Investigation of Multi user signal detection in large scale MU-MIMO systems

B Sairam Susheel,k Sai Krishna Prasad|Prof Dr kalapraveen Bagadi | SENSE

Motivation/ Introduction

In the past two decades we have seen a huge expansion of wireless communication industry. So the demand for capacity and frequency bandwidth has become increasingly high. In order to meet the increasing demand for high data rates many technologies have been studied. Among those, the use of antenna arrays deployed at both ends of a communications link, referred to the multiple input multiple-output (MIMO) communications technique. MU-MIMO has been shown to be a promising approach to increasing Spectral Efficiency as well as the system throughput.

SCOPE of the Project

The main theme of this project is to develop a technique that acts as a trade-off between complexity and BER performance.

Here we tested various linear and non linear algorithms in terms of complexity and BER performance.

To minimize the error caused during transmission and increase the capacity with better spectral efficiency by accommodating large number of users is the main challenge we need to face and our proposed technique LAS has met the above requirements to maximum extent.

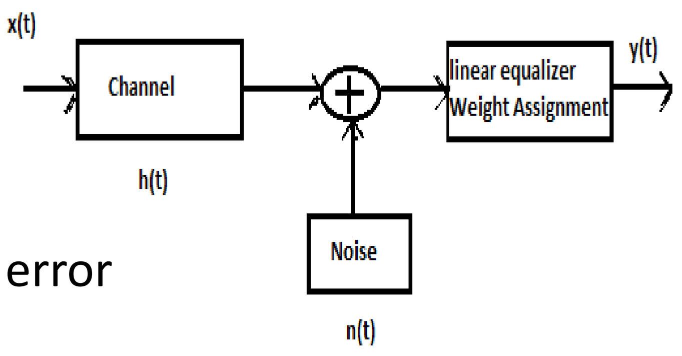
Methodology

Here we use ZF-LAS and MMSE-LAS to denote the conventional LAS algorithms with initial vectors generated by Zero Forcing and Minimum Mean Square Error detectors respectively and find the Euclidean distance as similar to that in Maximum Likelihood(ML).

A)ZeroForcing(ZF)

Zero Forcing is one of the linear algorithms used in communication systems which applies the inverse of the frequency response of the channel. If the channel response for a particular channel is H(s) then the input signal is multiplied the reciprocal of it. The ZF MUD scheme involves a linear transformation between the output signal and estimated channel

Y=HX+N say $x = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_t \end{pmatrix}$ $y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_r \end{pmatrix}$



The transmitted signal is detected form the least square error

$$\|\boldsymbol{y}-\boldsymbol{Hx}\|^2 = (\boldsymbol{y}-\boldsymbol{Hx})^H(\boldsymbol{y}-\boldsymbol{Hx})$$

$$= -2\boldsymbol{H}^H\boldsymbol{y} + 2\boldsymbol{H}^H\boldsymbol{Hx}$$

$$\hat{\boldsymbol{x}} = \left(\boldsymbol{H}^H\boldsymbol{H}\right)^{-1}\boldsymbol{H}^H\boldsymbol{y}$$

B)MMSE

The linear MMSE MUD scheme assumes a priori knowledge of noise variance and channel covariance. In this MMSE MUD, the weight matrix '$\boldsymbol{w}$' can be expressed by minimizing the mean square error, i.e. Where $\hat{x}$ is the estimate of $\boldsymbol{x}$. Hence,

$$\mathrm{MSE} = E\left[|\hat{x}-x|^2\right] \qquad \boldsymbol{w}^H = R_{yy}^{-1}R_{yx} \qquad R_{yy} = \left(\boldsymbol{H}^H\boldsymbol{H} + \sigma_n^2\boldsymbol{I}_P\right)$$

$$E\left[|\hat{x}-x|^2\right] = E\left[\left(w^H y - x\right)^H\left(w^H y - x\right)\right] \qquad \hat{\boldsymbol{x}} = (\boldsymbol{H}^H\boldsymbol{H} + 2\sigma_n^2\boldsymbol{I}_P)^{-1}\boldsymbol{H}^H\boldsymbol{y}$$

where $(.)^H$ indicates Hermitian transpose and $\boldsymbol{I}_P$ is P-dimensional identity matrix In the above equation, if SNR is high then $\sigma_n{}^2$ will become negligible. Hence, at higher SNR values the performance of ZF and MMSE MUDs are almost equal.

