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Interference Mitigation in Massive MIMO using Spatial Modulation Concept

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Abstract - This paper presents the concept of spatial modulation (SM) scheme for the Massive MIMO system. We consider the Massive MIMO system where K users, each equipped with multiple antennas, are jointly serviced by a multi-antenna base station transmitter (BSTx) using appropriate precoding scheme at the BSTx. The main idea introduced here is the utilization of the user's subchannel index corresponding to the precoding matrix used at the BSTx, to convey extra useful information. This idea has not been explored, and it provides significant throughput enhancements in a multiuser system with large number of users. We examine the performance of the proposed scheme by numerical simulations. The results show that as the number of users and the receiving antennas for each user increase, the overall system throughput gets better, albeit at the cost of some degradation in the BER performance due to inter-antenna interference (IAI) experienced at the receiver. We then explore zero-padding approach that helps to remove these IAI, in order to alleviate the BER degradations.

Keywords- Massive MIMO, Spatial Modulation (SM), Subchannel Selection Method, Zero-Padding (ZP) Method

I. INTRODUCTION

Massive multiuser multiple input multiple output (MIMO) systems have gained significant research attentions lately because they provide significant boost in the capacity of MIMO systems [1–3]. Multiuser MIMO systems have been investigated for long time now. However, a recent new development in this research area is the aggressive use of very large number of antennas, known as massive multiuser MIMO systems. Currently in the fourth-generation (4G) long-term evolution (LTE) for cellular system, the use of up to 8 × 8 MIMO systems have been standardized, both for single-user and multiuser systems.

It is hoped however that massive MIMO systems with hundreds of antennas at the base station (BS) will eventually be standardized in the fifth-generation (5G) cellular system, as part of the major data rate enhancement techniques to be introduced in 5G [4]. To this end, several research efforts have been devoted to studying the benefits of massive MIMO systems under different considerations.

Spatial modulation (SM) is another new promising transmission technique that uses antenna indexes in a multiple antenna system, as additional means of data transmissions. The main idea behind spatial modulation is to use the index of the active antennas at any time instant, transmitting or receiving antenna depending on whether the spatial modulation scheme is applied at the transmitter or at the receiver, to convey extra information. Thus, the information bits to be transmitted are divided into blocks of two parts [5]. The first part is mapped to a symbol chosen from the signaling constellation, where the number of bits per symbol depends on the type of modulation used. The second part determines the index of the antenna to be selected from a set of antennas available for data transmission or reception. Therefore, unlike antenna selection in the conventional MIMO systems which depends on the channel states and the received signal strength, antenna selection in spatial modulation depends on the incoming user data stream [6, 7].

Spatial modulation schemes were first introduced in [8,9], where the principle of wireless transmission in which the information is carried by both the index of the activeantenna and the symbol transmitted through this active antenna was illustrated. In [10], then, the idea of space shift keying (SSK) modulation was introduced as a modulationscheme, which uses only the spatial modulation concept. In the SSK scheme, there were no transmitted symbols. Only the antennas' indices were used to convey information. Because no symbols were transmitted, SSK reduces the system complexity by removing the amplitude/phase modulation (APM) required in the transmission and detection components, but at the expense of some degradation in the system's spectralefficiency. Since only one antenna is active at a time in the SSK scheme, the scheme exhibits no inter-antenna interference (IAI), just like a single antenna wireless system. In [11], a combination of spatial modulation (SM) and space-time block coding (STBC) were considered, in order to take advantage of the benefits of both schemes. A generalized version of SM called generalized spatial modulation (GSM) system with multiple active transmitting antennas (MA-SM) and low complexity detection scheme was introduced in [12-13]. In the GSM system, more than one transmitting antennas are active at the same time which increases the system spectral efficiency. In [14], Rong Zhang proposed a spatial modulation(SM) scheme at the receiver side for single user MIMO system called generalized precoding aided spatial modulation (GPASM).

In this paper, we propose the concept of spatial modulation (SM) at the receiver side for multiuser MIMO (MUMIMO) system. Our work can be considered a generalization of the work in [15] to the case of multiuser system. We study the performance of the proposed scheme by simulation, and we demonstrate that significant throughput enhancement can be obtained using the proposed scheme.

