component of the  $l^{\text{th}}$  tap, ‘ $\sigma_l^2$ ’ is the path gain. ‘ $H_{\omega}$ ’ is the independent identically distributed (i.i.d) random matrix with CN (0, 1) entries. ‘ $\sum$ ’ is the expectation operator, ‘ $I_{N_R}$ ’ is the identity matrix, ‘ $H_{\omega}^H$ ’ is the conjugate transpose of  $H_{\omega}$ , ‘ $N_T$ ’ and ‘ $N_R$ ’ represents the number of transmitter and receiver antennas respectively. As the transmission rate is lower than  $C$ , then the error probability decays exponentially with the transmission length.

$$\rho = \frac{P}{N_T N_0 \sigma_n^2} \quad (3)$$

Where, ‘ $P$ ’ denotes the total average energy available at the transmitter over a symbol period,

‘ $N_0$ ’ represents the additive white complex Gaussian noise.

In the high-SNR regime,

$$C = \sum_{i=0}^{r(R)-1} \log \left( 1 + \bar{\rho} \lambda_i(R) \right) \quad (4)$$

Where,  $\bar{\rho} = N_T \rho = \frac{P}{N_0 \sigma_n^2}$

The code rate  $R_c$  of the MIMO-OFDM system is generalized as,

$$R_c \square \frac{M_s}{MT} \text{ , symbols per channel use} \quad (5)$$

Where, ‘ $M_s$ ’ is the number of data symbols, ‘ $M$ ’ is the number of sub channels, ‘ $T$ ’ is the number of OFDM symbols.

The overall data rate  $R_D$  is given as,

$$R_D = R_c \left( \frac{N_T b C_d}{T_{symbol} + T_g} \right) \text{ , bps} \quad (6)$$

Where, ‘ $R_c$ ’ is the code rate, ‘ $N_T$ ’ is the number of transmit antenna, ‘ $b$ ’ represents the number of bits used depending on the recommended modulation scheme, ‘ $C_d$ ’ is the number of data subcarriers, ‘ $T_{symbol}$ ’ is the OFDM block duration, ‘ $T_g$ ’ is the guard interval. The forthcoming section aims at giving a brief overview of various processes involved in the transmitter and receiver blocks.

### 2.1 CS-QCSK Scheme

In CS-QCSK modulation scheme, the same time slot can be used to transmit both reference signal and information signals (symbol ‘ $S$ ’). However they are differentiated in the code domain by using different walsh codes. The transmitted CS-QCSK signal is given by,

$$S_s(t) = \sum_{k=0}^{N-1} W_{k,1} C_x(t-kT_c) + a_1 \sum_{k=0}^{N-1} W_{k,1} C_x(t-kT_c) + a_2 \sum_{k=0}^{N-1} W_{k,1} C_y(t-kT_c) \quad T_s = NT_c \quad (7)$$

It can be noted from the equation (7) that both the reference and the information signals acquires the same time slot for transmission, where  $a_1 \in \{-1, 1\}$ ,  $a_2 \in \{-1, 1\}$  are mapped from  $b \in \{0, 1\}$  which represents the information bit to be transmitted. In CS-QCSK scheme the reference and information signals are exploited using different Walsh code, where  $W_{R,k+1}$  represent the Walsh code for reference signal and  $W_{I1,k+1}$ ,  $W_{I2,k+1}$  represent the walsh code for the information signals,  $C(t)$  is the chaotic signal with duration of  $T_c$ . The reference and the information signal are independent of the chaotic carrier thereby the orthogonality of the signal can be assured by using different walsh code sequences. The final expressions for error rates associated with CS-QCSK modulation scheme under AWGN and Rayleigh channel conditions are given below. The detailed analytical and theoretical description about chaotic modulator / demodulator discussed under this section can be referred in the earlier work [4].