C)Maximum-Likelihood(ML)

The ML detector uses the Maximum a Posteriori (MAP) detection when all the users are equally likely to transmit. The ML detector which supports L simultaneous transmitting users, give rise to a total of 2^{mL} metric evaluations in order to detect the possible transmitted symbols of vector $\hat{x}$ where m represents the number of bits per symbol. This detector calculate Euclidean distance for all transmitted signal vectors and estimates the signals by expressing it as follows

$$\hat{\boldsymbol{x}} = \arg\left\{\min_{u}\|\boldsymbol{y}-\boldsymbol{H}\tilde{\boldsymbol{x}}_u\|^2\right\},\ u = 1,2,\ldots,2^{mL}$$

D) LikelihoodAscentSearch (LAS):

A family of low complexity detectors termed Likelihood Ascent Search (LAS) detectors have been proposed in [2] for large MIMO systems. The power of the LAS detector lies in the linear average per bit complexity and the excellent BER performance in large MIMO systems. A conventional LAS detector [2] starts from an initial solution vector x which can be the output from any known detector such as zero-forcing for example. It then searches through a sequence of solution vectors to refine the solution with monotonic likelihood ascent. At step n, the update algorithm for BPSK modulation using the LAS algorithm can be explained as follows. Given the initial vector $x(0) \in \{+1,-1\}^L$ and the search candidate sets (SCS) $L(n) \subseteq \{1, 2, \cdots L\}$, $\forall\ n \geq 0$, the j^{th} bit of $x(n+1)$ is given by

$$x_j(n+1) = \begin{cases} +1, & \text{if } x_j(n) = -1 \text{ and } M(x(n+1)) < M(x(n)) \\ -1, & \text{if } x_j(n) = +1 \text{ and } M(x(n+1)) < M(x(n)) \\ x_j(n), & \text{otherwise} \end{cases}$$

Results

Parameters	Value
Data frame size (N_F)	1000
Number of data frames (N_D)	1000
Modulation technique	BPSK
Number of Receiving Antennas (P)	128
Number of Users (L)	128
Channel	Rayleigh Flat Fading

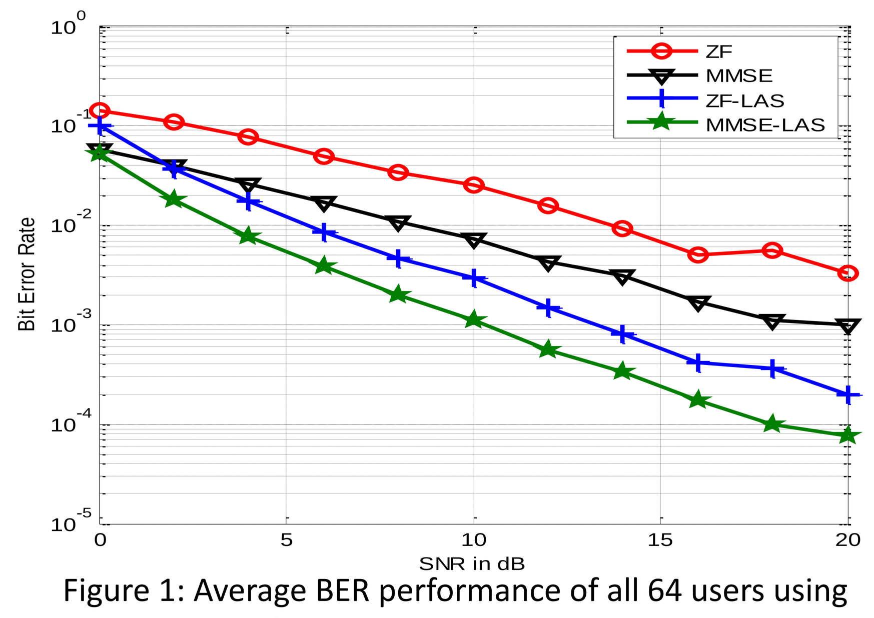


Figure 1: Average BER performance of all 64 users using various MUDs for a MU-MIMO system with 128 receiving antennas

