BER Comparison of Rayleigh Fading, Rician Fading and AWGN Channel using Chaotic Communication Based MIMO-OFDM System

Suchita Varade, Kishore Kulat

Abstract— This paper proposes, a technique which uses chaotic communication system combined with adaptive beamforming, for secure communications and to improve the system performance by mitigating interference. For secure communications, chaotic sequences are used. Many chaotic communication systems have been proposed, but most of them show a poor performance under realistic channel conditions (i.e. noise and multipath fading).This paper proposes a wireless communication structure based on two coupled chaotic systems. In order to enhance the error-rate performance of MIMO-OFDM system, adaptive beamforming is used. Evaluation and comparison of the performances of MIMO- OFDM system in the AWGN (Additive White Gaussian Noise) channel, Rician fading channel and the Rayleigh fading channel are provided. Results are verified and analyzed for two cases, one when adaptive beamforming is used in the proposed system and second when adaptive beamforming is not used in the proposed system. Computer simulations are done to verify the performance of the proposed approach. A simulation tool with a Graphical User Interface (GUI) which implements these algorithms is also developed to provide ease in the execution.

Index Terms—Chaotic Communication System, Adaptive Beamforming, LMS (Least Mean Squares), LMS-LMS (LLMS).

I. INTRODUCTION

Wireless communication systems are moving towards high transmission speeds and high capacity. This can be achieved by using higher system frequencies to enable a wide frequency band and using advanced system technology to achieve high quality and signal multiplexing. Antenna requirement for such advanced systems are:
1) High-gain and high-efficiency technology
2) Multi-antenna technology

With the rapid growth of wireless data traffic over voice traffic a powerful technique called "Smart Antennas" is used for improving the capacity (and coverage) of the emerging generations of wireless networks. Smart antennas provide the next substantial increase in throughput. The term "smart antennas" is referred to adaptive antennas with electrical tilt, beam width and azimuth control to follow relatively slow-varying traffic patterns. Smart antenna can form beams aimed at particular users or steer nulls to reduce interference [1].

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The phenomenon of multipath propagation has contributed significantly towards deterioration of quality of signal received in a wireless communication system [2]. Several techniques for multipath mitigation are in use in the current wireless communication technology standards [2]. With the steady rise in the number of wireless devices active in the environment, the concept of beamforming has gained popularity. When multiple communications are carried out simultaneously, then in multipath environment the interference from different directions will also increase. This multipath propagation causes the signal at the receiver to distort and fade significantly, leading to higher bit error rates (BER) [2]. To minimize the interference from different directions, smart antennas can be used at the receivers which form the beam in the direction of the incoming multipath and reject the interference coming from other directions [2].

To maximize the STC-OFDM system efficiency, the problem of CCI introduced by the space-time coding must be solved. The technique of beamforming, stemming from smart antenna is an effective method to remove co-channel interference (CCI) that is induced in the STC-OFDM system. Regarding beamforming techniques for STC-OFDM systems, some research attempts have been mainly focused on the transmit beamforming in downlink since the fact that download intensive services and wireless web browsing are to be introduced in the next generation [11], [12], [13], [14].Receive beamforming which is widely applied to uplink of cellular mobile systems to suppress CCI and minimize fading effects. In this research work receive beamforming is used to improve the interference rejection capability of the proposed system. The scheme of MIMO wireless systems incorporating a beamforming method before space-time decoder can effectively mitigate interference [15].

Wireless technologies have become popular in recent years and usually applied in multimedia broadcasting, environment monitoring, mobile communication, etc. In all applications, keeping information accuracy is very important. To improve the security and accuracy of transmitted information, a wireless communication structure based on two-coupled chaotic communication system is proposed.

Chaotic communication systems have been shown to provide certain advantages over conventional communication systems. Firstly, chaotic signals are much easier and faster to generate using a simple circuit. Hence, reduction in hardware cost is obtained. Secondly, the non-periodic and bifurcation behaviors of the chaotic signal can-not easily be intercepted and predicted thus an increase in system security is obtained. In addition, a large number of chaotic signals can be generated which is useful in multi-user environment.

All kinds of schemes utilizing chaos properties have been proposed in last decade and showed to provide advantage in terms of security, capacity, and BER performance. However, there are still plentiful of issues to be resolved before chaos-based systems can be put into practical use. [17, 18]

Here, a structure of two coupled chaotic communication is proposed which can be used for number of applications in wireless communication. In this work the emphasis is given on the reduction in the interference using adaptive beamforming in the chaotic communication based MIMO-OFDM system.

