Bit Error Rate Analysis of Multiuser Massive MIMO Wireless System Using Linear Precoding Techniques

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ABSTRACT

This paper presents bit error rate (BER) analysis of multiuser (MU) massive multiple input multiple out (MIMO) wireless system using linear precoding techniques. Considering the increasing demand for wireless communication that will provide seamless performance to meet users satisfaction, various precoding schemes have been developed and with massive MIMO projected to be a promising technology for 5G and next generation network. Therefore, this study was basically designed to examine the effect of linear zero forcing (ZF) and minimum mean square error (MMSE) precoders on BER performance of MU massive MIMO system with up to 32 base station antennas (BS) and communicating with up to 5 user mobile terminals (MTs). A model that describes downlink operation of MU massive MIMO wireless communication system with spatial multiplexing employing linear ZF and MMSE precoders such that each user is equipped with single antenna MT resulting in overall access points of 5 antennas was developed in MATLAB. Computer simulations revealed that ZF outperformed MMSE. This observation was validated by similar report on massive MIMO in previous study.

Keywords – **BER, Massive MIMO, Minimum mean square error, Precoding, Zero forcing**

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I. INTRODUCTION

The number of mobile terminals (MTs) connected to wireless communication network has risen recently and thereby resulting in increased data traffic over communication channels. With the use of mobile technologies increasing exponentially on daily basis, some advanced technology must be in place to meet the demand of large data traffic required by these gadgets. The next generation of wireless network called fifth generation (5G) standard is expected to address the limited capacity of present networks and should be able to solve the associated challenges common with existing standards such as coverage range, reliability of link, energy efficiency and latency [1]. Large-scale multiple input multiple output (known as massive-MIMO) system is seen as a technology that will satisfy the demands of 5G standard.

Massive-MIMO was originally regarded as a time division duplexing (TDD) based cellular model comprising many antenna elements installed at base transceiver stations (BTS) in a single-cell [1]. The general concept of large scale multiple antennas system usually called massive-MIMO, is described as a physical-layer technology, which provides each base station (BS) with a large number of antennas that has potential to spatially multiplex several MTs in order that communicating with them on the same time-frequency resource is possible [2]. However, for models of multiple-cell, it is suggested that non-orthogonal pilot sequences being used since it is difficult to maintain the pilot sequence orthogonality in different cells because of the small channel coherence time [3]. In the case of very high data rate and improved link reliability requirement, rather than using few antenna elements, huge array of antenna units is overlaid at BS in massive-MIMO. An approach that is completely different from previous standards, in which case maximum of 8 antennas [4] are deployed in a sectored topology. In massive-MIMO technology, energy continuously focused and directed towards the mobile terminal (MT)) using large-scale active antenna elements with the aid of different precoders. This therefore results in the reduction of radiated power requirement and multiuser interference [1].

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Considering data traffic, throughput in (bits/s) is taken as an essential parameter for measuring wireless network performance and it is defined as [5], [2] and expressed as: throughput = Bandwidth (Hz) × Spectral efficiency (bits/s/Hz).

Improving the throughput requires that the aspects of the bandwidth and the spectral efficiency be considered. There are disadvantages to increasing bandwidth based on lowering signal to noise ratio (SNR) for the same transmitted power [2]. One common approach to increase spectral efficiency is by employing many antennas at the transceiver [6].

Today, substantial attention has been given to Multiuser (MU) massive MIMO for fifth generations (5Gs) mobile communication. A massive MIMO is basically a MU-MIMO scheme having many base station antennas wherein a large numbers of antennas are severed at the same time [7]. This paper is designed to evaluate the performance of multiuser downlink system in MU massive MIMO system operating with spatial multiplexing using pre-coding techniques through computer simulation using MATLAB software.

II. PRECODING SCHEMES IN MU MASSIVE MIMO

It is been well reported that MIMO system effectively make the most of the multiple channels between the BS and users' MTs by employing the proper (space-time) coding to increase the throughput of the wireless system. Conversely, massive MIMO works by employing space division multiplexing such that each link between the BS to mobile terminal is known [8].
Precoding is basically a beamforming technique, which is used in massive MIMO to facilitate transmission of multi-streams. In recent years, precoding schemes in MIMO transmission have attracted increasing research interest since the inception of MU-MIMO that involves using large number of antennas at BS to concurrently serve multiple MTs. Beamforming is an approach that is designed to align the transmit signal in the direction of the transmit antenna array pattern [9]. Significant research has been carried out involving implementation of precoding schemes in MU massive MIMO downlink system.

