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Performance Evaluation of Multiuser Multiple Antennas Uplink System with MMSE Based Detectors

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A B S T R A C T

This paper presents performance evaluation of multiuser (MU) multiple antennas uplink system usually called MU-MIMO system with respect to BER and SNR using linear minimum mean square error (MMSE-Linear) and signal interference cancellation based MMSE (MMSE-SIC) as the detector schemes. The number of base station (BS) antennas, M, was fixed as either 8 or 10 at a given instant, while the number of user equipment (UE), K, was varied sequentially: 4, 6, and 8. It was assumed that each UE is equipped with one receive antenna. Computer based simulation conducted with MATLAB, revealed that system performance in terms of BER against SNR improves as the number of UE increases. Also, while MMSE-SIC provided better results than MMSE-Linear especially at low SNR, the later begins to show gradual superiority in performance as the SNR increases.

Keywords: Bit to error ratio, *MMSE-Linear, MMSE-SIC, Multiple* antennas

1. Introduction

The demand for efficient technology to enhance communication performance and internet services is on the rise. For instance, a key factor to economic growth has been attributed to increasing technology in electronic financing (Achebe, 2018). Also, communication between devices such as sensor nodes in wireless sensor networks (WSNs) has been enhanced by means improved communication protocols (Muoghalu et al., 2022; Ezeanya et al., 2023). Nevertheless, increasing big data traffic over wireless channels has been caused by huge number of user equipment (UE) connected to wireless communication network, and this effect is being solved using different methods. In addition, the continuous introduction of portable smart systems such as smart phones and IoTs based technologies into the market has resulted in tremendous increase demand for bandwidth by growing number of applications. Moreover, the limit of current wireless networks is already being push as a result of the several communication services such as video streaming and file sharing (Alshammari, 2017; Muoghalu et al., 2023). For instance, it is reported that mobile traffic data has increased from below 10 GB per month to 3.7 EB per month, which is 400 million time increment between 2000 and 2015 (Alshammari, 2017). Therefore, current growth in wireless communication has led to advance in wireless technology such that 4G is increasingly substituted with 5G and beyond.

Multiple antenna system usually called multi-input multi-output (MIMO) technique is one of the technologies that have been proposed as method to address the issues regarding high data demand by users. For quite sometimes, multiuser MIMO (MU-MIMO) technology has been available. This concept involves the use of more than one antenna at the base station (BS) to serve more than one user with individual receiving antenna. Enhanced spectral efficiency, energy efficiency, and reliability have been reported in literature with the use of MU-MIMO.

Uplink and downlink mode of operations can be used in categorizing wireless communication despite its complexity. In a scenario involving the BS antennas transmitting to UEs during communication, the downlink operating mode is established. On the other hand, with UEs transmitting to BS, the ensuing scenario is called uplink communication.

This paper is designed for uplink communication scenario in MU-MIMO system. The goal is to evaluate the performance of a MU-MIMO system employing two detection techniques –MMSE-linear and MMSE-SIC.

2. Literature Review

2.1 Multiple Antenna Technique

This scenario involves the use of more than one antenna at the transmitter side and the receiver side that results in a wireless communication called MIMO system. The technology has become a common configuration of antenna employed in several latest wireless networks in recent times (Agwah and Aririguzo, 2020; Achebe and Okwueze, 2023). MIMO is famous in Long Term Evolution (LTE), Wi-Fi and other wireless radio network to increase link reliability, capacity, speed of data transfer (data rate), and spectral efficiency. Several wireless routers employing MIMO system are presently in the market and in so doing has made it more popular. A typical MIMO channel is shown in Fig. 1a & b.

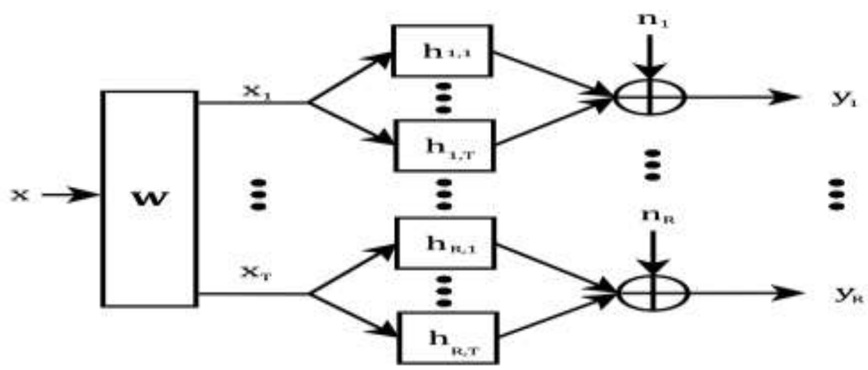

Fig. 1a - MIMO signal model (Borges et al., 2021)