II. SYSTEM MODEL

Consider a downlink multiuser MIMO (MU-MIMO) system shown in Figure 3.1 in which a base station transmitter (BSTx) with N_t transmitting antennas communicates simultaneously with K independent users on the same time-frequency resources. Each user is equipped with N_r receiving antennas and assuming that $N_t > N_r$. At any transmission time instance, the data for each user is divided into blocks of $n + p$ bits, where $n = \log_2 M$ (M is the symbol constellation size) and $p = \log_2 N_r$. The first n bits $[b_1 b_2 \cdots b_n]$ are mapped to a corresponding symbol in the constellation, while the next p bits $[b_{n+1} b_{n+2} \cdots b_{n+p}]$ are used to activate a particular receiving antennas. For simplicity of representation, the case where one receiving antenna is switched for each user is considered. However, works and results are easily extended to cases where two or more antennas are activated per user.

At the receiver side, when the user receives the correct symbol, the first n bits of the user data transmitted by the BSTx over a particular receiving antenna will be decoded using maximum likelihood (ML) estimate of the received signal, while the next p bits are added based on the index of the antenna from where the signal (or symbol) is received or detected.Thus, the index of this antenna also conveys useful information in addition to the transmitted symbol.

Let the vector $\mathbf{x} = [x_{m,j}^1, x_{m,j}^2, \ldots, x_{m,j}^K]^T$ represent the transmitted super symbols from the BSTx to all users, where the notation $x_{m,j}^k$ indicates that the BSTx transmits a modulated symbol $s_m \in \{s_1, s_2, s_3, \ldots, s_M\}$ to the kth user, and the symbol is to be received at the jth receiving antenna of the user, $j = 1,2, \ldots, N_r$. We fist assume that the channel is totally uncorrelated and that the channel state information (CSI) is available at the transmitter side.

The MU-MIMO channel matrix $\mathbf{H}$ for this system can be written as:

$$\mathbf{H} = \begin{bmatrix} \mathbf{H}^1 \\ \mathbf{H}^2 \\ \vdots \\ \mathbf{H}^K \end{bmatrix}$$

where, $\mathbf{H}^K, k = 1,2, \ldots, K$ is the $N_r \times N_t$ channel matrix corresponding to the kth user given by,

$$\mathbf{H}^k = \begin{bmatrix} h_{11}^k & h_{12}^k & \ldots & h_{1N_t}^k \\ h_{21}^k & h_{22}^k & \ldots & h_{2N_t}^k \\ & \vdots & & \\ h_{N_r1}^k & h_{N_r2}^k & \ldots & h_{N_rN_t}^k \end{bmatrix}$$

Now, to activate the receiving antenna for each user two methods are proposed:

1. The "Subchannel Selection" method and
2. The "Zero-Padding" method

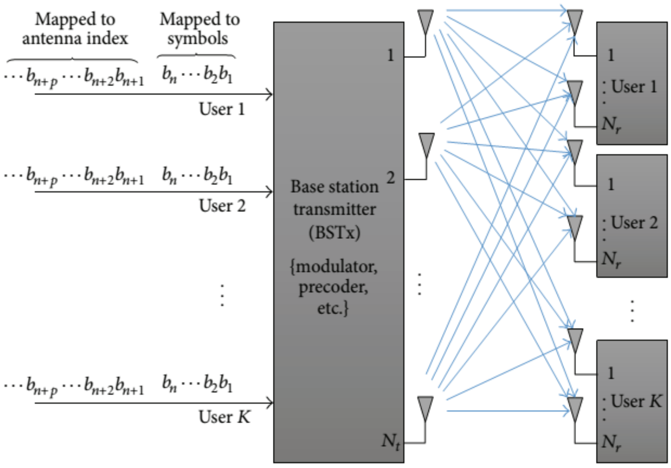


Figure 2.1: SM for Massive MIMO System

Subchannel Selection Method:

