Linear Detection in Massive MIMO for Next Generation Wireless Systems

Haresh L. Judal[1], Dr. Kishor G. Maradia[2]
[1]Ph.D.Scholar, GTU Ahmedabad, Electronics & Communication Engineering Department
[2]Professor & Head, E & C Engineering Department, Government Engineering College, Gandhinagar, Sector 28, Gujarat, India
(E-mail: haresh_judal@yahoo.co.in[1], kgmaradia@yahoo.com[2]*)*

Abstract—Multiple Input Multiple Output (MIMO) is an air interface solution used in 4^{th} generation wireless networks to achieve higher data rate. With a very large antenna arrays in Massive MIMO, the capacity will increase drastically. In this paper, performance is evaluated with MATLAB simulation of linear detectors for maximum ratio combining (MRC), zero-forcing (ZF) and minimum mean square error (MMSE) for large antenna arrays at Base station (BS) which are serving the small number of single antenna users. Performance is evaluated in terms of symbol Error Rate (SER) for MRC, ZF and MMSE and results show that MMSE and ZF detectors will outperform MRC. It has also been analyzed that increasing the antennas at BS for the small number of users will also help to reduce SER.

Keywords: MIMO, MRC, ZF, MMSE

1. Introduction

The Multiple-Input Multiple-Output (MIMO) communication system employs multiple antennas at the transmitter and receiver both side. MIMO has the potential to improve the capacity of wireless systems. MIMO systems offer additional degrees of diversity which can be used to combat multipath fading in a wireless channel.

Massive MIMO system is currently considered the most compelling technology for 5G wireless networks [1]. Massive MIMO Base station (BS) has a substantially large number of antennas. The BS contains antenna elements in the order of hundreds or more which serve tens of mobile terminals (MTs) in Massive MIMO. The large number of antennas in Massive MIMO results in huge spatial multiplexing gains, thus the capacity of the cellular network increases several fold. Adding more antenna lead to reduce radiated power, greater simplicity in signal processing and uniformly great service in the cell. Uncorrelated noise and multiuser interference effect can be reduced by coherently combining signals at BS antennas [2], [3]. Hence network capacities can be unprecedently achieved.

Massive MIMO is a promising technology for meeting the demand for higher data rates is also called Large scale Antenna systems [10, 11]. Massive MIMO with very large antenna arrays comprising one or few hundred at the BS serving tens of users will help to reduce intra cell interference with simple signal processing. If the number of BS antennas grows larger than the random channel vectors between the BS and the users, become pairwise orthogonal [4]. Using simple matched filter processing at the BS side uncorrelated noise as well as intracell interference disappears entirely if the infinite numbers of antennas can be taken at the BS. Massive-MIMO technology is a promising solution to meet a demand for higher data capacity in 5G Wireless Communication Networks. The increase in antennas at transmission and reception open a door for research in the theory of Communications.

In this paper, the comparison has been made between linear detectors in Massive MIMO environment. Performance analysis has been carried out in terms of symbol error rate (SER) for linear detectors using more antennas at BS which serving small number of users.

In this paper Section 2 explains MIMO model. Section 3 explains the Massive MIMO architecture and the theory behind it. Section 4 explains linear detectors used in Massive MIMO. The results from simulations are presented in Section 5. A conclusion of the paper is given in Section 6.

Notations: The superscript $(.)^H$ indicates conjugate transpose and I_N is the $N \times N$ identity matrix.

2. MIMO Model

MIMO systems employ multiple antennas at both sides. By sending different data streams from different antennas MIMO system can increase the capacity. MIMO can be used to enhance link reliability by transmitting the same data symbols from multiple antennas. A spatial multiplexing MIMO system transmits different data symbols from each transmitter. The signal from each transmitter combine over the air and are received by multiple receive antennas.

