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Performance evaluation of chaotic spreading codes in massive MIMO OFDM system

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Abstract

Background/Objectives: Wireless communication systems are growing towards the implementation of 5G communication systems to satisfy the demand of services in future. OFDMA has some shortcoming like one or more subcarriers of OFDM are completely affected due to the characteristic of the transmission channel. Spreading scheme has been introduced to combat the aforementioned issue. Furthermore, communication channels are affected by multipath fading which changes the amplitude of the received signal. This fading severely affects the communication systems. Therefore, it is essential to develop a more robust technique for higher data transmission and larger throughput. The main objective of this study is to design a massive MIMO-OFDM system for secure transmission of data. Chaos based sequence is used to spread the data before transmission which will solve intercell interference and improve the security of data. **Methods:** This study presents a chaos based massive MIMO-OFDM communication system. The proposed chaos based massive MIMO-OFDM system is implemented and its efficacy is evaluated by computing bit error rate. The effectiveness of the proposed system is investigated by varying the parameters including modulation methods such as PSK and QAM, number of users 10, 20 and 30 and spreading factor of 5, 10 and 15. **Findings**: Results clearly proved that the proposed system provides exceptional performance with 16QAM modulation scheme, 10 users at high spreading factor value of 15. **Novelty:** The uniqueness of the proposed system is with enhanced performance and usage of novel modulation scheme by varying the spreading factor value, when compared to its peers.

Keywords: Communication system; spreading code; chaotic code; massive MIMO-OFDM; bit error rate

1 Introduction

Multicarrier transmission techniques are regarded as the most promising candidates for the 4G communication systems. Among many multicarrier transmission schemes, OFDM is one of the leading schemes and is utilized in transmission systems such as DAB and DVB-T. To improve the data rate and throughput, a new technique by fusing MIMO and OFDM has been developed, named as MIMO-OFDM. MIMO-OFDM is the key technology to solve channel fading utilizing many antennas at the transmitter as well as receiver. The integration of MIMO and OFDM is a best way to satisfy the demand for high rate and reliable communication without increasing the bandwidth[1]. The rapid growth of communication technology and growing demand by the explosion of a greater number of users, the existing 4G systems are unable to fulfil the user requirements of high data rate demand. Therefore, massive MIMO systems have been introduced in 2010.

Massive MIMO systems are similar to multiuser MIMO system except that there is a greater number of antennas at the base station (>100) to alleviate the problems of the 4G communication systems and to increase spectral efficiency. Massive MIMO system offers better anti-noise and anti-narrow band fading ability, so as to make better use of resources and become the key technology for the 5G communication systems. Massive MIMO systems have been investigated widely in recent years. Massive MIMO can provide good array gain and spatial multiplexing gain it can enhance the performance and resistance to noise. Further to this, it can yield high spectral efficiency compared to conventional MIMO, i.e. ten times higher than MIMO.

Chaotic systems are deterministic, nonlinear, dynamic and highly sensitive to initial condition and system parameter. These systems can generate a greater number of signals which can be reconstructed precisely. In conventional communication systems, the transmitted signals are easy to intercept. To prevent such an issue, spread spectrum is used. This paper proposes a spreading scheme based on chaos system for massive MIMO-OFDM system with K users and base station is equipped with N antennas, $K < N$. The major contributions of this work are explained as follows: motivated by the characteristic of logistic map function, this paper proposes a chaos based massive MIMO-OFDM structure. At transmitter, the input data is generated and converted to corresponding symbols by the modulator. Spreading sequence is generated using logistic map function. The modulated data is multiplied with the spreading sequence before being processed by IFFT. After spreading, the resultant sequence is processed by the IFFT block for transmission. At receiver side, data receiver performs the reverse process of transmission in order to get original data. The efficacy of the proposed system is investigated by varying many parameters including modulation methods such as PSK and QAM, number of users, 10,20 and 30 and spreading factor of 5,10 and 15. The advantages of the proposed scheme are to provide secure communication, a receiver who may know the parameters of chaotic system, can recover the message. It is very hard to intercept because of spectral spreading.

The remainder of the paper is outlined as follows: a survey of related works is provided in Section 2. The proposed massive MIMO-OFDM system is explained in Section 3. Numerical results and performance of the developed system is discussed in Section 4. Empirical findings and conclusions are discussed in Section 5.

2 Literature Review

Massive MIMO system uses a higher number of antennas to simultaneously serve large number of wireless broadband terminals. Structure of Massive MIMO, components, advantages and disadvantages are provided in [1] [2]. Spreading codes plays an important role in communication system. To improve the performance, a good spreading code with good autocorrelation property to be used. Studies reported chaotic sequences have good autocorrelation property [3]. Authors in [4] analyzed the characteristic of many chaotic sequences. The authors used chaotic sequences to spread OFDM signal in time domain. Results demonstrated that the multiuser MIMO-OFDM with chaotic sequence spreading achieved better performance than other codes.