The use of the user's sub-channel index corresponding to the precoding matrix employed at the base station transmitter to send extra useful information in addition to the transmitted symbols was performed to implement spatial modulation in MU massive MIMO system in [10]. Two precoding algorithm Zero Forcing (ZF) and maximal ratio transmission (MRT) were used for the downlink transmitter operations, while for uplink receiver operations, ZF and MRC were used to carry out performance analysis of massive MIMO systems [11]. A reduced complexity linear transmitter precoding scheme achieved by re-using of several low-level operations as possible, such that inter-user interference (IUI) is eliminated in a downlink MU massive MIMO system [12]. The performance of a single-cell downlink system with ZF and conjugate beamforming (CB) precoding algorithms was evaluated by [13]. The problem of interference was addressed by combining a low complexity antenna selection (AS) technique with simple match filter (MF) in [14]. Performance comparison of CB and ZF precoding schemes for multiuser massive MIMO system was done in [15]. The overall sum rate of MU massive MIMO system was maximize using a hybrid precoding scheme that was indirectly designed employing weighted sum mean square error (WSMSE) by [16]. A Kaman-based hybrid analogue and digital precoding was applied in MU-MIMO system, which resulted in improved performance in terms of bit-to-error (BER) and spectral efficiency [17]. Two downlink beanforming algorithms for MU-MIMO system in which the first algorithm implements precoding without considering inter-cell interference (ICI) and the second algorithm considered ICI and tries to cancel transmissions in the path of UE in other cells was presented in [18]. In the study by [19], MRT algorithm uses a designed precoding matrix operation to reduce interference among multiple antennas. The performances of ZF and MRT techniques in downlink massive MIMO system were examined in [20]. A modified generalized block diagonalization (MGBD) to provide high throughput and BER performances so as to achieve desired data rate in MU-MIMO downlink system with base station antenna array configuration of up to 16 was proposed in [21]. Fifth generation (5G) downlink throughput improvement base on beam consolidation at vacant traffic was presented in [22].

Though a considerable amount of research has been carried out in this area, the various precoding techniques have been implemented such that every one of this scheme is designed to achieve certain criterion. Therefore, the goal of this paper is carried out performance analysis of MU-massive MIMO system in terms of BER against SNR using linear ZF and minimum mean square error (MMSE) precoding schemes.

III. SYSTEM DESIGN

Consider a downlink MU massive MIMO system shown in Fig. 1 having a BS equipped with large number of transmit antennas M and with K number of users connected in the network via a MT with one single antenna (such that M >> K). The MTs are serviced by the BS at the same time. With purpose of reducing model complexity, the following assumptions are made:

- The MTs share the same time and frequency resources.
- Pilot contamination does not exist.
- The channel state information (CSI) of the BS is considered to be perfect.
- Each user MT has one antenna such that the number of receive antennas equals the number of MTs.

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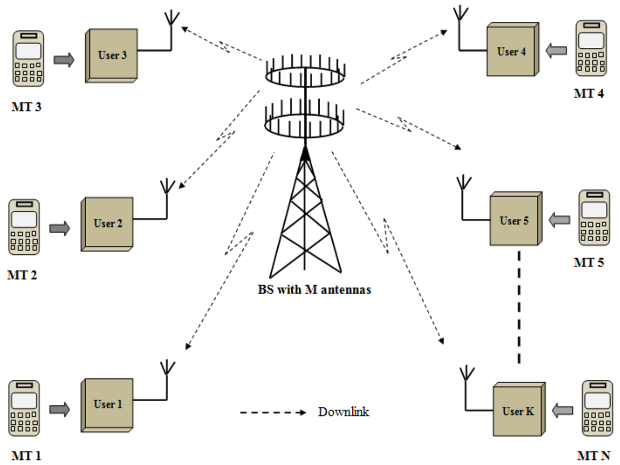

Fig. 1 Downlink massive MU-MIMO system

3.1 Mathematical Description of Data Transmission

In this subsection, downlink data transmission is mathematically described. Given a simplified downlink massive MIMO system a single cell shown in Fig. 2 such that data is transmitted via a perfect channel given by $K \times M$ channel matrix $H = [h_1^T \cdots h_K^T]^T$, where h_K stands as the 1×M channel vector among K^{th} user MT and BS.