The main idea of this method is the utilization of users' subchannels as a means of additional data transmission, by collecting the rows of user channel matrices into a multiuser precoding matrix used at the BSTx. For the case when one antenna is switched per user, one row is taken from a user channel matrix at a time. If more than one antenna are needed to be switched, then the corresponding number of rows are taken. After the transmitter precoding operations, the resulting transmitted $\hat{\mathbf{X}} \in \mathbb{C}^{N_t \times 1}$ vector can be written as

$$\hat{\mathbf{X}} = \mathbf{G}\mathbf{X},$$

where, $\mathbf{G} \in \mathbb{C}^{N_t \times K}$ is the multiuser precoding matrix for the current transmitted symbols which is determined by the p bits subblocks for all users.
The received vector $\mathbf{y} \in \mathbb{C}^{N_t K \times 1}$ may be written as

$$\mathbf{y} = \mathbf{H}\widehat{\mathbf{X}} + \mathbf{w},$$

where, $\mathbf{w} \in \mathbb{C}^{N_t K \times 1}$ is the Gaussian noise vector with all its elements having a zero mean and a variance of $\sigma^2 = N_0/2$.
The precoding is applied in a way that it can eliminate the effects of channel fading and multiuser interference at the desired receiving antennas. This can be achieved using either minimum mean square error (MMSE) precoding or zero forcing (ZF) precoding. Here, we choose ZF precoding in which the precoding matrix is given by

$$\mathbf{G} = \beta \mathbf{H_s}^H (\mathbf{H_s H_s}^H)^{-1},$$

where, $(\cdot)^H$ represents the Hermition transpose of a matrix and $\mathbf{H_s} \in \mathbb{C}^{K \times N_t}$ is the subchannel selected from $\mathbf{H}$ as enumeratedabove, and β is a normalization factor introduced in order to
meet the total transmitted power constraint after precoding.
This factor is given by

$$\beta = \sqrt{\frac{N_t}{tr[(\mathbf{H}_s \mathbf{H}_s^H)^{-1}]}}$$

where, tr[·] denotes the trace of a matrix. If the transmitted symbol of the kth user is precoded at the BSTx such that the fading-free data is received at the jth antenna of the user, then the vector $\mathbf{y}^k \in \mathbb{C}^{N_r \times 1}$ received by the kth user can be described as

$$\mathbf{y}^k = \beta x_{m,\hat{j}}^k + w_{\hat{j}}^k, \qquad \hat{j} = j$$
$$\mathbf{y}^k = v_{\hat{j}}^k + w_{\hat{j}}^k, \qquad \hat{j} \neq j$$

where, $v_{\hat{j}}^k = \sum_{i=1}^{N_t} h_{\hat{j}i}^k \hat{x_i}, \ \ \hat{j} \neq j$ is the effect of channel fading and multiuser interference, while $w_{\hat{j}}^k$ represents the Gaussian noise for the kth user at the $\hat{j}$th receiving antenna. For each user, the ML detector computes the Euclidean distances between the received signal and the set of possible super symbols $X_{m,j}^k \in \{x_{m,1}^k, x_{m,2}^k, \dots, x_{m,N_r}^k\}; m = 1,2,\dots,M$ transmitted.
Then, the ML detection operation at each user receiving device can be expressed as

$$[\hat{j}, \hat{m}] = \arg \min_{\substack{m \in \{1,2,\dots,M\} \\ j \in \{1,2,\dots,N_r\}}} \left\{ \left\| \frac{1}{\beta} \mathbf{y}^k - \mathbf{X}_{m,j}^k \right\|^2 \right\}$$

where, $\hat{m}$ is the argument of the symbol $s_{\hat{m}}$in the constellation that gives the minimum distance, while $\hat{j}$is the antenna indexat which the ML detector gets the minimum distance. The correct decision is obtained when $\hat{m} = m$ and$\hat{j} = j$.