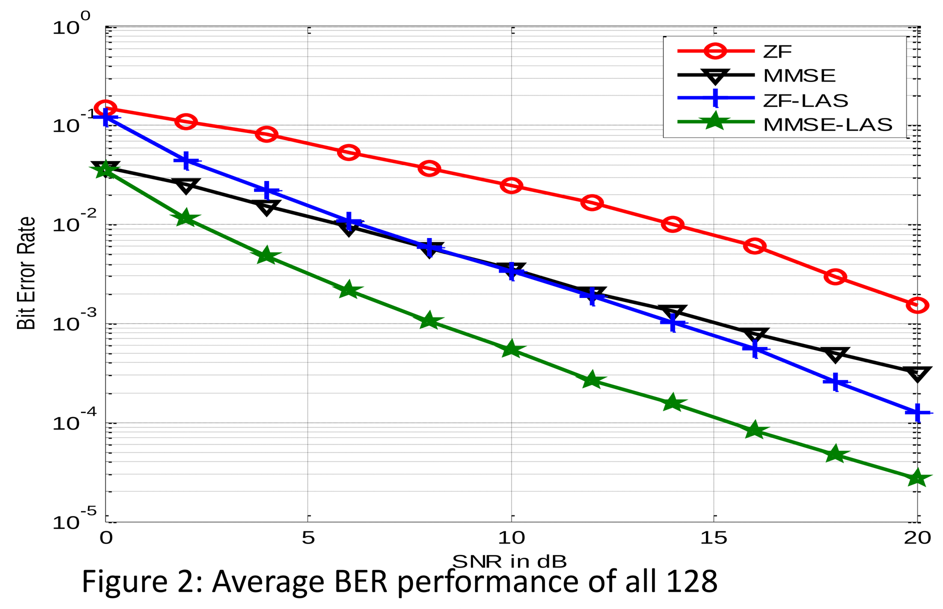


Figure 2: Average BER performance of all 128 users using various MUDs for a MU-MIMO system with 128 receiving antennas