In [5] authors utilized logic map function for spreading MIMO-OFDM signal. The OFDM signal is spread in time domain. Efficacy of the proposed method is analyzed by varying length of spreading factor. Results showed outstanding performance. In [6] authors developed MIMO-OFDM system in combination with DSSS coding Schemes. Results demonstrated that MIMO OFDM can recover original data more precisely. Furthermore, influence of spreading code length is analyzed. WH code and Gold code are used for spreading the signal. In wireless communication systems, achieving a highly secure data transmission is an extremely challenging task. Several DSSS schemes have been used to deal with the issue. In recent years, chaos systems have caught more attention due to its characteristics.

In [7] researchers addressed the challenge posed by CDMA systems. The authors utilized 3D chaotic system to generate spreading code. Each user is spread with 3D chaotic signals. Difference sequences are generator by varying initial conditions. Results proved that chaos-based CDMA system outperforms the 1D chaotic systems and Gold code. In [8] analyzed the strength of PN and chaotic codes in CDMA systems. Performance of CDMA system is plotted BER against SNR for varying fading power, memory and spreading sequences. Outcome demonstrated that chaotic codes provide better results compared to PN codes.

Authors in [9] proposed MIMO OFDM system. The authors used space-time frequency spreading to improve system throughput. Empirical finding revealed that chaos-based MIMO-OFDM yield high diversity gain than conventional MIMO MC CDMA.

Based on the recent works reported in the review, the following research gapes are identified. Chaotic sequences can be used to enhance the performance. Massive MIMO-OFDM system has never been investigated for different constellation techniques and for varying spreading factor value. To address the aforementioned constraints, this paper presents a chaos based massive MIMO-OFDM system.

3 Proposed massive MIMO OFDM system

This paper proposed a novel chaos based massive MIMO-OFDM system consisting of K users and N antennas at the base station (K<N), as shown in Figure 1. At transmitter, input data, b(t) with M-length is generated from uniformly distributed random signal with zero mean. Encoder block takes input data and maps the data to make it fit for further process.

The mapped data is converted to symbols by the modulator. In this study, two modulation schemes such as PSK and QAM are used to find out suitable one. Spreading employed to reduce multiple interference access and to improve the system performance.

The modulated signal is multiplied with the spread sequence. The modulated data is multiplied with the spreading sequence before being processed by IFFT. After spreading, the resultant signal is processed by IFFT block for transmission.

Chaotic systems are deterministic and random like noise in nature. These systems are sensitive to initial conditions, system parameters and have good correlation property. Logistic map function employed for generating spreading sequence.