The Bit error rates under AWGN channel condition is given by,

$$BER_{CS-QCSK} = \frac{1}{2} \operatorname{erfc} \left( \frac{3(E_b / N_0)}{\sqrt{\frac{3}{4}K + \frac{1}{2}K + 2(E_b / N_0)}} \right) \quad (8)$$

and for Rayleigh fading channel it is given by,

$$BER_{CS-QCSK} = \frac{1}{2} \operatorname{erfc} \left( \frac{3(\gamma_b)}{\sqrt{\frac{3}{4}K + \frac{1}{2}K + 2(\gamma_b)}} \right) \quad (9)$$

Where ‘ $E_b$ ’ is the bit energy, ‘ $K$ ’ is the spread factor, ‘ $N_o$ ’ is the noise power spectral density, ‘ $\gamma_b$ ’ is the product of  $(E_b/N_o)$  and the gain of the propagation path.

### 2.2 Modified Golden Code

Cyclic division Algebra (CDA), an effective mathematical tool which has excellent properties has been used in modified golden code. The RGR-GC is a modified version of golden code which is used to normalize the energy and in turn, achieves the improved performance in the system. A reduced golden ratio-golden code (RGR-GC) is obtained by choosing a minimum polynomial equation in such a way that, it yields the reduced golden ratio without losing the key properties of golden code. The minimum polynomial equation considered to yield

the reduced golden ratio is  $X^2-0.5x-0.5=0$ . The reduced golden ratio ‘ $\theta$ ’ is given as,  $\theta = \frac{1+\sqrt{2}}{2}$

Having defined the polynomial and RGR, the next attempt is to focus onto shaping up the process to obtain lossless property. Before shaping, the codeword using CDA is represented as,

$$\begin{bmatrix} a+b\theta & c+d\theta \\ i(c+d\sigma(\theta)) & a+b\sigma(\theta) \end{bmatrix} \quad (10)$$

where, the information symbols  $a, b, c, d \in Z[i]$ . The codeword ‘ $X$ ’ of the RGR-GC is denoted as,

$$X = \frac{1}{\sqrt{2}} \begin{bmatrix} \alpha(a+b\theta) & \alpha(c+d\theta) \\ i\sigma(\alpha)(c+d\sigma(\theta)) & \sigma(\alpha)(a+b\sigma(\theta)) \end{bmatrix} \quad (11)$$

Where  $a, b, c, d$  are QAM symbols and can take any value in  $Z[i]$ . In an infinite code  $C_\infty$ ,  $a, b, c, d$  can take any value in  $Z[i]$  which means that the finite signal constellations can be incised from infinite lattices. For the modified golden codes, designing an appropriate decoder still remains as a challenging task. This served as a motivation to propose a low complex good performance decoder.

### 2.3 Low Complexity Sphere Decoder

In this section, a novel low complex sphere decoder suitable for the Reduced Golden Ratio- golden code (RGR-GC) is described. To reduce the decoding complexity, many methods have been investigated. The low complexity decoding for the space time block codes and the key properties for reducing the decoding complexity has been analyzed broadly in [12]. The proposed method makes use of one of the properties in which the real and imaginary parts of the symbol are decoded individually. The channel matrix ‘ $H$ ’ is decomposed using QR decomposition method represented as  $H=QR$  where, ‘ $Q$ ’ is a unitary matrix and ‘ $R$ ’ is an upper triangular matrix. The zero entries and real elements in the ‘ $R$ ’ matrix can potentially reduce the decoding complexity. A low complex sphere decoder with tree search algorithm is used here where the real and imaginary parts of the symbol are decoded singly like a single symbol. At the receiver, received vector of samples  $y = [y_1 [1], y_2 [2], y_3 [3], y_4 [4]]^T$  is of the form,

$$y=Hx+n \quad (12)$$

where, ‘ $x$ ’ represents the transmitted symbol vector, ‘ $n$ ’ is the noise vector and ‘ $H$ ’ represents the

effective channel matrix given as,  $X = [x_1, x_2, x_3, x_4]^T$ ,  $n = [n_1[1], \dots, n_2[2]]^T$  and