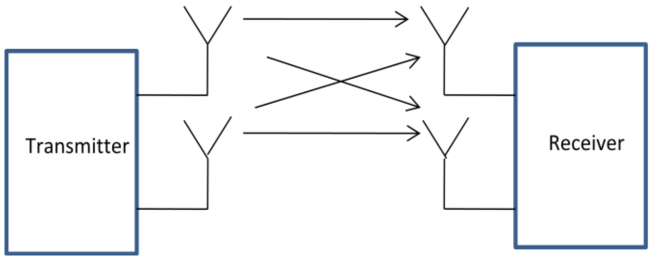

Fig.1 MIMO system Model

3. Massive MIMO

Massive MIMO model is described where BS is equipped with arrays of M antennas that receive data from N single antenna users where $M>>N$ *[4]*.
The signals from each transmitter combine over the air and are received by multiple receiver antennas.
In the uplink, the BS receives

$$y=\sqrt{p_u}Gx+n \quad (1)$$

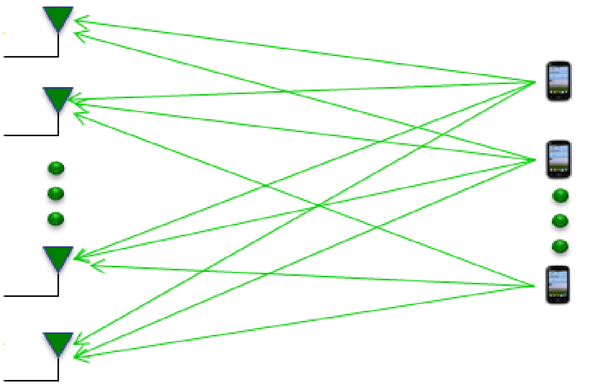

Fig.2 BS with arrays of M antennas that receive data from N single antenna users

Where $x=[x_1, x_2, \ldots\ldots x_N]^T$ is the vector of information symbols, x_N is transmitted by the single antenna N^{th} terminal. The G is the channel matrix between M antennas at the BS and N users are $G\in\mathbb{C}^{M\times N}$. The p_u is the normalized SNR of each user and n is the vector of additive white Gaussian noise with zero mean and variance 1.
The channel matrix G is modeled by independent fast fading, geometric attenuation and log-normal shadow fading.

$g_{mn} = h_{mn}\sqrt{\beta_n}$ Where m=1,2,…..M
Where h_{mn} denotes fast fading coefficients and $\sqrt{\beta_n}$ represents the geometric attenuation and shadow fading.
The sum channel capacity of the channel model described above is [5].

$$C_{sum} = log_2(det(I_N + p_u G^H G)) \quad (2)$$

4. Linear Detectors

Using Maximum Likelihood Detector (MLD) optimal performance can be achieved, but it will require complex signal processing methods at the BS. Linear processing techniques like MRC, ZF and MMSE will give a suboptimal performance, and it will require less complex signal processing. Linear receivers perform quite well when the BS contains a large number of antennas compared to the users. [5].
In this paper, we have simulated the SER for MRC, ZF and MMSE detectors [8, 9]. Suboptimal low complexity Massive MIMO detection at BS combining is done using $r=A^H y$ [4, 9].
For MRC: $A=G$ (3)

MRC will require less computational complexity among all linear Massive MIMO detectors.

For Zero Forcing: $A= G\,(G^H G)^{-1}$ (4)

For MMSE $A= G\,(G^H G + \frac{1}{p_u} I_N)^{-1}$ (5)

The received vector for MRC is derived from (1) and (3),

$$r=G^H(\sqrt{p_u}Gx+n) \quad (6)$$

It is assumed that users $x_1, x_2, x_3 \ldots\ldots\ldots x_N$ are independent.

The received vector for ZF detector is derived from (1) and (4)

$$r = (G^H G)^{-1} G^H(\sqrt{p_u}Gx+n) \quad (7)$$

$$=\sqrt{p_u}\,x+(G^H G)^{-1}G^H n \quad (8)$$

It will able to suppress multiuser interference.
From (1) and (5), the vector received for MMSE linear detector is

$$r = (G^H G + \frac{1}{p_u} I_N)^{-1} G^H(\sqrt{p_u}Gx+n) \quad (9)$$

At higher SNR MMSE detector will work as a ZF detector and at lower SNR MMSE will works as a MRC detector.

5. Simulation Results

Symbol error rate (SER) performance analysis using simulation has been carried out for MRC, ZF and MMSE linear detectors.
Linear receivers perform well when the BS containing a large number of antenna elements serving tens of mobile terminals (MTs) which is the case of Massive MIMO. The system parameters that were used in simulations of linear detectors MRC, ZF and MMSE for Massive MIMO are shown in Table 1.