The proposed system uses a technique of chaotic communication based STC and adaptive beamforming algorithm (LMS and LLMS) for MIMO-OFDM system for the improvement of BER performance. This combined technique enhances security and performance of the system in terms of BER. The study has focused on various adaptive beamforming algorithms and its use in the system to improve the performance in terms of BER.

Organization of this paper is as follows. Section2 present chaotic communication system .Section 3 presents a proposed system while adaptive beamforming algorithms LMS & LLMS is given in section 4 where as simulation results are given in Section 5 followed by the conclusions. In this paper the symbols [.]*, [.]T, and, [.]H, are conjugate, transpose and, conjugate transpose operators, respectively.

II. CHAOTIC COMMUNICATIONS SYSTEMS

A general chaotic system can be described as the following dynamic equation:

$$\dot{x} = Ax + g(x) \tag{1}$$

Where Ax is the linear part, g(x) is the nonlinear part of this system. In this paper, the chaotic security system is constructed by using Lorenz's chaotic system which is an autonomous 2-order nonlinear system. We propose a concept of Transmitter-Receiver structure as shown in Fig. 1.

The scheme of secure communication can be distributed by a coupled chaotic system. The input message M is masked by the chaotic state and transmitted. The equations of encrypt and decrypt systems at transmitter and receiver side are presented as following:

Encrypt side (Tx):

$$\dot{x} = Ax + g(x,v) + Lz_x \tag{2}$$

Where, $v = x1 + M$

Decrypt side (Rx):

$$\dot{y} = Ay + g(y,v) + Lz_y \tag{3}$$

Where, $x \in R^n$ and $y \in R^n$ are the state vectors. Ax and Ay are the linear part, g(x, v) and g(y, v) are the nonlinear part of this system, L is the controller gain of the system, K>0 is the coupling strength between master and slave system, zx and zy are the feedback signal.

$$x = \begin{bmatrix} x_1 & x_2 & x_3 \end{bmatrix}^T$$

$$y = \begin{bmatrix} y_1 & y_2 & y_3 \end{bmatrix}^T$$

$$A = \begin{bmatrix} -a & a & 0 \\ c & -(1+k) & 0 \\ 0 & 0 & -b \end{bmatrix}$$

$$g(x,v) = \begin{bmatrix} 0 & -vx_3 & vx_2 \end{bmatrix}^T$$

$$g(y,v) = \begin{bmatrix} 0 & -vy_3 & vy_2 \end{bmatrix}^T$$

$$L = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \end{bmatrix}, \qquad z_x = M \ , \qquad z_y = v - y_1$$

Where, elements of control gain L should satisfy the condition:

$$l_1 > -a, l_2 = a + c, l_3 = 0$$

The synchronization error and its error dynamic are defined as follows:

$$e = x - y = \begin{bmatrix} e_1 & e_2 & e_3 \end{bmatrix}^T \tag{4}$$

$$\dot{e} = \dot{x} - \dot{y} = Ae + g(x,v) - g(y,v) + L(z_x - z_y) \tag{5}$$

The goal is designing the controller gain L such that the input message M can be recovered in the receiver side. The masking message can be obtained as recovered message R shown as

$$R = v - y_1 = (x_1 + M) - y_1 \tag{6}$$

$$x_1 = y_1, R = M$$

Here we have considered two-coupled system and values of different parameters are selected as given below:

A = [0.1 0.2]
M = [0.2 0.1]
L = [0.15 0.25]
x = [0.22 0.19]
zx = [0.3 0.6]