$$H = \begin{bmatrix} h_{11}[1] & 0 & \phi h_{21}[1] & 0 \\ 0 & h_{21}[2] & 0 & \phi h_{11}[2] \\ h_{12}[1] & 0 & \phi h_{22}[1] & 0 \\ 0 & \phi h_{22}[2] & 0 & \phi h_{12}[2] \end{bmatrix} \begin{bmatrix} \alpha & \beta & 0 & 0 \\ -\beta & \alpha & 0 & 0 \\ 0 & 0 & \alpha & \beta \\ 0 & 0 & -\beta & \alpha \end{bmatrix} \quad (13)$$

respectively, where,

$$\phi = e^{j\frac{\pi}{4}}, \alpha = \cos(\theta), \beta = \sin(\theta)$$

It is noted from the equation (13), that the channel matrix  $H=QR$  is an orthogonal-triangular decomposition of the effective channel matrix. The Gram-Schmidt orthonormalization approach is followed for the decomposition. The decomposition procedure is applied to the columns of  $H$ , then the entry of  $R$  in row  $i$  and column  $j$  will be the inner product between the  $i^{\text{th}}$  column of  $Q$  and  $j^{\text{th}}$  column of  $H$ , where  $r_{i,j} = q_i^* h_j$ . In direct computation of  $R$ , the diagonal elements and the other elements are complex by nature whereas the elements  $r_{1,2}$  and  $r_{3,4}$  are real in nature. The diagonal and nondiagonal elements are computed from the effective channel matrix. The total cost metric  $P(x)$  is denoted by the expression as,

$$\begin{aligned} P(x) &= \|y - Hx\|^2 \\ &= \|z - Rx\|^2 \\ &= \|z - R_1x_1 - R_2x_2 - R_3x_3 - R_4x_4\|^2 \end{aligned} \quad (14)$$

The minimum of the overall cost metric  $P(x)$  is chosen to be the decoded symbol vector 'x'. Using tree search algorithm the minimum of overall cost metric  $P(x)$  can be estimated. The RGR-GC associated with different  $x_i$  ( $i=1,..4$ ) at each level using a sphere decoder with four level tree has been discussed. A four level tree which associates  $d^R = x_4^R$  and  $d^I = x_4^I$  in the first level,  $c^R = x_3^R$  and  $c^I = x_3^I$  in the second level,  $b^R = x_2^R$  and  $b^I = x_2^I$  in the third level and  $a^R = x_1^R$  and  $a^I = x_1^I$  in the fourth level and so forth. The cost metric function can be rewritten and given by the expression as,

$$\begin{aligned} P(X) &= \|V^I - Aa^I\|^2 + \|V^I - Ab^I\|^2 + \|V^R - Aa^R\|^2 + \|V^R - Ab^R\|^2 \\ &+ \|Z_3^I - Dc^I\|^2 + \|Z_4^I - Dd^I\|^2 + \|Z_3^R - Dc^R\|^2 + \|Z_4^R - Dd^R\|^2 \end{aligned} \quad (15)$$

Each symbol  $(x_1), (x_2), (x_3), (x_4)$  and the number of combinations are denoted by  $Q$ . The decoding

complexity  $\sqrt{Q}$ , comes from the fact that the symbols  $(x_1^R)$  and  $(x_1^I)$  are decoded separately. Finally, the decoding complexity is obtained as  $O(Q^{1.5})$ . The modified golden codes are found to satisfy all the properties of golden code. An exhaustive treatment on modified golden codes can be referred from [14].