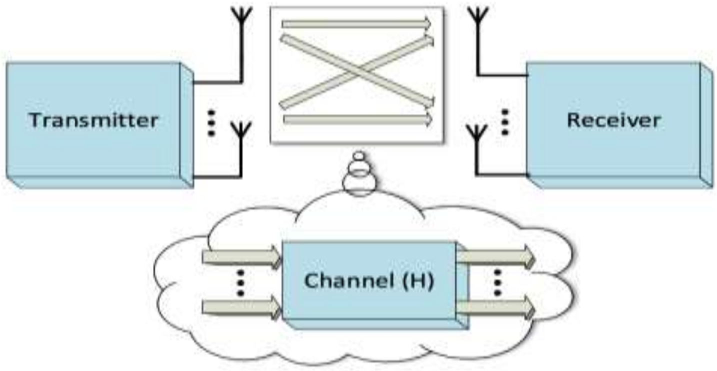

Fig. 1b - Architecture of MIMO system (Borges et al., 2021)

Spatial Multiplexing

Spatial multiplexing involves the use of N transmit antennas and M receive to enable MIMO system to linearly increase with the minimum of N or M without employing additional bandwidth or transmit power (Agwah & Aririguzo, 2020). The spatial multiplexing scheme in MIMO system, which is its working principle, can be analogically likened to the combination of single input multiple output (SIMO) and multiple input single output (MISO)otherwise regarded as receive diversity and transmit diversity respectively, wherein multiple channels are combined to give a stronger signal with higher SNR. Nevertheless, for MIMO, the outcome of spatial multiplexing is a signal with higher SNR gain than either SIMO or MISO. This is realized in MIMO by sharing the whole SNR between its data streams so that each has a lower power level.

Spatial Diversity

Multiple directions in space as well as increase in transmission reliability of communication between transmitter and receiver is provided by spatial diversity. Thus in spatial diversity, different routes are employed to carry the same stream of data from transmit antenna to receive antenna when the different routes or channels fade in a way that is not statistically dependent so that information may be received from the channel or channels with maximum signal to noise ratio (SNR) (Agwah & Aririguzo, 2020; Achebe and Muoghalu, 2023; Achebe, 2022). Spatial correlation is used to reduce spatial diversity. Diversity coding is employed in the absence of channel state information that is when the channel knowledge is unknown at the transmitter. A single data stream is transmitted; however the signal is coded by technique called space-time coding. Each antenna at the transmitter transmits signal with full or near orthogonal coding. Hence, by taking advantage of the independent fading of the multiple antenna links, diversity coding improves signal diversity. There are two types of spatial diversity: transmit diversity and receive diversity. In the transmit diversity, more than one antenna is installed at the transmitter side for transmitting coded information to a receive antenna. Whereas for receive diversity one antenna is designed to transmit coded information to numerous antennas at the receiver side.

2.2 Multiuser Multiple Antenna System

The complexity associated with SU-MIMO regarding the receiver side is moved to the BS in MU-MIMO that has more computational capability. In MU-MIMO system, a matrix W (Khwandah et al., 2021) as shown in Fig. 2 is applied at the side of the transmitter and does a pre-weighting of the data (Clerckx and Oestges, 2013). In computing the pre-weighting matrix during the channel coherence time, a number of uplink pilots are transmitted by the UEs simultaneously. The transmitted uplink pilots are received by all the BS antennas that compute the matrix W. The precoding of the data streams and the distribution of the data streams to each antenna port are performed using the measured magnitude and phase resulting in the distance from each user to every element of the antenna array. Therefore, the separation of the multiuser layer is not required at the receiver since each UE independently receives data from the other UEs with improved signal interference to noise ratios (SINRs) (Khwandah et al., 2021; Osuagwu et al., 2025).