III. PROPOSED MIMO- OFDM SYSTEM

A. System model

Fig.2 presents the block diagram of the chaotic communication based OFDM system with smart antenna. The OFDM transmission and reception are respectively presented in Fig.2 (a) and Fig.2 (b).
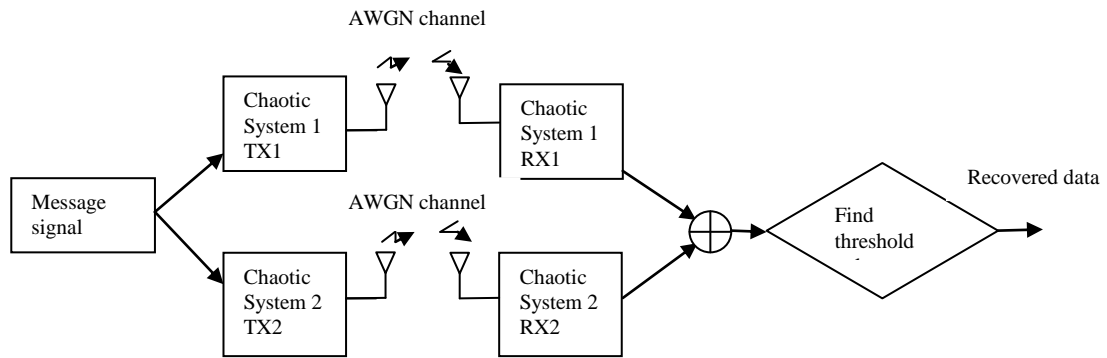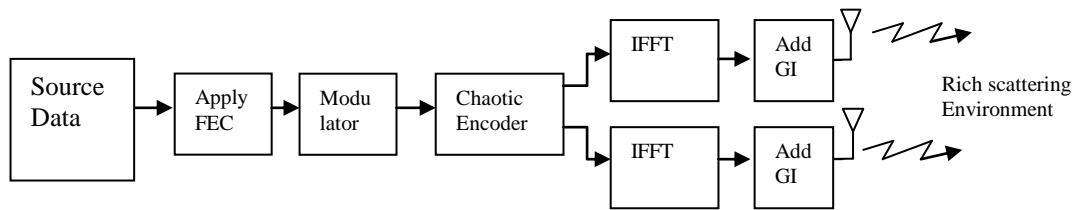
Fig.1 Proposed two-coupled chaotic communication system

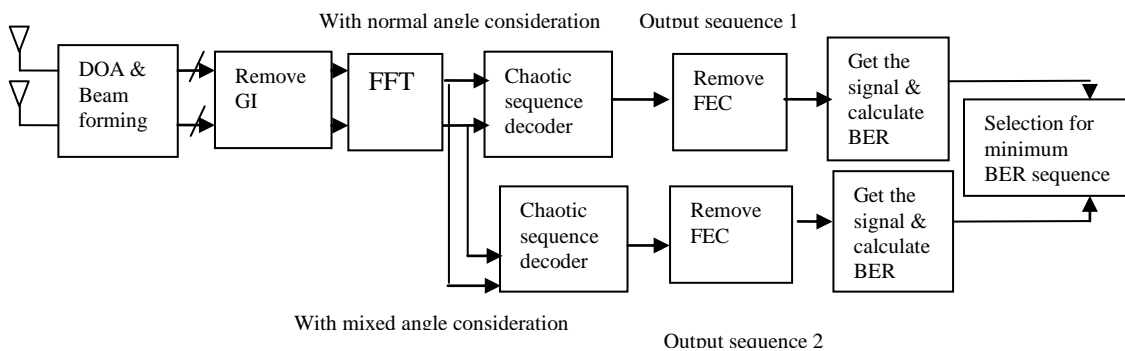**Fig.2 (a) Block diagram for the simulated MIMO- OFDM Transmitter**

Fig.2 (b) Block diagram for the simulated MIMO-OFDM Receiver

A. Transmitter Part

At transmitter first, the data is generated from a random source, consists of a series of ones and zeros. Data input bits are converted into symbol vector using modulation. Modulation scheme used to map the bits to symbols are BPSK, QPSK, 16 PSK, 256 PSK.

Since the transmission is done block wise, when forward error correction (FEC) is used, the size of the data generated depends on the block size used, modulation scheme used to map the bits to symbols (BPSK, QPSK), and whether FEC is used or not [1]. The generated data is passed on to the next stage i.e.to the FEC block.

Forward error correcting codes are applied to normal convolution code sequence and interleaved convolution code sequence. The error correcting codes are used, to avoid long run of zeros or ones, as the data generated is randomized. This results in ease in carrier recovery at the receiver. The randomized data is encoded using tail biting convolution codes (CC) with a coding rate of ½.

The sequence is then fed to the chaotic communication system. The Chaotic communication converts the block of

m-binary symbols into two encrypted sequences. The signal is encrypted using Equ. 2. Two coupled chaotic communication system is used, hence two sequences are generated. The two output signals from Chaotic communication system x1 and x2 termed as Chaotic sequence 1 and Chaotic sequence 2 as shown in fig.(2) . These sequences are then passed onto the next stage, the IFFT, to convert into time domain

$$Sj(n) = \frac{1}{N} \sum_{n=0}^{N-1} x_j \exp(\frac{j2\pi kn}{N}) \qquad (7)$$

Where, j is the number of transmitting antennas and i is the number of chaotic sequence. Here for two coupled system there are two chaotic sequences.

