

Assessment of Uplink Massive MIMO in Scattering Environment

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Abstract-This paper investigates the performance of massive MIMO systems under the effect of multipath propagation environment. Linear Minimum Mean Squared Error (MMSE) is considered to assess the performance of BPBK/OFDM based uplink massive MIMO transmission. Bit Error Rate (BER) and channel capacity in Non Line Of Site (NLOS) multipath fading environment are presented. The results show a correlation between the number of antennas and the performance of the system.

Keywords-massive MIMO; BER; BPSK; OFDM; MMSE; multipath

I. INTRODUCTION

MIMO technology is one of the essential factors that lead the development of wireless communications over the last couple of decades [1]. Besides being extremely bandwidth efficient, recent MIMO based communication systems are capable of providing reliable transmission in the order of several Giga bits per second [2]. Advancements in this area have been achieved through various MIMO detection techniques that offer improved performance and reduced complexity [3-5]. Multiuser MIMO (MU-MIMO) is a class of the MIMO technology in which a group of users are able to communicate wirelessly with one or more antennas and Space Division Multiple Access (SDMA) is exploited to transmit different signals on the same band. Due to its tremendous advantages, MU-MIMO has been adopted in most of the wireless communication standards during the last decade [6]. It has been shown that there is a correlation between the number of users that can be served concurrently and the number of antennas in the Base Station (BS). As a result, more users can communicate using the same time and frequency resources when the BS is equipped with a large number of antennas [7].

Recently, the concept of MU-MIMO has been developed to massive MIMO where antenna arrays can be used at the BS [8, 9]. This means that the number of antennas at the BS is very large compared to the number of antenna users within a cell. This new technology has been adopted in the 5G NR (New Radio) which has been developed by the 3rd Generation Partnership Project (3GPP) for 5G mobile networks [10]. Its characteristics eliminate the problem of small scale fading and

the multiuser interference which makes linear detection techniques optimal. As a result, energy and spectral efficiencies are substantially increased [9]. Moreover, massive MIMO leads to huge capacity improvement that could reach up to a 50 fold increase [11, 12]. It has been shown that increasing the number of antennas in the BS enhances link reliability and improves data rate due to the increased number of possible paths for the signal [13]. It also enables the targeted use of the spectrum via the beamforming technology which results in robustness against interference and jamming [14, 15].

This paper investigates the performance of massive MIMO systems under scattering multipath environment. An OFDM-based uplink transmission case where the BS is equipped with a number of antennas larger than the number of users is considered.

II. SYSTEM MODEL

The main characteristic of massive MIMO is that the BS is equipped with antenna arrays which allow serving a large number of users in the same frequency band. The high multiplexing gain ensures reliable communication with linear processing. The system model of the uplink MU-Massive MIMO considered in this paper is shown in Figure.1.

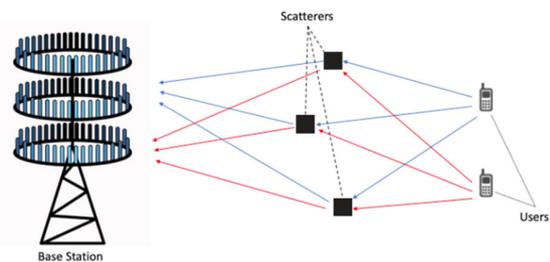


Fig. 1. Uplink massive MIMO multipath propagation.

N single antenna users are served with a BS equipped with K antennas in the single cell scenario. Let $h_{n,k}$ indicate the uplink channel coefficient between the n -th user and the k -th BS antenna [4].

$$h_{n,k} = g_{n,k} \sqrt{d_n} \quad (1)$$

where $g_{n,k}$ and d_n denote small scale fading and large-scale fading coefficients respectively. While the large-scale fading coefficients depend on the user's position, users are assumed to have independent small-scale fading. As a result, the channel matrix is given by :

$$\mathbf{H} = \begin{pmatrix} h_{1,1} & \dots & h_{K,1} \\ \vdots & \ddots & \vdots \\ h_{1,K} & \dots & h_{N,K} \end{pmatrix} = \mathbf{G}\mathbf{D}^{\frac{1}{2}} \quad (2)$$

Therefore:

$$\mathbf{H} = \mathbf{G}\mathbf{D}^{\frac{1}{2}} \quad (3)$$

where:

$$\mathbf{G} = \begin{pmatrix} g_{1,1} & \dots & g_{K,1} \\ \vdots & \ddots & \vdots \\ g_{1,K} & \dots & g_{N,K} \end{pmatrix} \quad (4)$$

$$\mathbf{D} = \begin{pmatrix} d_1 & & \\ & \ddots & \\ & & d_N \end{pmatrix} \quad (5)$$