## 2.4 Orthogonal Frequency Division Multiple (OFDM)

Orthogonal Frequency Division Multiple (OFDM) is the most vibrant technique applied in high data rate wireless systems. It divides the input bit streams into many different sub streams and sends them over many different sub channels. The sub channels are orthogonal, so that intersymbol interference can be eliminated. The process involved in the OFDM transceiver block is, the input bit streams are mapped according to modulation (QPSK / QAM) to data symbols. The serial bit streams are converted into many parallel blocks. Then, each block of symbols is forwarded to IFFT and transformed into an OFDM signal. The pilot symbols are used for channel estimation or synchronization. OFDM signal is then appended with the cyclic prefix. The length of the cyclic prefix is chosen in such a way that cyclic prefix should be larger than the maximum path delay of the channel to avoid intersymbol interference (ISI). Then the OFDM blocks are converted to serial signals and transmitted. At receiver, it is assumed to have perfect timing and carrier frequency synchronization. The received signals are converted to parallel signals and then the cyclic prefix is removed. Then it is fed to the FFT block with the estimated channel information and the data symbols are detected. After demodulation, the output bit streams are obtained. The unique merits of OFDM are highly spectral efficient, simple implementation by FFT, low receiver complexity, highly robust, high flexibility for link adaptation, etc. It also has its own challenging issues, like peak-to-average-power ratio (PAPR) and carrier frequency offsets.

## 3 Results and Discussions

A MIMO-OFDM system supporting the cellular network scenario is considered. The proposed chaotic based logic comprising of a CS-QCSK modulation, reduced complex golden codes and OFDM technique are implemented in the considered system. The performance of the implemented logic is tested and verified through simulation analysis. The simulation has been done on MATLAB 7.10 and the Table 1 list out the parameters used for the

simulation. For realistic scenario, parameters have been extracted from the references [3, 12, and 23]. This section presents the simulation results obtained for the proposed chaos based MIMO-OFDM scheme. The basic idea is to estimate the quality of the proposed logic in terms of quantifiable parameters like BER, spectral efficiency, capacity and complexity.

TABLE 1. Simulation Parameters

PARAMETERS	VALUES
No. of bits	$2 \times 10^4$
Txt and Rxv antenna Type	MIMO(2X2)
Chip duration( $T_c$ )	2 microsecond
Symbol duration( $T_s$ )	2 millisecond
Transmission power(P)	43dBm
Noise power spectral density( $N_0$ )	1 dBm
Chaotic Mapping Type	Logistic map
Spread factor(K)	60
Coding Type	Modified Golden STBC encoder
Decoder Type	Low complex sphere decoder
Modulation	CS-QCSK,QPSK
Bandwidth	20MHz
No. of Subcarriers	52
No. of Pilots	4
OFDM Symbol Duration	4 micro second
Guard Interval	800 nano second

Subcarrier spacing	312.5 KHz
FFT Size	64
Channel Type	Rayleigh Fading

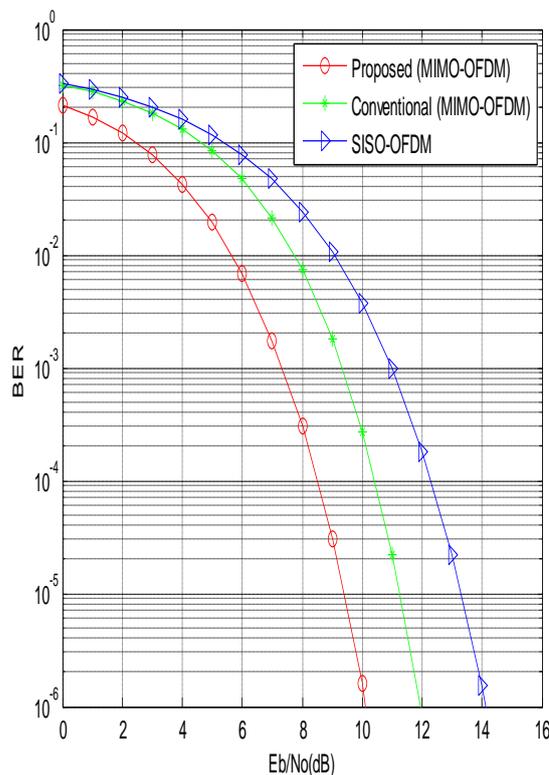


Fig.3. BER performance comparison of the chaotic MIMO-OFDM with the conventional schemes.