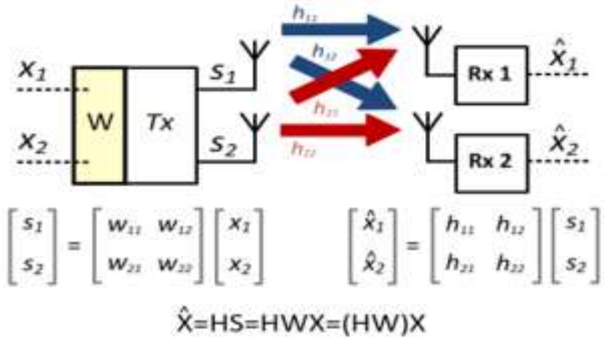

Fig. 2 - MU-MIMO architecture (Khwandah et al., 2021)

3. Method

3.1 Uplink Configuration of MU-MIMO

Assuming an uplink multiuser multiple antenna configuration shown in Fig. 3 that consists of M antennas at the BS and K users per N receive antennas, the channel coefficient matrix of ith user in the uplink network is defined by: $H_i \in C^{M \times N}, (i = 1, 2, \Lambda, K)$. There are two important constraints that must be reached in this scenario. The first is that $M \geq KN$. On the other hand, there should be several transmit antennas as the transmitted data streams (Hu and Yang, 2011). Now, given $x_i \in C^{N \times 1}, (i = 1, 2, \Lambda, K)$ represents the ith user data streams, taken to be zero-mean white random transmitted signals such that each has unit energy. Applying a linear precoder W_i for each user, the receive signal at the BS is described by:

$$y = \sum_{i=1}^{K} H_i x_i + n \quad (1)$$

where n = zero-mean white Gaussian noise vector.

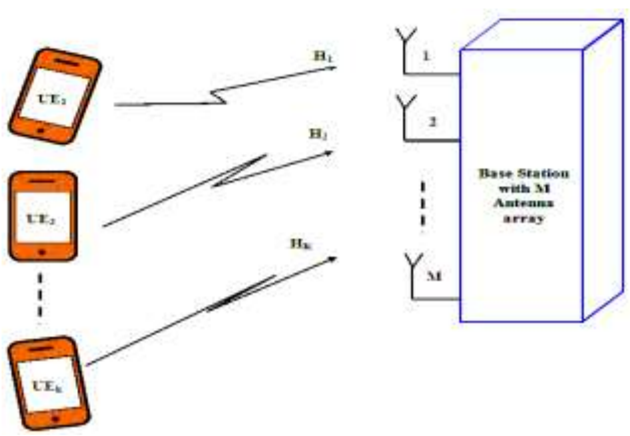

Fig. 3 – Uplink communication block diagram

3.2 Detection Method

In this section, the detection schemes considered in this paper are presented. These are: linear minimum mean square error (MMSE-Linear) and signal interference cancellation based MMSE (MMSE-SIC). MMSE is used as a means of supressing both interference and noise components. Thus, as a detector, it ensures MSE between the transmitted signal and the receiver's estimate.

The expression representing the MMSE of ith stream of data is defined by:

$$W_i = \left(H_i H_i^* + \frac{1}{SNR} I \right)^{-1} H_i^* \quad (2)$$

where H_i and H_i^* are Rayleigh fading channel with independent, identically distributed (i.i.d.) and complex conjugate of H_i respectively. SNR stands for signal to noise ratio. For signal interference cancellation (SIC) technique, based MMSE benchmark, the process is defined by:

$$W_{iSIC} = \left(H_i^H H_i + \sigma_n^2 I\right)^{-1} H_i^H \tag{3}$$

where the superscript H in Eq. (3) represents the Hermitian transpose and σ_n^2 represents variance of noise.

3.3 Performance Evaluation Parameters

Bit error ratio (BER) against SNR is considered for carrying out the system performance evaluation. With SNR, the total BER is an average quantity and not an instantaneous quantity given by (Cho et al, 2010):

$$BER = \int_0^{\infty} Q\left(\sqrt{\frac{\alpha^2 P}{\sigma_n^2}}\right) 2\alpha e^{-\alpha^2} / d\alpha \tag{4}$$

The relationship between the BER and the Signal to Noise Ratio (SNR) is expressed by:

$$\mathrm{BER} = \frac{1}{2}\left(\sqrt{\frac{\mathrm{SNR}}{2+\mathrm{SNR}}}\right) \tag{5}$$

For high SNR, Eq. (5) is further expressed as in Eq. (6):

$$BER \cong \frac{1}{2 \times SNR} \tag{6}$$

4. Results

The system parameters are: $M = 8, 10$; $K = N = 4, 6, 8$; SNR = 25 dB; packet size = 1000, and signal square root = 1. QPSK modulation technique is used. In carrying out the simulation, the number of BS antennas was considered to be 8 or 10 at a given time as against varying user number of UE. Each K UE in network is assumed to be equipped with a single receive antenna. The computer simulation studies conducted in MATLAB environment for the MU-MIMO with linear MMSE and SIC MMSE are graphically presented Fig. 4 to 9 and the numerical analysis are listed in Tables 1 and 2. Also, it is assumed that each UE is equipped a single receive antenna.