Selecting the Subchannel: Subchannel $\mathbf{H}_s$is selected in a way that the precoding operation at the BSTx can remove the effect of channel fading and multiuser interference at the desired receiving antennas of the users. For simplicity of illustration, we considered the case where only one antenna is switched per user here. In this case, we need to receive the correct data at only one receiving antenna per user. This can be obtained by choosing the elements of the subchannel $\mathbf{H}_s$ from the MU-MIMO channel $\mathbf{H}$ such that the kth row of $\mathbf{H}_s$ is selected from the kth user channel $\mathbf{H}^{\boldsymbol{k}}$according to the$p$ subblock in the user data. Therefore, the total number of available subchannels is $2^{Kp} = (N_r)^K$.
Subchannel Selection for a system with two users (K= 2), four transmitting antennas (N_t= 4), and two receiving antennas for each user (N_r= 2) as shown in Figure 3.2.
The channel matrix user 1 and user 2 are given by

$$\mathbf{H}^1 = \begin{bmatrix} h_{11}^1 & h_{12}^1 & h_{13}^1 h_{14}^1 \\ h_{21}^1 & h_{22}^1 h_{23}^1 h_{24}^1 \end{bmatrix}$$
$$\mathbf{H}^2 = \begin{bmatrix} h_{11}^1 & h_{12}^1 & h_{13}^1 h_{14}^1 \\ h_{21}^1 & h_{22}^1 h_{23}^1 h_{24}^1 \end{bmatrix}$$

The MU-MIMO channel matrix $\mathbf{H}$ can be written as

$$\mathbf{H} = \begin{bmatrix} \mathbf{H}^1 \\ \mathbf{H}^2 \end{bmatrix} = \begin{bmatrix} h_{11}^1 & h_{12}^1 & h_{13}^1 h_{14}^1 \\ h_{21}^1 & h_{22}^1 h_{23}^1 h_{24}^1 \\ h_{11}^2 & h_{12}^2 & h_{13}^2 h_{14}^2 \\ h_{21}^2 & h_{22}^2 h_{23}^2 h_{24}^2 \end{bmatrix}$$

If we assume that QPSK modulation format is used at the transmitter, the incoming data for each user is divided into blocks of 3 bits. The fist 2 bits are mapped onto the appropriate QPSK symbol, while the third bit for each user determines which row from the user channel matrix $\mathbf{H}^k$is selected to constitute the subchannel $\mathbf{H}_s$ to be used as precoding matrix for the transmitted symbols. Instead of determining the subchannel matrix $\mathbf{H}_s$according to the p subblock for each user separately, we group the subblock p for all users into subchannel selection code C ∈ {00, 01, 10, 11} and then select $\mathbf{H}_s$ according to the code C at any time instant.

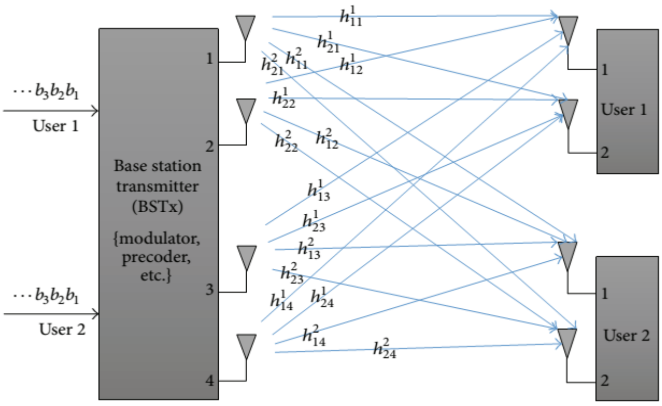


Figure 2.2: SM for Massive MIMO system with
K= 2, N_t= 4, and N_r= 2

The number of the available subchannels are $(N_r)^K = 4$ with $\mathbf{H}_s;\ s = 1,2,3,4$ is given by

$$\mathbf{H}_1 = \begin{bmatrix} h_{11}^1 & h_{12}^1 & h_{13}^1 h_{14}^1 \\ h_{11}^2 & h_{12}^2 h_{13}^2 h_{14}^2 \end{bmatrix};$$

$$\mathbf{H}_2 = \begin{bmatrix} h_{11}^1 & h_{12}^1 & h_{13}^1 h_{14}^1 \\ h_{21}^2 & h_{22}^2 h_{23}^2 h_{24}^2 \end{bmatrix};$$

$$\mathbf{H}_3 = \begin{bmatrix} h_{21}^1 & h_{22}^1 & h_{23}^1 h_{24}^1 \\ h_{11}^2 & h_{12}^2 h_{13}^2 h_{14}^2 \end{bmatrix};$$

$$\mathbf{H}_4 = \begin{bmatrix} h_{21}^1 & h_{22}^1 & h_{23}^1 h_{24}^1 \\ h_{21}^2 & h_{22}^2 h_{23}^2 h_{24}^2 \end{bmatrix}$$