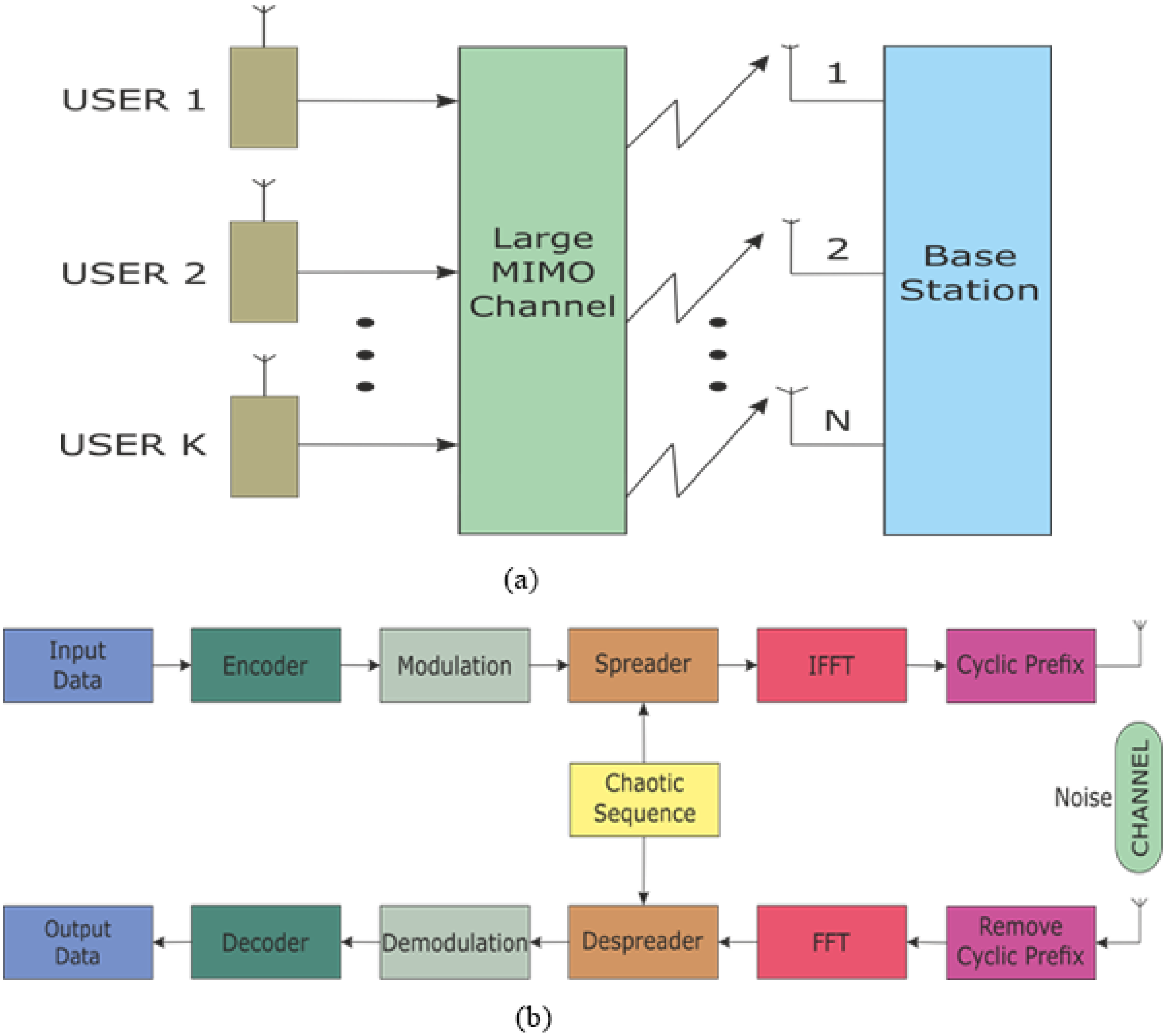


Fig 1. (a) Massive MIMO system (b) Processing of OFDM symbol with chaotic spreading code

Logistic map function is an iterative function and future value depends on the initial condition $x_{t+1} = f(x_t)$, where x_t is a chaotic value generated at the t^{th} iteration. Logistic map function can be expressed as,

$$x_{n+1} = \lambda x_n (1 - x_n) \tag{1}$$

Where, x_n is the state variable, [0,1], λ is the system or growth parameter[1,4] and n is the number of iterations, [0, α]. The generated sequence is converted into bipolar signal by using thresholding method.

$$b_k = f(x_n) = \begin{cases} 1 & \text{if } x_n > Th \\ -1 & \text{otherwise} \end{cases} \tag{2}$$

Let the modulated signal be 'u'. Spreading is done by multiplying encoded signal with the generated chaos sequence to generate spreading signal in time domain, given in Equation (3) .

$$sp = ub = (sp_1, sp_2, \ldots . sp_{Nt}] \tag{3}$$

Where, N is the number of users. The resultant signals are applied to OFDM modulators, where the signals are converted into parallel form, converted into frequency domain signals by using IFFT. Suppose kth IFFT input to ith antenna, X_k^i, k = 0,1,2, ….M-1, i=1,2,….Nt.

$$x_n^i = \frac{1}{\sqrt{M}} \sum_{n1=1}^{M} X_{n1}^i e^{\frac{i2\pi nn1}{N}} \qquad n = 1, 2, \ldots N \tag{4}$$

After IFFT process, cyclic prefix is added to overcome inter-symbol interference. Finally, the signals are converted into serial form for transmission. The vector representation of the transmitted symbol from kth antenna can be represented as,

$$x_k = \left[x_k^0, x_k^1, \ldots . . x_k^{(N_t-1)}\right]^T \tag{5}$$

The received signal from pth (p=0,1,…Nr-1) antenna can be expressed as,

$$y_k = \left[y_k^0, y_k^1, \ldots . y_k^{(N_r-1)}\right]^T \tag{6}$$

$$Y_k = \sqrt{E} HX + n_0 \tag{7}$$

Where, 'Y' is the received signal at 'kth' user, E represents the transmitting power $|E| = 1$, H is the channel and 'n_o' is the AWGN with zero mean and unit variance. At the receiving end, data receiver performs the reverse process of transmitter to obtain the original data.

4 Results and Discussions

In this section, numerical results based on the simulation outcomes of the proposed chaos based massive MIMO-OFDM to validate its effectiveness is presented. To show the effectiveness, the computer program was performed on MATLAB 2016a software. Parameters employed for implementing the proposed system is provided in Table 1.