B. MIMO channel model

1) AWGN Channel

For an AWGN (Additive White Gaussian Noise) channel, 'θ' is a constant and is equivalent to the AoA of the LoS propagation path. In this case,

we use the so-called narrowband data model to model the received signal at the antenna arrays. The narrowband data model assumes that the envelope of the signal wave front propagating across the antenna array essentially remains constant. This model is valid when the signals or the antennas have a bandwidth that is much smaller than the carrier frequency f_c. Under the above assumptions, the vector from of the baseband complex equivalent received signal can be written as,

$$Y(n) = V(\theta)s(n) + G(n) \tag{8}$$

Where, $V(\theta)$ is the array manifold vector and $G(n)$ is AWGN with zero mean and two-sided power spectral density given by No/2. This is simply a plane-wave model.

2) Rayleigh Fading Channel

In wireless telecommunications, multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. Causes of multipath include atmospheric ducting, ionosphere reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings.

The effects of multipath include constructive and destructive interference, and phase shifting of the signal. This causes Rayleigh fading. The standard statistical model of this gives a distribution known as the Rayleigh distribution. Rayleigh fading is a term used when there is no direct component, and all signals reaching the receiver are reflected. Mathematically, the multipath Rayleigh fading wireless channels modeled by the channel impulse response (CIR)

$$h(t) = \sum_{l=0}^{Lp-1} \alpha_l \partial(t - \tau_l) \tag{9}$$

Where, L_p is the number of channel paths, α_l and τ_l are the complex value and delay of path l, respectively. The paths are assumed to be statistically independent, with normalized average power. The channel is time variant due to the motion of the mobile terminal, but we will assume that the CIR is constant during one OFDM symbol.

3) Rician MIMO Channel

A Rician model is obtained in a system with LOS propagation and scattering. The model is characterized by the Rician factor, denoted by K and defined as the ratio of the line of sight and the scatter power components. The pdf for a Rician random variable x is given by

$$p(x) = 2x(1+k)e^{-k(1+k)x^2}I_0(2x\sqrt{k(k+1)}) \qquad x \geq 0 \tag{10}$$

Where

$$K = \frac{D^2}{2\sigma_r^2}$$

and D^2 and $2\sigma_{r2}$ are the powers of the LoS and scattered components, respectively. The powers are normalized such that

$$D^2 + 2\sigma_r^2 = 1$$

The channel matrix for a Rician MIMO model can be decomposed as,

$$H = DH_{LOS} + \sqrt{2}\sigma_r H_{RAYL} \tag{11}$$

Where, H_{LOS} is the channel matrix for the LoS propagation with no scattering and HR_{ayL} is the channel matrix for the case with scattering only.

C. Receiver

This is the final part of the communication system and the most important one. In the receiver the signal is received by forming the beam in the desired signal direction, demodulated and then combined by using receiver, and probabilistic symbol estimation is performed.

At receiver first of all the direction of arrival of the multipath signals are determined. Here the assumption is that the multipath components of the signal are strong enough to distinguish them from noise. The LMS and LLMS beamforming algorithms are used to form the beam in the direction of incoming signal.

The OFDM receiver is shown in Fig. 2(b). At the receiver, the signals are received and combined with different path loss and different fading fluctuation. Receiving antennas used at the receiver are 2. The received OFDM symbol before OFDM demodulation can be formulated as:

$$y(n) = FFT[s(n)h(n)] + G(n) \tag{12}$$

Where, $G(n)$ represents an uncorrelated additive white Gaussian noise, $h(n)$ is the communication channel impulse response, and $S(n)$ is the transmitted OFDM symbol in the nth carrier duration.

1. The first thing done at receiver (in simulation) is estimation of angle of reception.

2. Find out the sum of power of all incident signals for each angle from (0° to 180°) of all elements. (As the sequences are scattered.)

3. From the maximum peak in the power spectrum we can estimate the DOA's of the desired signals.

4. Two transmitting and two receiving antennas are used. So at the receiver we get four copies of the received signal.

5. Two copies from chaotic system 1 and two from chaotic system 2.

At the receiver these copies are termed as normal angle reception signals i.e. when the signal from transmitting antenna 1 Tx1, is received by the receiving antenna 1, Rx1 same is the case for Rx2.So,two signals: normal angle reception signal 1and normal angle reception signal 2 are obtained.