Table-1 Simulation parameters for Linear Detectors in Massive MIMO

Description	Parameters
No. of Receive Antennas at BS =M	64,128
No. of Users =N	16,25
SNR in dB	1:10
Linear Detectors	MRC, ZF, MMSE

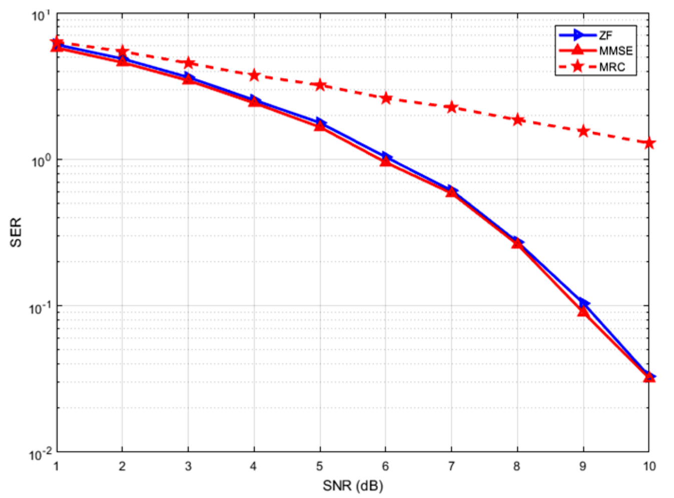

Fig. 3 SER Performance Comparison for M=128 Receive Antennas at Base station and N=25 Users

As shown in the fig. 3 MRC linear detector performs worst in terms of SER, whereas ZF and MMSE detectors provide comparable performance. It has been found from the simulation that using ZF detector there is only a small penalty in error rate performance compared to a MMSE detector.

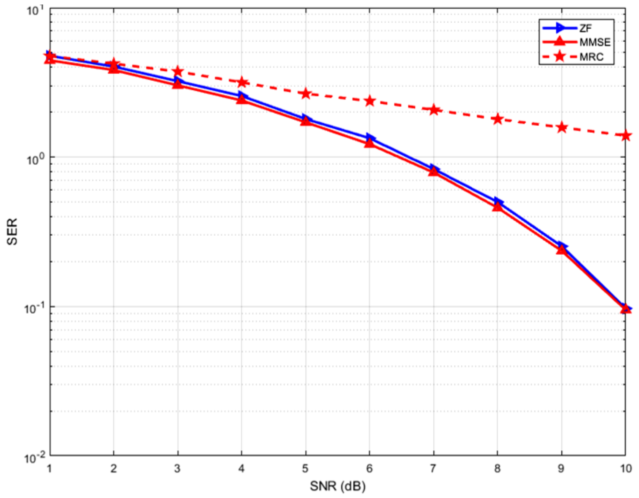

Fig.4 SER Performance Comparison for M=64 Receive Antennas at Base station and N=16 Users

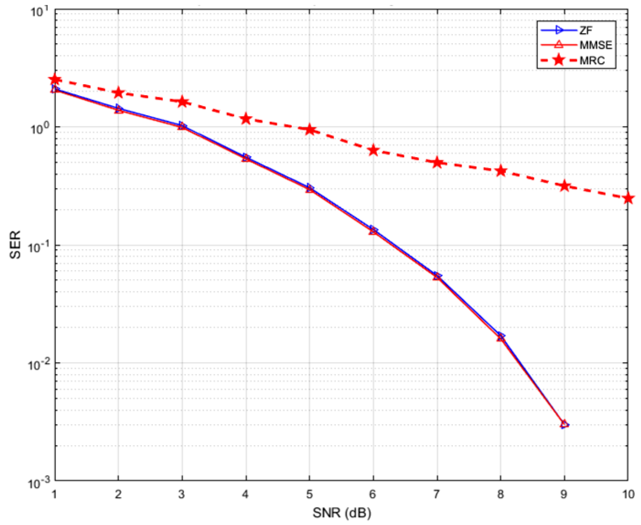

Fig.5 SER Performance Comparison for M=128 Receive Antennas at Base station and N=16 Users

As per the simulation result of Fig. 4 and Fig. 5, improved SER performance can be achieved with increased number of antennas from 64 to 128 at BS while keeping the number of users constant.

So it is concluded that if more antennas taken at BS to receive signals SER will reduce drastically. Massive MIMO with very large antenna arrays at the Base station (BS) serving tens of users will help to reduce intra cell interference with simple signal processing.

6. Conclusion

In Massive MIMO systems, ZF and MMSE will outperform compared to MRC in terms of SER while MMSE and ZF will give comparable results. It was also found that if the size of antennas has been increased at the BS antennas for a small number of serving users, then there is an improvement in the performance of SER.

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