Table 1. Parameters employed for implementation

Parameters	Value
Modulation schemes	M-ary PSK, QAM
Modulation order	2,4,8
Spreading sequence	Logistic map
Spreading factor	5,10,15
Number of transmitters	10,20,30
Number of receivers	100
Channel	Multipath Rayleigh
Number of subcarriers	64
Cyclic prefix length	32

Initially, message bits are generated. Modulators are used for converting bits into symbols. The obtained symbols are spread in time domain by using chaotic sequence. Research studies proved that the correlation characteristics of chaotic systems are better than possessed by merit of employing a chaotic sequence as spreading codes[6]. Further to this, chaotic sequence is random, noise like nature. In this work, logistic map function is used to generate the spreading code by setting, initial condition, x0=0.01 and system parameter, λ=3.89. Sample of generated sequence and its auto correlation plot is shown in Figure 2.

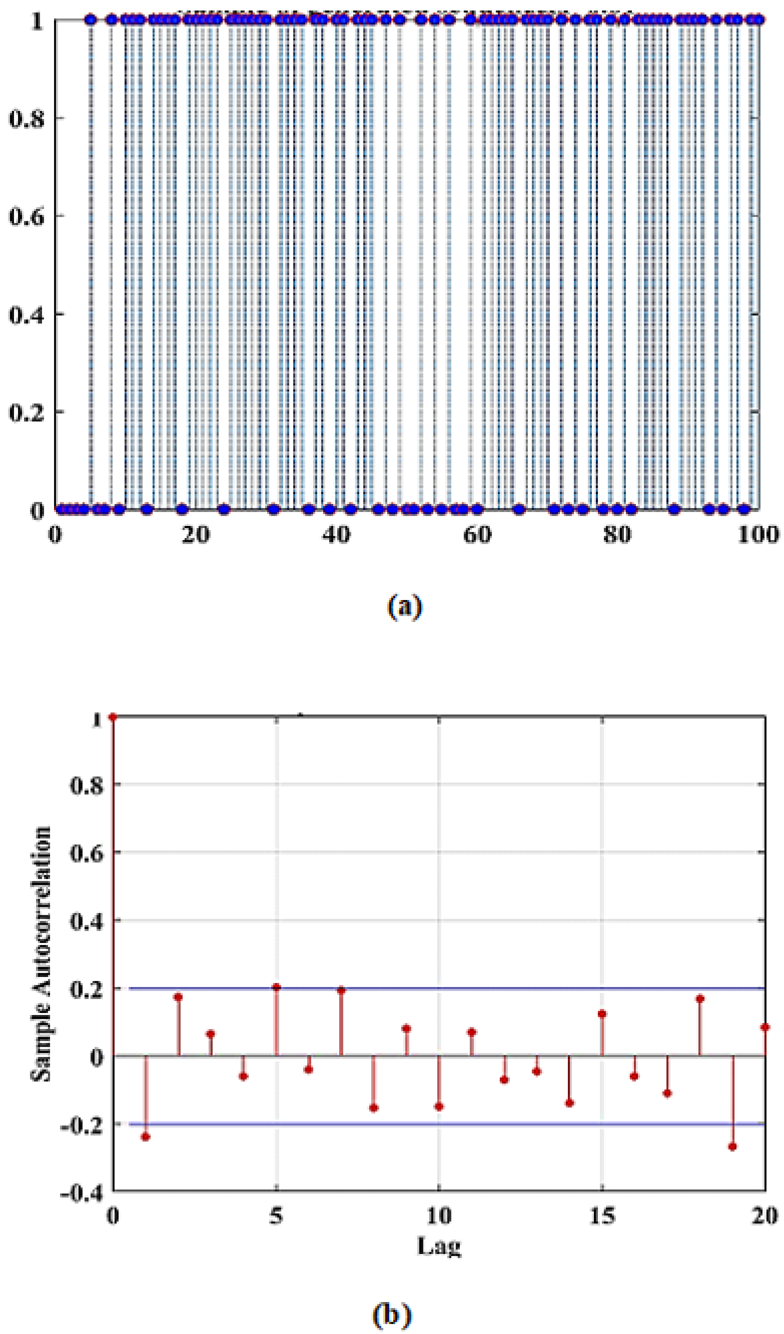


Fig 2. Spreadingcode (a) Generated sequence (b) Autocorrelation plot

4.1 Performance analysis

Several experiments are conducted to assess the performance of the developed scheme by varying many parameters including modulation schemes, SF value and number of users.