The code C is mapped to the subchannel sets as follows:

C = 00 $\mathbf{H}_1$; C = 01$\mathbf{H}_2$

C = 10 $\mathbf{H}_3$; C = 11$\mathbf{H}_4$

At the receiver side, after the ML detection for each user, if the symbol is detected at the first receiving antenna, then b_3= 0, and if the symbol is detected at the second antenna, b_3= 1.

Zero-Padding (ZP) Method:

In the subchannel selection method, we activated the desired receiving antennas for all users by choosing the appropriate elements of the subchannel matrix $\mathbf{H}_s$ to precode the input data at the BSTx in order to eliminate the effect of channel fading and multiuser interference at the desired receiving antennas for the users. However the other antennas are affected by these channel impairments. Now we will activate the receiving antennas by zero-padding method such that all receiving antennas for each user will receive zeros, except for the activated antennas which will receive the transmitted symbols.

In this way,we can totally cancel the effect of channel fading and multiuser interference on the received data by precodingthe zero-paddedinput data using the MU-MIMO channel matrix $\mathbf{H}$ (assuming $\mathbf{H}$ is available at the transmitter side).

Consider the general system in Figure 3.1, after zero-padding the input vector $\mathbf{x}$, we will get a vector $\mathbf{X}_{zp} = [\mathbf{X}_{zp}^1, \mathbf{X}_{zp}^2, \dots, \mathbf{X}_{zp}^K]$ where $\mathbf{X}_{zp}^k \in \mathbb{C}^{1\times N_r}$ denotes the zero-padded vector corresponding to the kth user. For the case where only one receiving antenna is activated per user, this can be written as

$$\mathbf{X}_{zp}^k = \left[\underbrace{0,0,\dots,0}_{j-1}, x_{m,j}^k, \underbrace{0,0,\dots,0}_{N_r-j}\right]$$

After zero-forcing precoding, the transmitted vector $\widehat{\mathbf{X}_{zp}} \in \mathbb{C}^{N_t\times 1}$ can be written as

$$\widehat{\mathbf{X}_{zp}} = \mathbf{G}\mathbf{X}_{zp}$$

where, in this case, precoding matrix is given by

$$\mathbf{G} = \beta \mathbf{H}^H (\mathbf{H}\mathbf{H}^H)^{-1},$$

$$\text{where, } \beta = \sqrt{\frac{N_t}{tr[(\mathbf{H}\,\mathbf{H}^H)^{-1}]}}$$

The received vector $\mathbf{y} \in \mathbb{C}^{N_r K\times 1}$ may be written as

$$\mathbf{y} = \mathbf{H}\widehat{\mathbf{X}_{zp}} + \mathbf{w}$$

where, $\mathbf{w}$is defined in (4). The received vector $\mathbf{y}^k \in \mathbb{C}^{N_r\times 1}$ for kth user can be described as

$$\mathbf{y}^k = \beta x_{m,\hat{j}}^k + w_{\hat{j}}^k, \quad \hat{j} = j$$

$$\mathbf{y}^k = 0 + w_{\hat{j}}^k, \quad \hat{j} \neq j$$

where, $w_{\hat{j}}^k$ is defined in (7). From (15) it is obvious that for each user, only one receiving antenna will receive the transmitted symbol and the other antennas will receive zeros. The ML detector is then applied as in (8).