Now, when, receiving antenna 1 Rx1, received the signal from transmitting antenna 2 Tx2, termed it as mixed angle reception. Same is the case for Rx2. So, two signals mixed angle reception signal 1 & mixed angle reception signal 2 are obtained.

After estimating the angle of arrival, adaptive beamforming algorithms LMS and LLMS algorithms are used to minimize the interference. This algorithm is described in section IV.

After receiving four copies of the signal, signals are fed to the FFT for frequency domain transformation. For decoding of the signals chaotic decoders are used. Here the signals are decrypted using the Equ. (3).After decryption signals are added and threshold value can be calculated.

After this FEC is removed from the decoded sequence for normal angle reception signal & mixed angle reception signal.

Now these two sequences are compared to find out which sequence has minimum value of error in bits. For this each sequence is matched with the input sequence to find out which sequence has minimum BER. Finally it gives the result in terms of recovered sequence & recovered mode i.e. recovered sequence is from which mode: normal reception mode or mixed reception mode along with the angle of recovery.

IV. ADAPTIVE BEAMFORMING

This section describes adaptive beamforming algorithm LMS and LLMS.

A. LMS algorithm

Because of its simplicity and robustness, the LMS algorithm has become one of the most popular adaptive signal processing techniques adopted in many applications including antenna array beamforming. Moreover, there is always a tradeoff between the speed of convergence of the LMS algorithm and its residual error floor when a given adaptation step size is used.

The LMS algorithm is a popular solution used in beamforming technique. This algorithm is easy to implement with low computation and performs pretty well. The basic LMS algorithm is expressed as follow [8]

$$w(n+1) = w(n) + 2\mu x(n)e(n) \tag{13}$$

The reference signal d(t) generated at the receiver is usually assumed to have similar statistical properties as the transmitted signal.

For the purpose of simulation, we will simply assume that the reference signal is identical to the incoming signal. The error signal $e(n) = d(n) - y(n)$ is fed into the weight updating algorithm. The criterion for determining the weights is based on minimizing the mean squared error (MSE) between the beam former output and the reference signal:

$$E(e^2) = E(d^2) - 2w^H r - w^H R_{xx} w \tag{14}$$

Where R_{xx} is the autocorrelation matrix of the received signal x and $r = E[dx]$ is the cross-correlation between the reference signal and the received signal. The MSE surface is a quadratic function of w and is minimized by setting its gradient with respect to w to zero.

$$\Delta w[E(e^2)] = -2r + 2R_{xx} w = 0$$

Yielding the well-known Wiener-Hopf solution-

$$w_{opt} = R_{xx}^{-1} r$$

The LMS algorithm is a stochastic gradient optimization algorithm that converges to this solution. It is based on a traditional optimization technique called the Method of Steepest Descent. The weight vector is made to evolve in the direction of the negative gradient which points towards the minimum.

$$w(n+1) = w(n) + \frac{\mu}{2}\{-\nabla w[E(e^2(n))]\} \tag{15}$$

Where Rxx and r are given by

$$R_{xx}(n) = x(n)x^H(n) \tag{16}$$

$$r(n) = d(n)x(n) \tag{17}$$

This gives us a simple expression for weight updating

$$w(n+1) = w(n) + 2\mu x(n)e(n) \tag{18}$$

The LMS algorithm is initiated with an arbitrary value W (0) for the weight vector at n=0. The successive of the weight vector eventually leads to the minimum value of the mean squared error.

B. LLMS-based adaptive beamforming

The LLMS algorithm is shown in Fig.3. [20].The intermediate output, LMS1 yielded from the first LMS section, LMS1, is multiplied by the image array factor (A′) of the desired signal. The resultant "filtered" signal is further processed by the second LMS section, LMS2. For the adaptation process, the error signal of LMS2, e_2, is fed back to combine with that of LMS1, to form the overall error signal, e_{LLMS}, for updating the tap weights of LMS1. As shown in Fig.2, a common external reference signal is used for both the two LMS sections, i.e. d1 and d2 .The error signal for updating LLMS1 at the jth iteration is given by

$$e_{LLM}(j) = e_1(j) - e_2(j-1) \tag{19}$$

$$e_1(j) = d_1(j) - w_1^H(j)X_1(j) \tag{20}$$

$$e_2(j) = d_2(j) - w_2^H(j)X_2(j) \tag{21}$$

The input signal of LMS2 is derived from the LMS1, such that

$$X_2(j) = A' y_{LMS1}(j) = w_1^H(j)X_1(j) \tag{22}$$

Where, A' is the image of the array factor of the desired signal. The weight vector W for the ith LMS section is updated according to

$$w_i(j+1) = w_i(j) + \mu_i e_i(j)X_i(j) \tag{23}$$

Where, $0 < \mu_i < \mu_0$ and 'i' is 1 for LMS1 and 2 for LMS2.μi is the step size and μ0 is a positive number that depends on the input signal statistic.