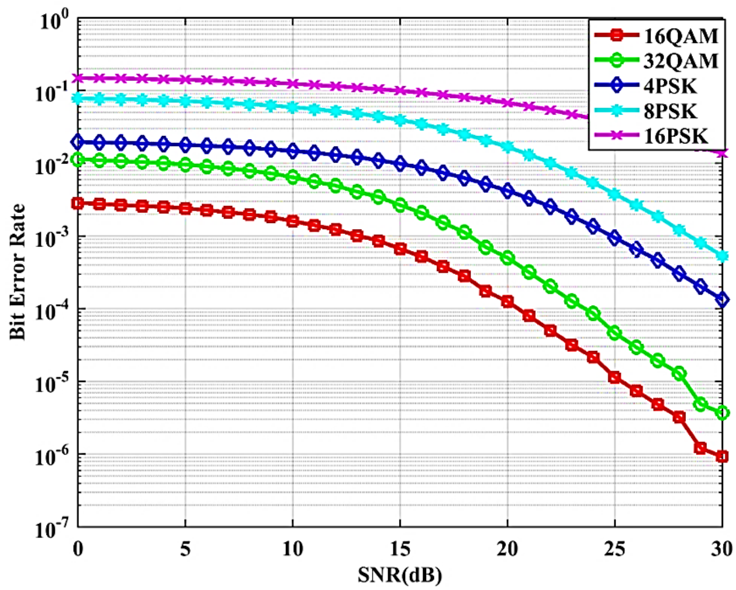
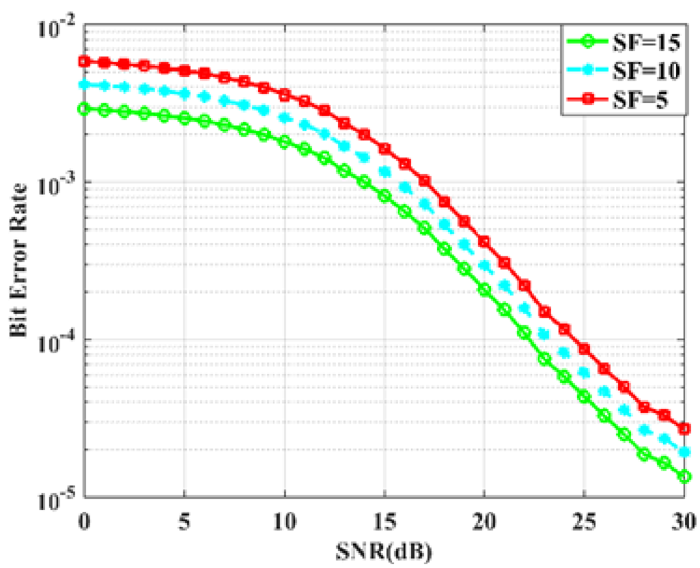


Fig 3. BER performance against modulation schemes

Figure 3 shows the BER outcomes of the designed massive MIMO-OFDM involving two modulation schemes M-ary PSK and QAM. SNR is varied from 0 to 30 dB. BER of the PSK and QAM modulation schemes are compared for different modulation orders, PSK (M=4,8,16) and QAM (M=16,32).



(a)

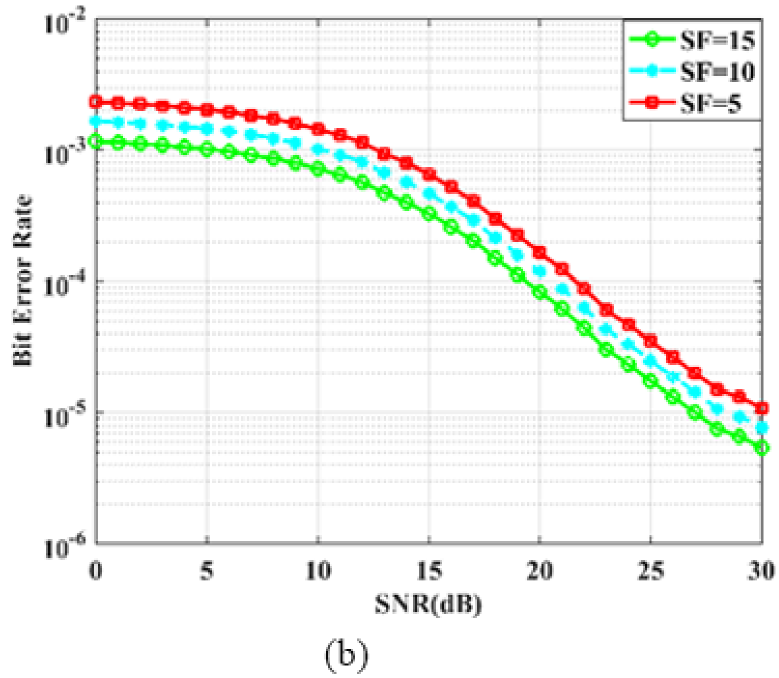
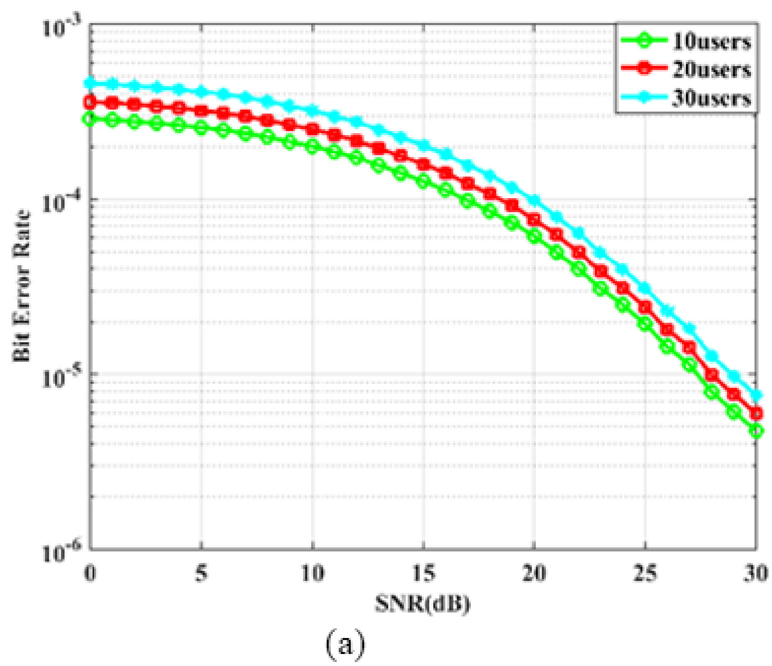