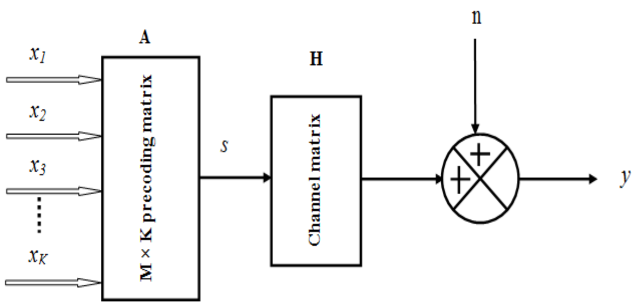

Fig. 2 A single cell downlink massive MIMO system model

Usually, the propagation channel is designed assuming large-scale and small-scale fading [15]. Small-scale fading has been assumed in this context and with elements of H representing the channel gain among M antennas at BS and MTs as defined in Eq. (1) considered to be separately and identically distributed Gaussian distribution with unit variance and zero mean. Hence, mathematically,

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} & \cdots & h_{1M} \\ h_{21} & h_{22} & h_{23} & \cdots & h_{2M} \\ h_{31} & h_{32} & h_{33} & \cdots & h_{3M} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ h_{K1} & h_{K2} & h_{K3} & \cdots & h_{KM} \end{bmatrix} \quad (1)$$

Given that each user will receive its information signal from the vector K×1, hence the received signal is represented by the input-output relationship of the massive MU-MIMO antenna channel considering the simplified model in Fig. 2 and is defined by:

$$y = Hs + n \quad (2)$$

where s is an $M \times 1$ vector of precoded transmitted signals, y is the $K \times 1$ vector of signals received by MTs, n is $K \times 1$ user MT additive white Gaussian noise (AGWN) vector with independently and identically distributed Gaussian distribution with zero-mean and unit variance.

Given that a linear precoding takes place at the BS for both effectiveness and analytical simplicity, the expression in Eq. (3) can be established for s considering Fig. 2 while neglecting the transmitted signal power.

$$s = Ax \quad (3)$$

where A is an $M \times K$ precoding matrix, and x represents input vector such that $x = [x_1 \quad x_2 \quad x_3 \quad \cdots \quad x_K]^T$ where x_k is the k^{th} user data symbol that is assumed independently and identically distributed Gaussian distribution with zero-mean with unit variance.

Assuming the precoding matrix has $\|A\| = 1$ [15] and P_s representing the transmitted power from BS (i.e. overall average energy at the BS in one symbol period). Therefore, Eq. (3) can further be defined considering the transmitted from the BS as given by:

$$s = \sqrt{P_s} Ax \quad (4)$$

Introducing Eq. (4) into Eq. (2) results in:

$$y = \sqrt{P_s} HAx + n \quad (5)$$

Applying the notation $A = [a_1 \quad a_2 \quad a_3 \quad \cdots \quad a_k]$, an i^{th} antenna transmitted signal can be defined by:

$$s_i = \sqrt{P_s} \sum_{j=1}^{k} a_{ij} x_j \quad (6)$$

The k^{th} user MT received signal can be expressed by:

$$y_k = \sqrt{P_s} \sum_{j=i}^{K} \sum_{m=1}^{M} h_{k,m} a_{m,j} x_j + n_k \quad (7)$$

From Eq. (7), the desired signal part when $j = k$ and the interference part can be expressed by:

$$y_k = \underbrace{\sqrt{P_s} \sum_{m=1}^{M} h_{k,m} a_{m,k} x_k}_{\text{desired signal}} + \underbrace{\sqrt{P_s} \sum_{j \neq k}^{K} \sum_{m=1}^{M} h_{k,m} a_{m,j} x_j}_{\text{interference}} + \underbrace{n_k}_{\text{noise}} \quad (8)$$

It can be seen from Eq. (8) that received signal of each user comprises desired signal, interference known as multiuser interference (MUI), and noise (which is an AWGN) having zero-mean with variance $N_0 = 1$, such that $n_k \in \mathcal{CN}(0,1)$ for all users.

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3.2 Bit Error Rate Signal to Noise Ratio

In evaluating the performance of data channels, bit error rate (BER) is considered as an essential parameter. One important parameter that should be known during signal transmission from one point to another over wireless link is the number of errors that will appear in the received signal. As an assessment parameter of a wireless system, BER can assess the full end to end performance of a system. Hence, BER is described as the rate of error occurrence in a wireless communication system during transmission of data or signal from transmitter to receiver. It can be expressed mathematically as:

$$\text{BER} = \frac{\sum N_B}{N_E} \tag{9}$$

where N_B is the number of bits transmitted, and N_E is the number of errors.

Signal to noise ratio (SNR) is used to describe the fraction of signal power to noise power. It is mathematically defined and expressed in decibel (dB) by:

$$\text{SNR} = \frac{P_{signal}}{P_{noise}} = 10\log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \tag{10}$$

where P_{signal} signal power, and P_{noise} is the noise power.