V. SIMULATION RESULTS

In this section, the computer simulations investigate the BER performance of the proposed technique chaotic
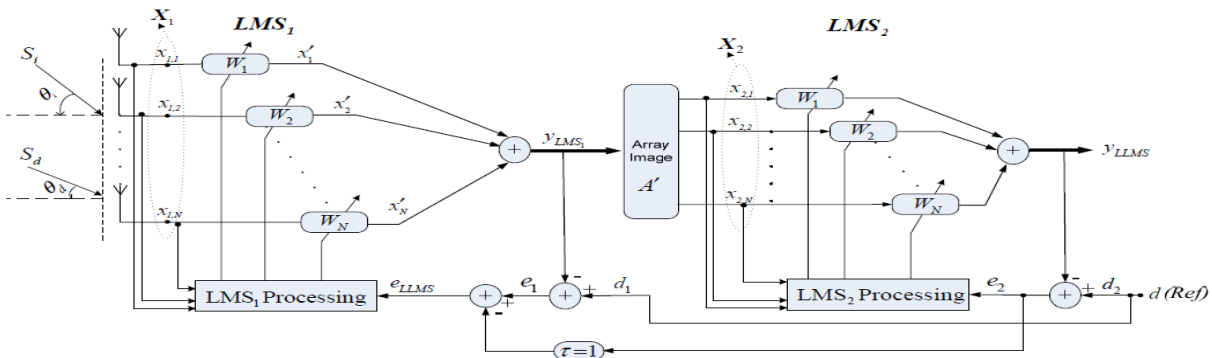
Fig.3 LLMS algorithm [as proposed in Reference 20]

communication based MIMO-OFDM system using adaptive beamforming. The system model has been tested for BPSK, QPSK modulations with an AWGN, Rayleigh and Rician fading channels. The simulation results are shown in Fig.4. In the simulation, there are 2 transmitter antennas and the number of the receiving antennas is 2. The DOAs of two transmitter antennas for desired user are 10°, 90°. It has been observed that when the signals are scattered then it changes the angle of arrival. The simulation result of Fig. 5 shows the BER comparison of proposed technique for MIMO-OFDM system.

Table-I Simulation Parameters considered for simulation

Parameter	Value/Type
Input size	500 bits
No. of Carriers	64
IFFT/FFT size	64
SNR range	1-25
Carrier modulation used	BPSK,QPSK
Channel used	AWGN, Rician & Rayleigh

A. Responses to various channels for BPSK Modulation
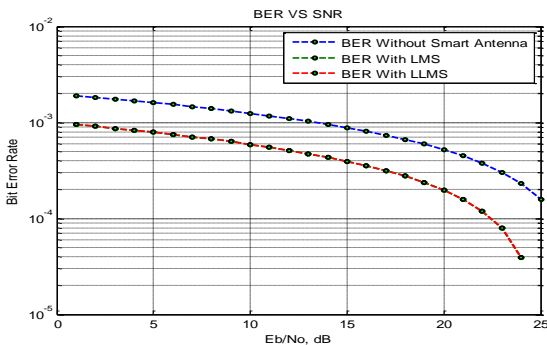

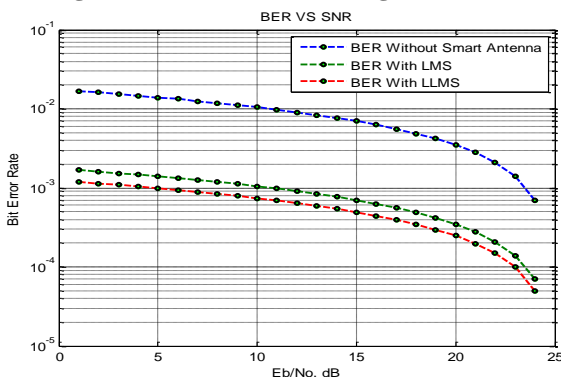**Fig. 4(a) BER for BPSK using AWGN channel**