Fig 4. Performance against SF (a) PSK modulation (b) QAM modulation

Figure 3 shows comparison of BER versus SNR between PSK and QAM modulation schemes for various modulation order. From the Figure 3, it is observed that 16QAM possess minimal BER whereas 16PSK provides the worst performance. For an instance, at SNR 16dB, the value of BER for 16QAM, 32 QAM,4 PSK, 8 PSK and 16 PSK to 0.0005,0.0021,0.0087,0.0350 and 0.0942 respectively. Figure 4 compares the efficacy of the developed system with PSK and QAM modulation which is influenced by SF of 5,10 and 15.



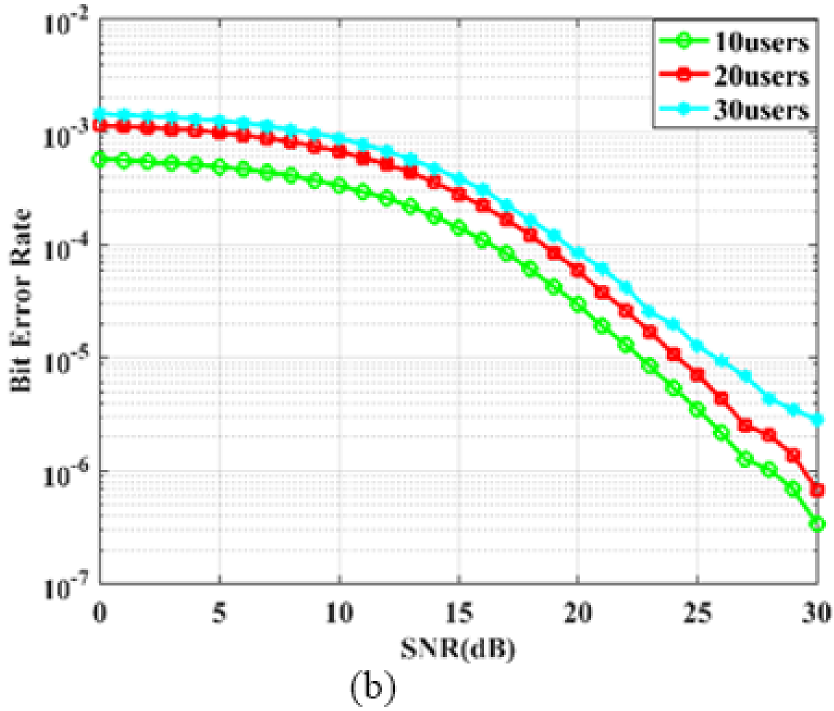


Fig 5. BER vs. SNR of the proposed system by varying number of users (a) PSK modulation(b) QAM modulation

It can be seen apparently that the system performance is depends on spreading factors. It is observed from both the graphs that the system performance improved by increasing spreading factor. For an example, for PSK, at SNR= 23 dB, the BER value of SF 5, 10 and 15 to be 1.52 X 10^{-4}, 1.08 X 10^{-4} and 7.58 X 10^{-5} respectively. It proves BER decreases with increasing spreading factor. Similarly, for QAM modulation, at SNR= 20 dB, the BER value of SF 5, 10 and 15 to be 1. 67 X 10^{-4}, 1.11 X 10^{-4} and 8.36 X 10^{-5} respectively. This further confirmed that the developed system can be improved by increasing SF value.