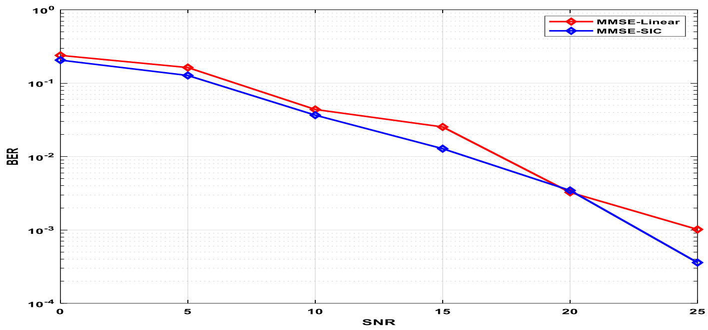

Fig. 4-BER against SNR for *M* = 8, *K* = 4

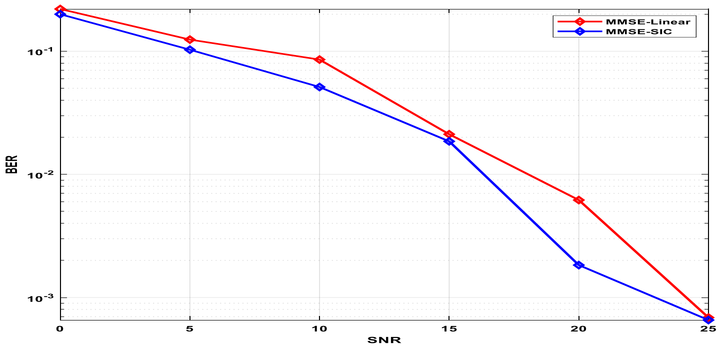

Fig. 5-BER against SNR for *M* = 8, *K* = *6*

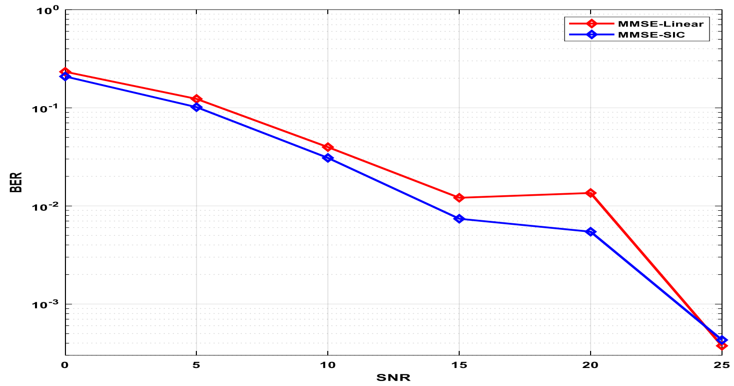

Fig. 6-BER against SNR for *M* = 8, *K* = *8*

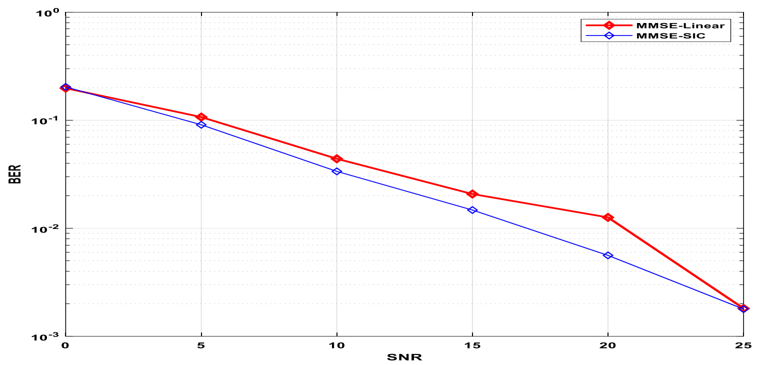

Fig. 7-BER against SNR for *M* = 10, *K* = *4*

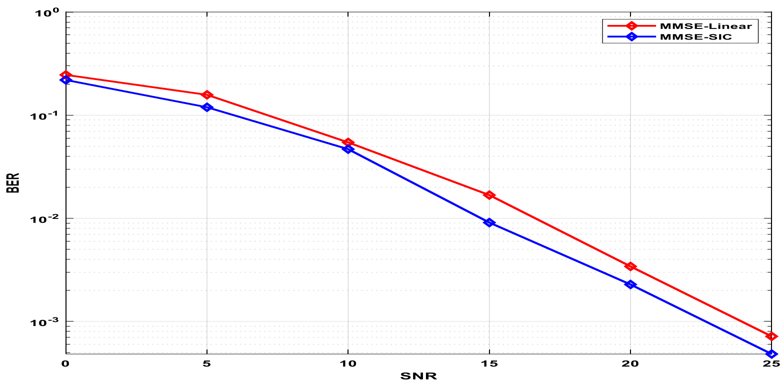

Fig. 8-BER against SNR for *M* = 10, *K* = *6*

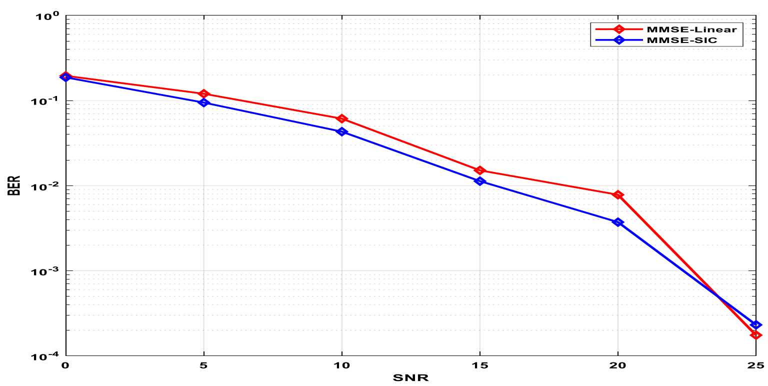

Fig. 9-BER against SNR for *M* = 10, *K* = *8*

Table1 Numerical Performance with M = 8

SNR (dB)	**BER for M = 8 MMSE-Linear/MMSE-SIC**		
	K = 4	**K = 6**	**K = 8**
0	0.2389/0.2059	0.2220/0.1998	0.2327/0.2083
5	0.1630/0.1272	0.1243/0.1029	0.1230/0.1014
10	0.0438/0.0366	0.0855/0.0512	0.0397/0.0308
15	0.0253/0.0128	0.0212/0.0185	0.0121/0.0074
20	0.0035/0.0033	0.0062/0.0018	0.0135/0.0055
25	0.0010/0.0003	0.0007/0.0007	0.0004/0.0004

Table2 Numerical performance with M = 10

SNR (dB)	**BER for M = 10 MMSE-Linear/MMSE-SIC**		
	K = 4	**K = 6**	**K = 8**
0	0.2037 /0.1981	0.2457/0.2194	0.1953/0.1871
5	0.1071 /0.0908	0.1575 /0.1193	0.1202/0.0947
10	0.0440/0.0336	0.0544 /0.0468	0.0613/0.0431
15	0.0208/0.0148	0.0168/0.0091	0.0151/0.0113
20	0.0126/0.0056	0.0034/0.0023	0.0078/0.0037
25	0.0018/0.0018	0.0007/0.0005	0.00018/0.00023

The performance of both detection techniques as presented in Fig. 4 to 9 for an uplink communication with fixed number of antennas at the BS for a given that and varied number of user equipment UE, revealed that signal strength increases as the as the noise level decreases. This is measured by the ratio of transmitted data (signal) to noise, which is expressed as a function of f bit to error ratio (BER). Thus, as the BER reduces the SNR increases. The system performance is further enhanced by increasing number of UE. As shown in Tables 1 and 2, improvement is recorded when the UE is higher such that for K = 6 the system yielded better performance compare with K = 4. Similarly, for K = 8, better performance was observed compared to K = 4 and K = 6, respectively. Looking separately on the performance of MMSE-Linear and MMSE-SIC, it is evident that the later yielded better performance than the former especially at low SNR. However, it was observed that as SNR increases, MMSE-Linear begins to show almost the same results as MMSE-SIC in some cases and gradual superiority to MMSE-SIC especially from 25 dB. For instance, when M = 8, with K = 6 and K = 8, both techniques yielded the same results, while at M = 10, K= 6 and K= 8, MMSE-Linear gradually overcomes MMSE-SIC at 25 dB respectively.

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