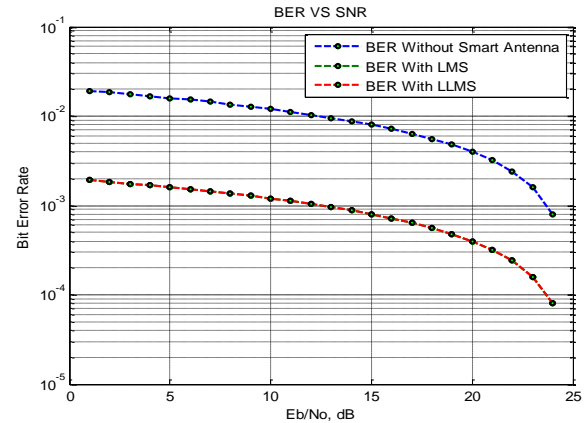**Fig.4 (b) BER for BPSK using Rician channel**

Fig. 4(c) BER for BPSK using Rayleigh channel

In AWGN channel, BER of 0.0002 is achieved for the SNR value of 20 dB using Adaptive beamforming, whereas for the same BER without using adaptive beamforming SNR value is 24 dB. Thus Less signal power is required when adaptive beamforming is used. In Rician channel, BER of 0.0006 is achieved for the SNR value of 12 dB using Adaptive beamforming, whereas for the same BER without using adaptive beamforming SNR value is 24 dB. In Rayleigh channel, BER of 0.0008 is achieved for the SNR

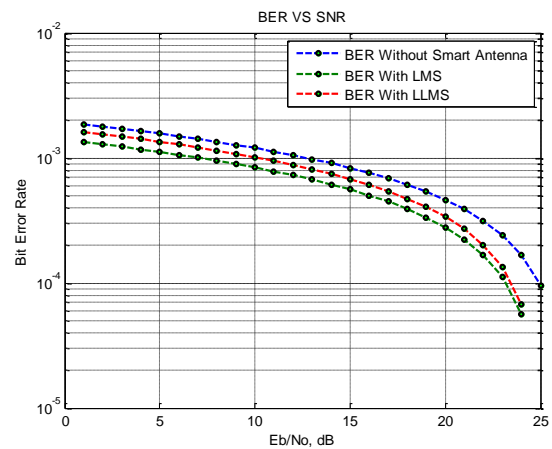*B. Responses to various channels for QPSK Modulation*

Fig.5 (a) BER for QPSK using AWGN channel

Table-II
BER for BPSK modulation using AWGN, RICIAN & RAYLEIGH channel

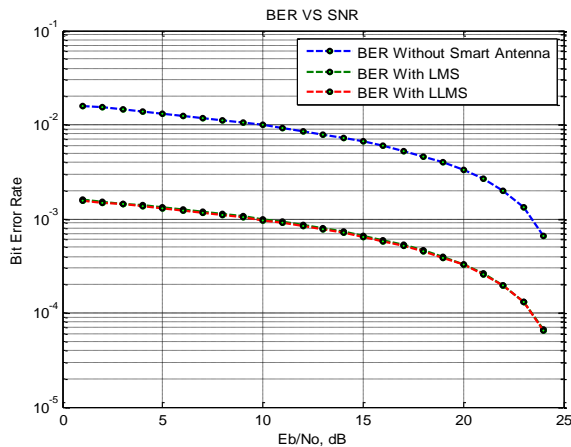| SNR (in dB)	BER(BPSK)					
	AWGN Channel		Rician Channel		Rayleigh Channel	
	Without beamforming	With LMS/LLMS	Without beamforming	With LMS/LLMS	Without beamforming	With LMS/LLMS
2	0.0018	0.0009	0.016	0.0011	0.018	0.0018
4	0.0016	**0.0008**	0.014	0.001	0.016	0.0016
6	0.0015	0.0007	0.013	**0.0009**	0.015	0.0015
8	0.0013	0.00066	0.011	0.0008	0.013	0.0013
10	0.0012	0.00059	0.01	0.0007	0.012	0.0012
12	0.0011	0.00052	0.009	**0.0006**	0.01	0.001
14	0.0009	0.00043	0.0076	0.0005	0.0088	**0.0008**
16	0.0008	0.00035	0.0062	0.0004	0.0072	0.00072
18	0.0006	0.00023	0.0048	0.0003	0.0056	0.00056
20	0.0005	**0.00019**	0.003	0.0002	0.004	0.0004
22	0.0003	0.00011	0.002	0.0001	0.0024	0.00024
24	**0.0002**	0.000039	**0.0006**	0.000049	**0.0008**	0.00008