Figure 5 shows the BER comparison of the developed system according to the number of users in case of PSK and QAM modulation schemes. From the Figure 5, it is observed that BER value increases with increasing number of users. To obtain a BER value of 10^{-6} for PSK modulation-based system needs an SNR of 28dB, but this requirement falls to 23dB for QAM modulation-based system with 10 users and BS equipped with 100 antennas. It is also found that as the number of users increases, the SNR needed to obtain a BER of 10^{-6} will be higher. For 20 users, PSK based massive MIMO-OFDM requires 28dB to obtain a BER value of 10^{-6} but QAM based massive MIMO OFDM achieves at 25dB.A similar observation can be drawn for 30 users.

4.2 Comparison with existing approaches

To further demonstrate the dominance, the performance of the proposed chaos-based massive MIMO-OFDM scheme has been compared with the previous methods including Discrete Wavelet Transform (DWT) based massive MIMO-OFDM (Kansal et al. 2019) and PN sequence based massive MIMO-OFDM (Li et al. 2019) which were reported in the literature. The efficacy of the proposed system is compared with the state-of-art methods in two objectives:

1. To compare the performance of the proposed system with the existing methods by varying the modulation schemes.
2. To compare the performance of the proposed system with the existing methods by varying the number of users.

To compare the performance of the proposed chaos based massive MIMO-OFDM with the earlier methods, two modulation schemes namely PSK and QAM, spreading factor is 15 and different number of users with count of 10, 20 and 30 are considered. Then performance of the proposed system is compared with the earlier methods in terms of BER for PSK and QAM modulation with different number of users are tabulated in Tables 2 and 3 respectively.

Table 2. Performance comparison in terms of BER (PSK modulation)

No. of users	Methods	SNR (dB)						
		0	5	10	15	20	25	30
10	DWT based	0.00036	0.00032	0.00025	0.00015	7.73 X 10^{-5}	2.43 X 10^{-5}	5.98 X 10^{-6}
	PN based	0.00046	0.00041	0.00032	0.00020	9.89 X 10^{-5}	3.11 X 10^{-5}	7.64 X 10^{-6}
	proposed	**0.00028**	**0.00025**	**0.00020**	**0.00012**	**6.18 X 10^{-5}**	**1.95 X 10^{-5}**	**4.78 X 10^{-6}**
20	DWT based	0.00050	0.00045	0.00035	0.00022	0.00010	3.40 X 10^{-5}	8.37 X 10^{-6}
	PN based	0.00073	0.00065	0.00051	0.00032	0.00015	4.98 X 10^{-5}	1.22 X 10^{-5}
	proposed	**0.00034**	**0.00030**	**0.00024**	**0.00015**	**7.42 X 10^{-5}**	**2.34 X 10^{-5}**	**5.74 X 10^{-6}**
30	DWT based	0.00086	0.00077	0.00060	0.00038	0.00018	5.83 X 10^{-5}	1.44 X 10^{-5}
	PN based	0.0012	0.00106	0.00083	0.00052	0.00025	8.09 X 10^{-5}	1.99 X 10^{-5}
	proposed	**0.00063**	**0.00056**	**0.00044**	**0.00028**	**0.00013**	**4.29 X 10^{-5}**	**1.05 X 10^{-5}**

Table 3. Performance comparison in terms of BER (QAM modulation)

No. of users	Methods	SNR (dB)						
		0	5	10	15	20	25	30
10	DWT based	0.00058	0.00049	0.00034	0.00014	2.98 X 10^{-5}	3.55 X 10^{-6}	3.42 X 10^{-7}
	PN based	0.00087	0.00076	0.00053	0.00023	5.11 X 10^{-5}	7.74 X 10^{-6}	1.72 X 10^{-6}
	proposed	**0.00023**	**0.0002**	**0.00014**	**5.70 X 10^{-5}**	**1.19 X 10^{-5}**	**1.42 X 10^{-6}**	**1.37 X 10^{-7}**
20	DWT based	0.00161	0.00139	0.00095	0.0004	8.34 X 10^{-5}	9.94 X 10^{-6}	9.58 X 10^{-6}
	PN based	0.00232	0.00202	0.00142	0.00062	0.00014	2.06 X 10^{-5}	4.58 X 10^{-6}
	proposed	**0.00069**	**0.00059**	**0.00041**	**0.00017**	**3.58 X 10^{-5}**	**4.25 X 10^{-6}**	**4.10 X 10^{-7}**
30	DWT based	0.00277	0.00237	0.00162	0.00068	0.00014	1.70 X 10^{-5}	1.64 X 10^{-6}
	PN based	0.00377	0.00328	0.00231	0.00101	0.00022	3.35 X 10^{-5}	7.44 X 10^{-6}
	proposed	**0.00127**	**0.00109**	**0.00074**	**0.00031**	**6.56 X 10^{-5}**	**7.79 X 10^{-6}**	**7.52 X 10^{-7}**

From Table 2, it was observed that the proposed scheme provides better results by providing low BER for different number of users when compared to the earlier methods which were taken for comparison. For an instance, PSK modulation at SNR is equal to 20 dB and 20 users, the BER value of PN based, DWT based and proposed system are 0.00010, 0.00015 and 7.42 X 10^{-5} respectively. Similarly, it can be seen from Table 3 that the proposed method achieves low BER for QAM modulation with greater number of users when compared to the earlier methods. For an instance, QAM modulation at SNR is equal to 30 dB and 30 users, the BER value of PN based, DWT based and proposed system are 1.64 X 10^{-6},7.44 X 10^{-6} and 7.52 X 10^{-7} respectively.