From the Fig. 3 it can be inferred that the proposed Chaos based MIMO-OFDM scheme provides better BER performance compared to the other schemes. For a BER of  $10^{-3}$ , the conventional MIMO-OFDM scheme and SISO-OFDM requires 9.3 dB and 11.2 dB (approx) respectively. However, the proposed Chaos based MIMO-OFDM scheme requires 7.2 dB (approx). The best proven modulation scheme (CS-QCSK) and coding scheme (modified golden code) are combined with the spectral efficient OFDM technique called chaotic MIMO-OFDM is used. The concatenation of these effective schemes would obviously offers improved performance which is justified through the performance graph shown in fig.3.

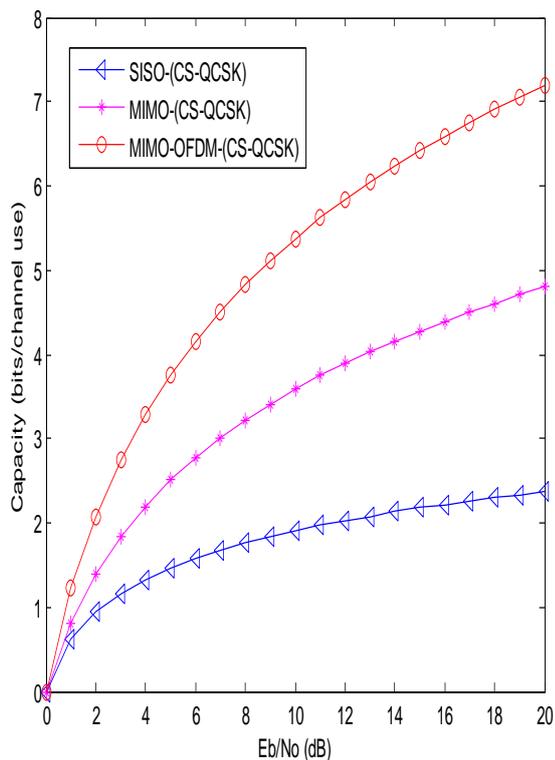


Fig. 4. Capacity comparison of the proposed scheme with the conventional schemes

In addition to it, the MIMO concept is well known to boost the capacity and that is incorporated in the proposed scheme. It is observed from fig. 4 that, for the  $E_b/N_0$  of 6dB, the proposed Chaos based MIMO-OFDM offers the capacity of 4.2 (bits/ channel use), chaos based MIMO scheme provides 2.7 (bits/ channel use) and the CS-QCSK scheme offers 1.5 (bits/ channel use). The proposed scheme exhibits maximum capacity among the other two, which is evident from the fig.4, thereby validates the effectiveness of the

scheme.

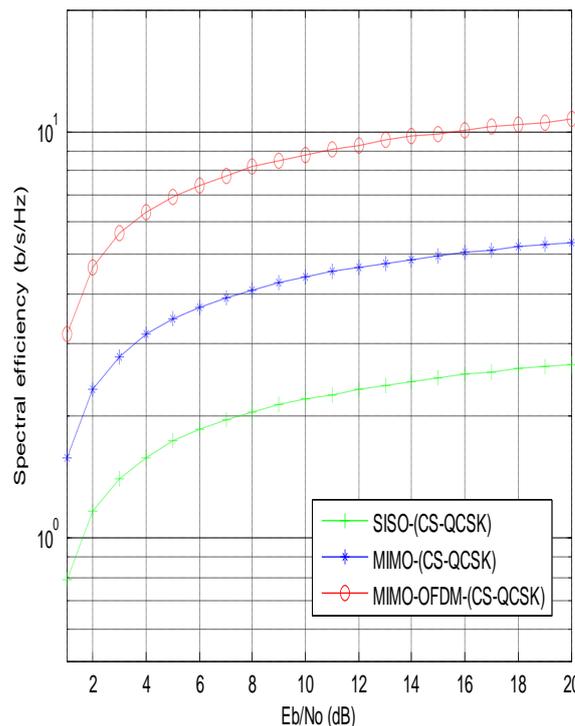


Fig. 5. Spectral efficiency comparison of the proposed scheme with the other conventional schemes