Therefore, $\mathbf{y} \in \mathbb{C}^{K \times 1}$ represents the uplink received signal which is expressed as:

$$\mathbf{y} = \sqrt{\sigma}\mathbf{H}\mathbf{x} + \mathbf{n} \quad (6)$$

where σ represents the transmit power, $\mathbf{x} \in \mathbb{C}^{N \times 1}$ denotes the vector of the uplink transmitted signal from the users, $\mathbf{H} \in \mathbb{C}^{K \times N}$ is the uplink channel matrix in (2) and $\mathbf{n} \in \mathbb{C}^{K \times 1}$ is a Gaussian distributed noise vector with zero mean and unit variance. Therefore, the n -th user is transmitting the x_n sample which represents the n -th element of $\mathbf{x} = [x_1 \dots x_n]^T$. In this paper, data symbols needed to form the OFDM blocks are randomly selected from the BPSK alphabet with a normalized energy. While the coefficients of the small scale fading for different users are assumed to be independent and identically distributed, the channel vectors of the users become asymptotically orthogonal when the number of antennas at the BS grows to a very large value [16] and:

$$\mathbf{H}^H\mathbf{H} = \mathbf{D}^{\frac{1}{2}}\mathbf{G}^H\mathbf{D}^{\frac{1}{2}} \approx \mathbf{K}\mathbf{D} \quad (7)$$

where \mathbf{H}^H is the transpose conjugate (Hermitian) of the channel matrix.

The experimental measurements in [17] prove the favorable propagation characteristics of massive MIMO which supports the assumption made in (7). Therefore, the uplink channel capacity of the massive MIMO system is:

$$C = \log_2 \det(\mathbf{I} + \sigma\mathbf{H}^H\mathbf{H}) = \sum_{n=1}^N \log_2(1 + \sigma M d_n) \quad \frac{\text{bit}}{\text{s}} \quad \text{Hz} \quad (8)$$

III. SIGNAL DETECTION

Data streams which represent the different signals sent by the various users in the massive MIMO system must be separated, which can be done by a number of detection techniques. One of these is the Maximum Likelihood (ML) detector. The problem with this kind of detection is the

complexity which grows exponentially as the number of antennas increases. Hence, it is not practical for massive MIMO [18]. MMSE, which is a linear sub-optimal detector, is an alternative with low complexity and is used in this paper. When the number of BS antennas is much larger than the number of users, asymptotic capacity can be achieved using the linear MMSE detector. The received uplink MIMO signal can be demultiplexed at the BS as:

$$\mathbf{r} = \mathbf{U}^H\mathbf{y} \quad (9)$$

where \mathbf{r} is an $N \times 1$ vector that contains the data sent by N users and \mathbf{U} is the $K \times N$ linear detection matrix given in (10) which represents the linear MMSE estimator:

$$\mathbf{U} = \mathbf{H} \left(\mathbf{H}^H\mathbf{H} + \frac{\rho_n^2}{\rho_x} \mathbf{I} \right)^{-1} \quad (10)$$

where ρ_n^2 and ρ_x represent the variances of the signal and the noise respectively.

IV. SYSTEM SIMULATION

Table I shows the parameters that were used to assess the performance of the uplink massive MIMO system according to the system model and the signal detection described above. A large number of flat fading channels and BPSK/OFDM realizations are generated when Monte-Carlo simulation that includes error counting method was exploited. MATLAB simulation of the uplink BPSK/OFDM block transmission was conducted according the flowchart diagram shown in Figure 2.

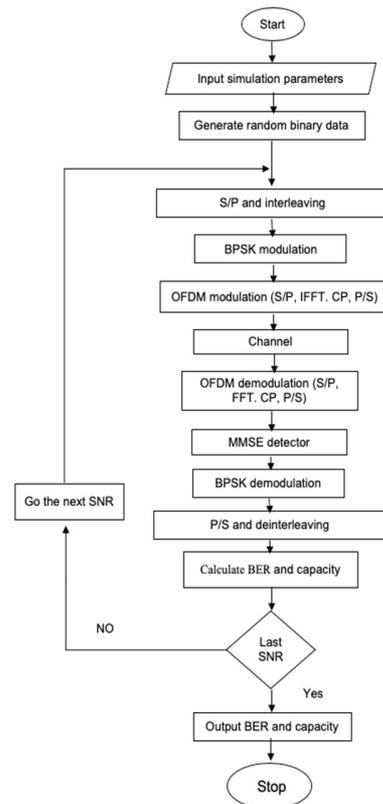


Fig. 2. Massive MIMO flowchart diagram.