IV. SIMULATION RESULTS

The simulation results of the performance of a massive or large-scale MU-MIMO system with spatial multiplexing incorporating ZF and MMSE precoding schemes. The model represents a single cell downlink system in which each user connected to BS communicates with an MT of a single antenna. The network has K users, such that the system is configured in way that each user MT has a single access point antenna. That is the number of antennas per user is one. The simulation was conducted in MATLAB. The users in the network were varied from 2, 3, and 5 (i.e. K = 2, 3, 5) such that the number of receive antenna N = K. The number of BS antennas M = 16, 32, the number transmitted packets was 1000, SNR = 25 dB, and signal square root power (i.e. $\sqrt{P_s}$) = 1. The modulation scheme used in the model is quadrature phase shift keying (QPSK).

The simulation in this case is based on the fact that the M >>N, i.e. the number of BS antennas is very much greater than the number of receive antennas. However, in future research, the number of receive antennas can be increased.

The performance of system is evaluated in terms of BER against SNR to compare the effective of both linear precoders. Simulations were basically carried out for two scenarios i.e. when the M = 16 and 32, while varying the number of users.

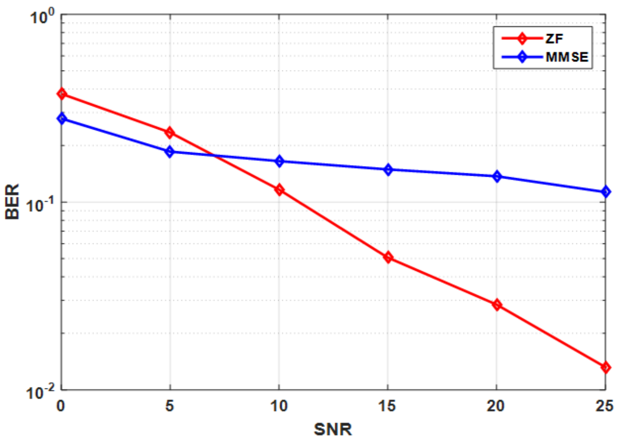

Fig. 3 BER against SNR for M = 16, K = 2

The simulation curves in Figure 4 represent that BER performance of ZF and MMSE when M = 16, K = 3. The simulation analysis shows that BERs of 0.01321 and 0.1131 at SNR = 25 were produced by ZF and MMSE precoders respectively.

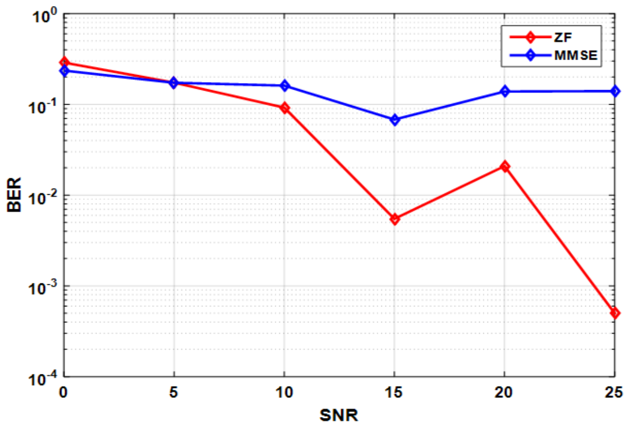

Fig. 4 BER against SNR for M = 16, K = 3

Figure 3 is the BER curves for ZF and MMSE when the BS has 16 antennas with 2 MTs served. The curves show that at SNR = 25, ZF provided BER of 0.0005, while MMSE offers BER of 0.1402.

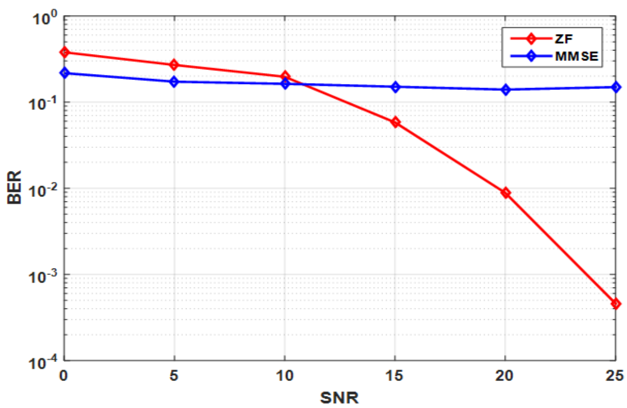

Fig. 5 BER against SNR for M = 16, K = 5

With the number of BS antennas M = 16, and with number of users K = 5, ZF yields BER of 0.0004594 while MMSE offers BER of 0.1495 at SNR = 25 as shown in the simulation curve in Fig. 5.