As an illustration of the zero-padding method, consider the system in Figure 3.2 with the same information. Here the code C determines how the input vector **x** is zero-padded to obtain $\mathbf{X}_{zp}$ as

$\longrightarrow$ C = 00 $\mathbf{X}_{zp} = [x_{m,1}^1, 0, x_{m,1}^2, 0]$

$\longrightarrow$ C = 01 $\mathbf{X}_{zp} = [x_{m,1}^1, 0, 0, x_{m,1}^2]$

$\longrightarrow$ C = 10 $\mathbf{X}_{zp} = [0, x_{m,1}^1, x_{m,1}^2, 0]$

$\longrightarrow$ C = 11 $\mathbf{X}_{zp} = [0, x_{m,1}^1, 0, x_{m,1}^2]$

The vector $\mathbf{X}_{zp}$ is then precoded using the system matrix **H**. For a system with K users and N_r receive antennas for each user, there will be $2^{Kp} = N_r^K$ available combinations of zero-padded input vector $\mathbf{X}_{zp}$.

III. SIMULATION RESULTS

Simulation Parameters:

Parameters	Values
No. of users	1, 2, 4, 8
No. of Tx	2, 4, 8, 16, 32, 64
No. of Rx(user)	1, 2, 4, 8
No. of Rx	2, 4, 8, 16, 32, 64
Modulation method	Spatial Modulation
Symboling Scheme	BPSK, QPSK, M-QAM
SNR values	1 to 20(dB)
Precoding Methods	ZF& MMSE

BER performance of Spatial Modulation for 8x8 Multiuser-MIMO (MU-MIMO) using MMSE Precoding is shown in figure 3.1.Here 8 different users, each equipped with single antenna simultaneously transmit the data. On the receiving side same number of users, each equipped with same number of antennas receives the data individually at a time.Results shows that the Bit Error Rate (BER) is acceptable for the given SNR values.

As the size of the QAM-constellation is increased, the simulation results get degraded. This is due to the fact that as the number of constellation points increased, the given region is divided into more and more parts which leads to the increased errors in the threshold detection. This degrades the BER performance.In the case of more than four constellation points, their distances with respect to origin are averaged over the number of points.

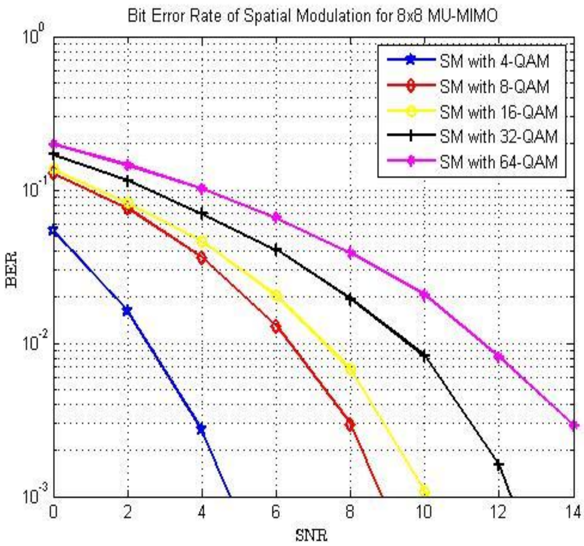


Fig 3.1: BER performance for 8x8 MU-MIMO
using MMSE Precoding

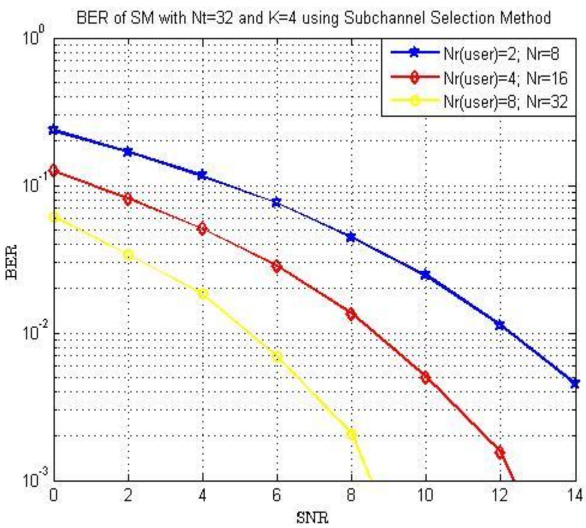


Fig 3.2: BER performance of Massive MIMO System using Subchannel Selection Method