From comparison results, it was clearly observed that the proposed chaos based massive MIMO-OFDM system provides promising results when compared to the existing methods that were taken for comparison.

This is because of utilizing chaotic sequence to spread the signal before transmission. Additionally, the advantages of the proposed scheme are to provide secure communication, a receiver who may know the parameters of chaotic system, can recover the message. It is very hard to intercept because of spectral spreading.

5 Conclusion

This study presents a massive MIMO OFDM system based on chaotic map function. The system structure and its function are explained and performance is evaluated by measuring BER. The outcomes confirmed that the proposed scheme offers the potential to solve the demands for secure transmission over a massive MIMO-OFDM communication network. Efficacy of the proposed method is analyzed by varying modulation schemes, number of users, and spreading factor. From the empirical finding, it is proved that the developed system with QAM at high spreading factor provides better results than PSK based on BER. For future research direction, 3D chaotic sequences will be explored to further improve the performance.

Nomenclature

BER	-	Bit Error Rate
CDMA	-	Code Division Multiple Access
DAB	-	Digital Audio Broadcasting
DSSS	-	Direct Sequence Spread Spectrum
DVB-T	-	European Terrestrial Digital Television
FFT	-	Fast Fourier Transform
IFFT	-	Inverse Fast Fourier Transform
MC-CDMA	-	Multicarrier Code Division Multiple Access
MIMO	-	Multiple Input Multiple Output
OFDM	-	Orthogonal Frequency Division Multiplexing
OFDMA	-	Orthogonal Frequency Division Multiple Access
SF	-	Spreading Factor
SNR	-	Signal to Noise Ratio
WH	-	Walsh Hadamard

References

1) Berceanu MG, Florea C, Halunga S. Performance comparison of massive MIMO system with orthogonal and nonorthogonal multiple access for uplink in 5G systems. *Applied Sciences*. 2020;10(20). Available from: https://dx.doi.org/10.3390/app10207139.
2) Kansal L, Sharma V, Singh J. Multiuser massive MIMO-OFDM system incorporated with diverse transformation for 5G applications. *Wireless Personal Communications*. 2019;109(4):2741–2756. Available from: https://dx.doi.org/10.1007/s11277-019-06707-1.
3) Mandi MV, Haribhat KN, Murali R. Deriving binary sequences from chaotic sequences having good cross correlation properties". In: and others, editor. Proc. of the Int. Conf. on Machine Intell. IEEE. 2013;p. 29–35. Available from: https://doi.org/10.1109/ICMIRA.2013.13.
4) Yogeeswaran S, Parasuraman S, Manimaran A. Channel estimation of MIMO-OFDM through wavelet transform to improve the spectral efficiency and data transmission rate. *IOP Conference Series: Materials Science and Engineering*. 2020;925. Available from: https://dx.doi.org/10.1088/1757-899x/925/1/012004.
5) Yamazaki R, Shimada Y, Ikeguchi T. Chaos MIMO system with efficient use of information of bits. *Nonlinear Theory and Its Applications, IEICE*. 2020;11(4):546–560. Available from: https://dx.doi.org/10.1587/nolta.11.546.

6) Cheng SJ, Wang WQ, Shao H. MIMO OFDM chirp waveform design with spread spectrum modulation. In: and others, editor. IEEE China summit and Int. conf. on Sig. and Inf. Proc. 2014. Available from: https://doi.org/10.1109/ChinaSIP.2014.6889233.
7) Liu Y, Yang LL, Xiao P, Haas H, Hanzo L. Spatial Modulated Multicarrier Sparse Code-Division Multiple Access. *IEEE Transactions on Wireless Communications*. 2020;19(1):610–623. Available from: https://dx.doi.org/10.1109/twc.2019.2947042.
8) Alqahtani AH, Humadi K, Sulyman AI, Alsanie A. Experimental Evaluation of MIMO-OFDM System with Rateless Space-Time Block Code. *International Journal of Antennas and Propagation*. 2019;2019:1–8. Available from: https://dx.doi.org/10.1155/2019/6804582.
9) Guerreiro J, Dinis R, Campos L. On the Achievable Capacity of MIMO-OFDM Systems in the CathLab Environment. *Sensors*. 2020;20(3):938–938. Available from: https://dx.doi.org/10.3390/s20030938.