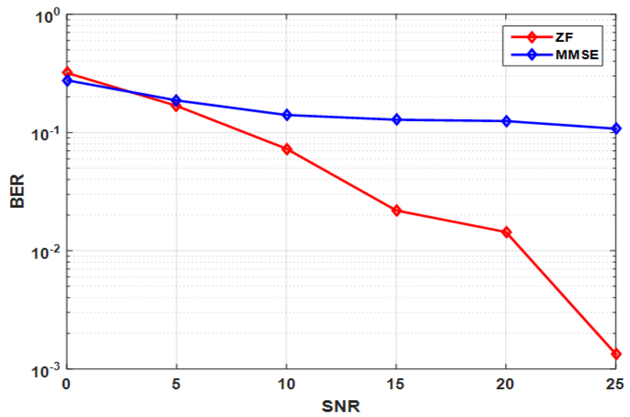

Fig. 6 BER against SNR for M = 32, K = 2

In this case as shown in Fig. 6, M = 32, K = 2 and the BERs obtained at SNR = 25 looking at the curves are 0.001336 for ZF and 0.1076 for MMSE respectively.

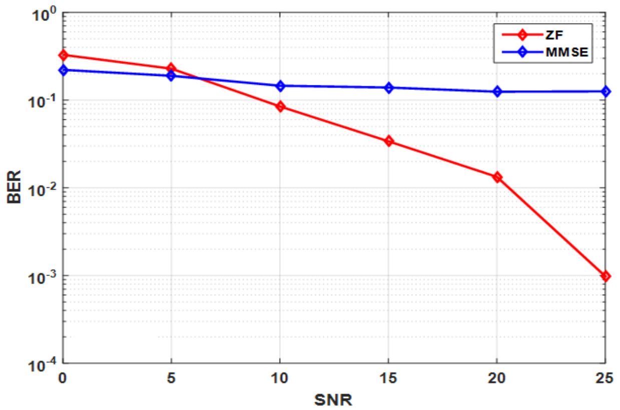

Fig. 7 BER against SNR for M = 32, K = 3

Now, with M = 32 serving 3 received antennas representing the MTs of three users, the curves revealed that ZF provided BER of 0.0009792 while MMSE offered BER value of 0.1256 respectively.

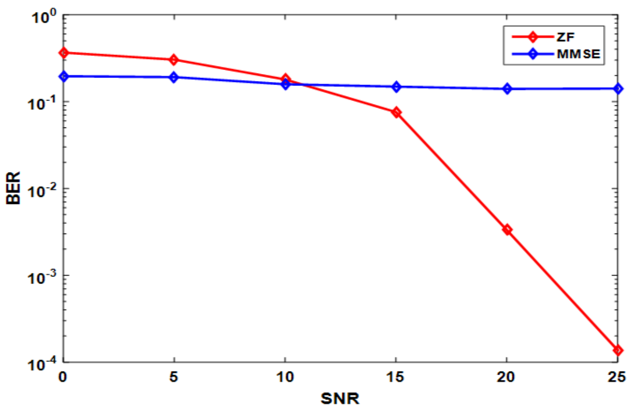

Fig. 8 BER against SNR for M = 32, K = 5

The system in this scenario is evaluated considering when M = 32 and K = 5. The performance curves from the simulation show that ZF and MMSE respectively provide BER of values 0.0001375 and 0.1413.

Generally, the simulations have shown increasing the number of BS antennas together number receive antennas resulted in improved BER especially with ZF. Also, for the entire simulation analysis, ZF outperformed MMSE. Though as shown in the simulation curves, MMSE seems to provide better performance than ZF for SNR less than or equal to 5. This conforms to the outcome reported in [8] that for the performance of massive MIMO, ZF was found to outperform other precoding schemes i.e. MMSE and maximum ratio combining (MRC), for high SNR conditions.

V. CONCLUSION

The MU massive MIMO system simulated in has shown that increasing number of antenna at the BS can improve BER performance. The study has shown the performance of linear zero forcing (ZF) and minimum mean error square (MMSE) precoding schemes in multiuser (MU) massive multiple input multiple output (MIMO) system. The results of computer simulation conducted in MATLAB environment have revealed that ZF outperforms MMSE for high SNR conditions. The essence of this study is to examine the effect of precoders in BER performance of MU massive MIMO system. The study has shown via simulation conducted in MATLAB that increasing number of antennas in both transmit and receive ends results in improved BER performance.

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