Spectral efficiency, being a critical and significant parameter has also been tested for the proposed logic. Fig. 5 shows the spectral efficiency comparison of proposed Chaos based MIMO-OFDM with the other two. It is inferred that, for the  $E_b/N_0$  of 6dB, the proposed Chaos based MIMO-OFDM scheme has the spectral efficiency of 7.4 (bits/sec/Hz). The chaos based MIMO and chaotic modulation scheme CS-QCSK has the spectral efficiency of 3.8(bits/sec/Hz) and 1.9 (bits/sec/Hz) respectively. This hike in spectral efficiency is due to the reason that both the powerful approaches namely OFDM and CS-QCSK had been fused in leading to an enhanced spectral efficiency. It is also important to note that merging these two schemes indeed increases the complexity of the entire transmission process. For this sake, to get a clear understanding about the quantum of the increased complexity, analysis on computational complexity had also been done further.

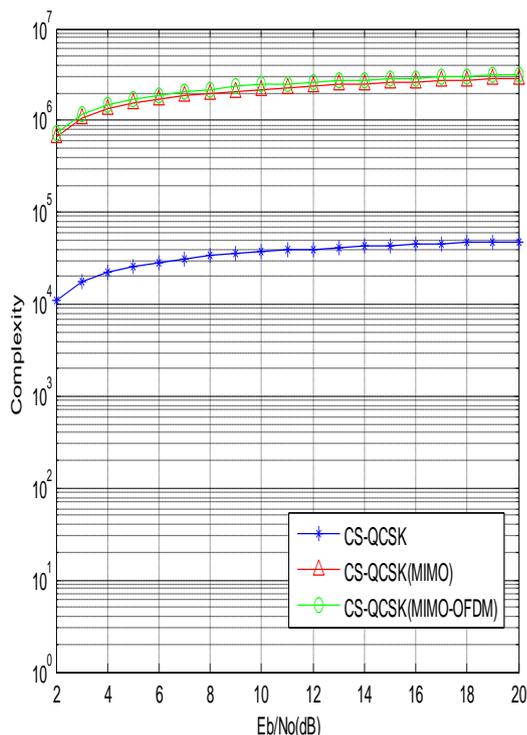


Fig. 6. Complexity analysis of proposed Chaos based MIMO-OFDM scheme and Conventional schemes

Finally, the complexity analysis graphs were plotted for the proposed Chaotic MIMO-OFDM scheme and conventional schemes. From figure 5, it is inferred from the graph that, for a fixed  $E_b/N_o$  of 4 dB the number of operations performed by the proposed scheme is  $1 \times 10^6$  (approx), for chaotic MIMO scheme, the number of operations required is approximately  $1 \times 10^6$  and for CS-QCSK scheme, the number of operations required is approximately  $1 \times 10^4$ . The complexity analysis expression is derived for the proposed scheme and the analysis is done through it. The complexity analysis equation is represented as,

$$Comp\{Chaotic\ MIMO-OFDM\} = 12N + 4M + 2P + 2Q + 188R + 450$$

Where, 'N' is the ratio of symbol duration to the chip duration, 'M' represents the number of iterations involved in the process, 'R' denotes the number of symbols used, 'P' and 'Q' are the number of multiplier units and the subcarriers respectively. Though the proposed scheme has more computational complexity compared to the conventional schemes, it offers other benefits like improved BER performance, spectral efficiency and higher data rate.

## 4 Conclusion

A strenuous problem in wireless scenario is to offer high speed data service by protecting the data over the erring fading channel effectively. In this paper, a chaos based MIMO-OFDM scheme which is a combination of a novel coding scheme (modified golden code) and chaotic modulation scheme (CS-QCSK) with OFDM technique, as a single entity has been proposed. As highlighted earlier that the amalgamation of MIMO wireless technology with OFDM technique scheme improves the system performance, the proposed scheme additionally enhances the performance significantly. The simulation analysis was executed using MATLAB 7.10 platform and the obtained results of the proposed scheme provides improved BER performance by 17.8%, capacity improvement by 14.2% and spectral efficiency improvement by 17.5% with marginal increase in complexity compared to the other conventional schemes.

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