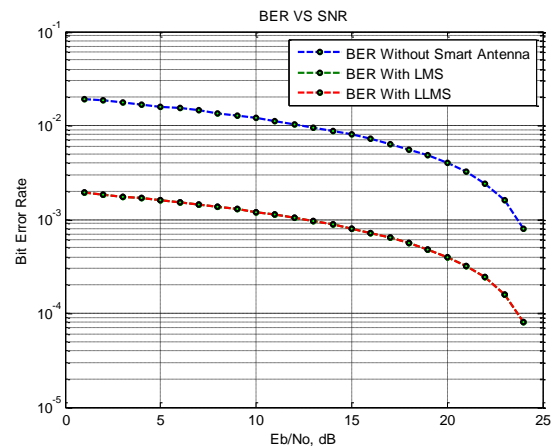**Fig.5(b) BER for QPSK using Rician channel**

Fig.5(c) BER for QPSK using Rayleigh channel

Table-III
BER for QPSK modulation using AWGN, RICIAN & RAYLEIGH channel

SNR (in dB)	BER(QPSK)					
	AWGN Channel		Rician Channel		Rayleigh Channel	
	Without beamforming	With LMS/LLMS	Without beamforming	With LMS/LLMS	Without beamforming	With LMS/LLMS
2	0.0017	0.001	0.016	0.0011	0.018	0.0018
4	0.0016	0.0011	0.014	0.001	0.016	0.0016
6	0.0014	0.001	0.013	0.0009	0.015	0.0015
8	0.0013	0.00094	0.011	0.0008	0.013	0.0013
10	0.0012	0.00083	0.01	0.0007	0.012	0.0012
12	0.001	0.0007	0.009	0.00064	0.01	0.001
14	0.0009	0.00061	0.0076	0.00054	0.0088	0.0008
16	0.0007	0.0005	0.0062	0.00044	0.0072	0.00072
18	0.0006	0.00039	0.0048	0.00034	0.0056	0.00056

20	0.0004	0.00027	0.0034	0.00024	0.004	0.0004
22	0.0003	0.00016	0.002	0.00014	0.0024	0.00024
24	0.0001	0.00005	0.00067	0.000049	0.0008	0.00008

Table-IV
SNR for different modulation using different channels for BER 10^{-3}

Range for SNR required for BER 10^{-3}	BPSK		QPSK	
	Without beamforming	With LMS/L LMS	Without beamforming	With LMS/L LMS
AWGN	14	1	12	7
Rician	23	4	23	9
Rayleigh	24	14	24	14

In AWGN channel, BER of 0.0007 is achieved for the SNR value of 12 dB using adaptive beamforming, whereas for the same BER without using adaptive beamforming SNR value is 16 dB.In Rician channel, BER of 0.0007 is achieved for the SNR value of 10 dB using Adaptive beamforming, whereas for the same BER without using adaptive beamforming SNR value is 24 dB. In Rayleigh channel, BER of 0.0008 is achieved for the SNR value of 14 dB using Adaptive beamforming, whereas for the same BER without using adaptive beamforming SNR value is 24 dB.

VI. CONCLUSION

In this work, performance comparison of chaotic communication based MIMO-OFDM system is given with and without using adaptive beamforming. The use of chaotic communication system can increase the security prospective of the system due to it bifurcation behavior when varying the initial condition. On the other hand, adaptive beamforming can more effectively mitigate interference and enhances the system performance. The proposed scheme has been verified in AWGN channel, Rayleigh Fading channel and Rician Fading channel. It has been observed that BER performance of the system is improved with adaptive beamforming.The adaptive beamforming improves the system performance greatly using BPSK modulation compared to the QPSK modulation.Many times QPSK and BPSK performs in similar manner especially during non stationary environment. In general BPSK scheme should have least priority compared to other mapping schemes, while considering in terms of spectral efficiency, bandwidth and bit rate support. Channels perform in the following order in terms of best (less SNR requirement) to worst (more SNR requirement) to maintain the required BER: AWGN, Rician, Rayleigh.

Future extension of this work has a lot of scope as noted.The proposed system is used with 2-order chaotic communication structure. It can further extend for 3-order chaotic communication structure. Currently, single user simulation is used; however it can be increased for multiple user scenarios.

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