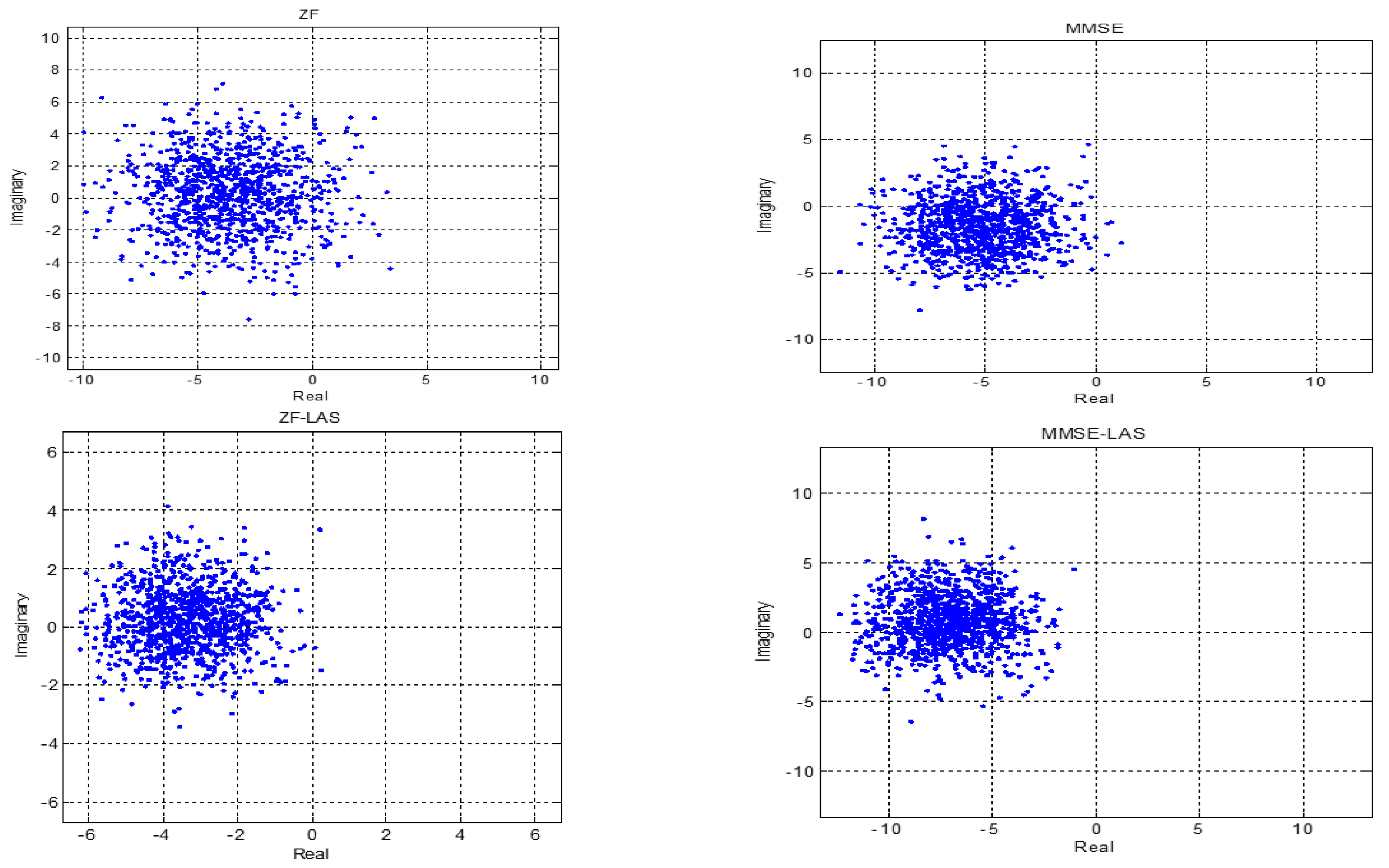


Figure 3: Estimated symbol distribution of User-1 using various MUDs when User-1 is always transmitting '–1' at 10 dB SNR value (a) ZF (b) MMSE (c) ZF-LAS (d) MMSE-LAS

Multiuser Detector	Complexity order
ZF	$N_F \times N_D$
MMSE	$N_F \times N_D$
ZF-LAS	$N_F \times N_D \times L$
MMSE-LAS	$N_F \times N_D \times 2^{mL}$

In the above fig 3.3, 3.4 the average BER performance for different proposed techniques have been plotted for two scenarios say 64 and 128 users. By the above plot we can clearly observe that LAS-MMSE has outperformed all the other techniques. Similarly in the boundary conditions scenario fig 3.5, the number of bits falling into the corresponding region has also been good in the case of LAS-MMSE than other techniques. So LAS when applied with initial vectors generated by ZF and MMSE has shown less complexity and optimal BER.

Conclusion/ Summary

Here to the LAS technique we applied multiple inputs say that the vectors generated by ZF and LAS. have drawn mathematical results by simulating with the help of MATLAB. Here we have compared different techniques by taking boundary conditions in which the transmitted bits fall into and also the BER performance into consideration and have drawn conclusions saying that LAS-ZF and LAS-MMSE has outperformed the conventional ZF,MMSE and ML techniques. And here the conclusions have been drawn from the results shown above saying that LAS has better spectral efficiency and lesser complexity in detection of the received signal bits.

Contact Details

bikkinasairam.susheel2013@vit.ac.in , saikrishna.prasad2013@vit.ac.in

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