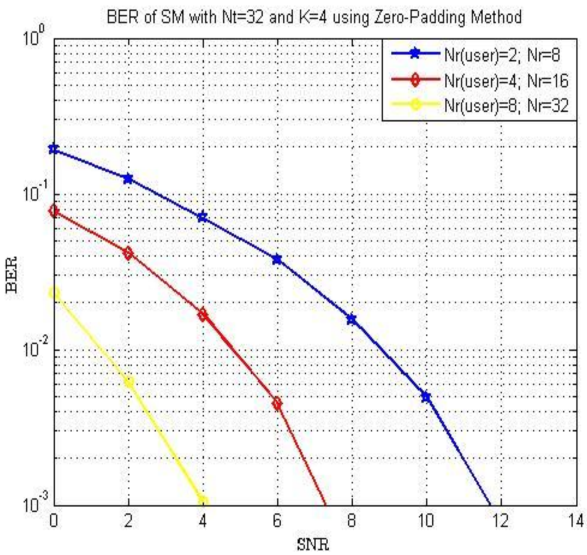
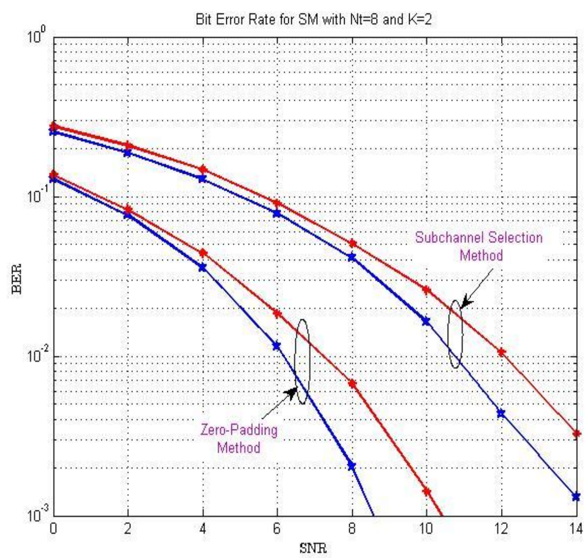


Fig 3.3: BER performance of Massive MIMO System using Zero-Padding Method



Nr(user)=2, Nr=4
Nr(user)=4, Nr=8

Fig 3.4: BER performance for Massive MIMO system using MMSE Precoding

BER performance of Spatial Modulation technique for simple Massive MIMO system using Minimum Mean Square Error (MMSE) Precoding scheme is shown in figure 3.2.Here antenna selection is done by using Subchannel Selection Method. Total of 32 transmitting antennas and 4 users each equipped with different number of receiving antennas have been considered. The results shows that, as the number of receiving antennas per user increased, for the same SNR values, BER decreased i.e. system performance improved.
BER performance of Spatial Modulation technique for simple Massive MIMO system using Minimum Mean Square Error (MMSE) MMSE Precoding scheme is shown in figure 3.3.Here antenna selection is done by using Zero-Padding (ZP) Method. Total of 32 transmitting antennas and 4 users each equipped with different number of receiving antennas have been considered.The results shows that, as the number of receiving antennas per user increased, for the same SNR values, BER decreased i.e. system performance improved.
BER performance of Spatial Modulation technique for simple Massive MIMO system using MMSE Precoding scheme is shown in figure 4.6.Two methods **Subchannel Selection Method** and **Zero-Padding Method** have been simulated and compared using same parameters.The above results shows that, Zero-Padding method gives a significant improvement in the BER performance over Subchannel Selection Method.

IV. CONCLUSION

In this paper we present the concept of spatial modulation (SM) scheme for Massive MIMO system. In this scheme, the index of the active receiving antenna of each user in a Massive MIMO system is used to convey extra information in addition to the transmitted symbols. Simulation results show that significant increase in the system throughput is achieved as the number of available receiving antennas per user is increased. Two methods are proposed for implementing the SM scheme for Massive MIMO system: Subchannel selection method and Zero-paddingmethod.BERperformanceofthe proposed methods are also studied. Our results show that for the subchannelselectionmethod,theBERperformancedegrades with increasing the number of users serviced by the BSTx or the number of receiving antennas per user. For the zero-padding method, increasing the number of users does not affect the BER performance since the multiuser interference is totally removed by the combination of zero-padding and precoding operations applied at the BSTx.

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