After setting the system parameters, the random binary data are transformed to parallel data streams. Data frames that consist of BPSK symbols go through an IFFT with size = 2048 where cyclic prefix size is 128 in order to produce the OFDM modulated signal. This signal goes through the channel which represents the massive MU-MIMO $N \times K$ as shown in (6). Within the massive MU-MIMO $N \times K$ flat Rayleigh fading channel, each path that links the transmitter to the receiver antenna is modeled as an FIR filter where the complex coefficient is Gaussian with zero mean and unit variance. The received signal is then OFDM demodulated, where the cyclic prefix is removed and FFT is applied. MMSE detectors separate the received signal into different data streams which are BPSK demodulated. Unlike the Zero Forcing (ZF) detector that only minimizes the interference without reducing noise, the linear MMSE detector selects the \mathbf{U} that minimizes the mean squared error $e = E[\|\mathbf{U}^H \mathbf{y} - \mathbf{x}\|^2]$ and hence achieves an optimal balance between noise reduction and interference cancelation. However, the computational complexity which results in time complexity, of the MMSE linear detectors is $O(KN + KN_2 + N_3)$ [11].

TABLE I. UPLINK MASSIVE MIMO SIMULATION PARAMETERS

Parameter	Specification
Signal constellation	BPSK
Number frames	1000
Bits per frame	10000
IFFT size	2048
Channel	Rayleigh fading
Cyclic prefix	128
Equalizer	MMSE
Simulation tool	MATLAB

V. NUMERICAL RESULTS AND DISCUSSION

The BER results for various number of users N and a fixed number of BS antennas $K=50$ are shown in Figure 3. It is observed that BER reduces as the number of users increases. The improvement is obvious when the entire E_b/N_0 range is considered. This results in a gap in the BER of different numbers of users.

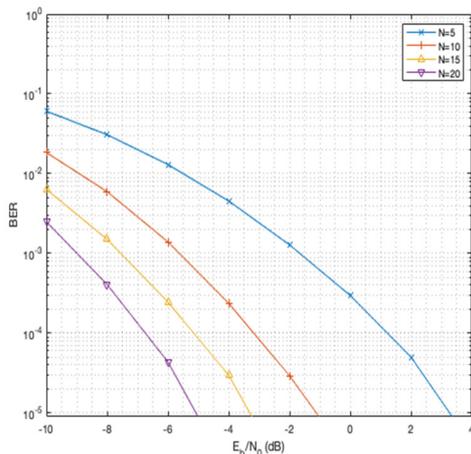


Fig. 3. BER vs. $K=50$ for different number of users N .

Figure 4 shows the BER performance of the same system. However, the number of users N is fixed at 10 while the number of antennas K varies. Increasing the number of antennas K at the BS results in enhanced transmission. Thus, the BER decreases because the multipath fading and multi-user interference effects are almost eliminated when the number of antennas at the BS is much larger than the number of users: $K \gg N$ [19]. One of the advantages of massive MIMO is that it provides service to a large number of users at the same time and its performance can be affected by the number of users [17]. The impact of the number of users on the channel capacity is illustrated in Figure 5. The simulation results show a positive correlation between the number of users and the capacity of the channel: the uplink channel capacity increases as the number of users increases. Therefore, spectral efficiency is proportional to the number of users within the cell in massive MIMO systems.

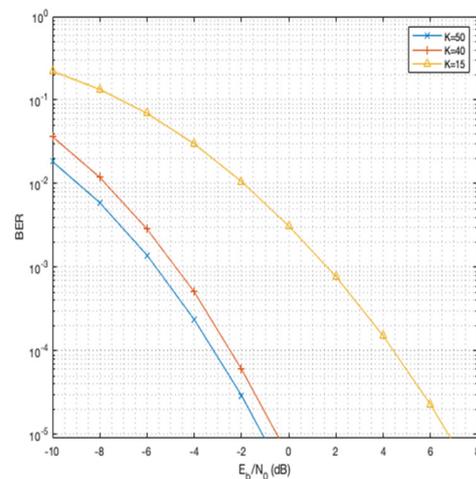


Fig. 4. BER vs. users $N=10$ for different number of BS antennas K .

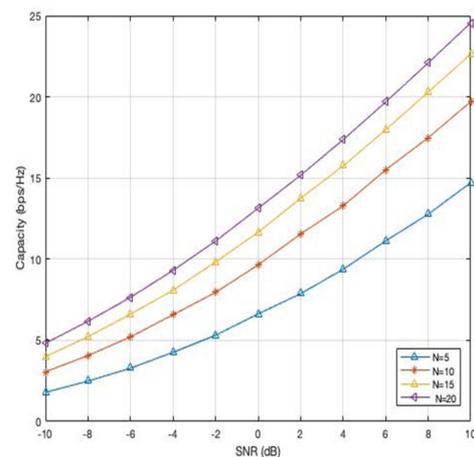


Fig. 5. Uplink capacity for different users N vs BS with $K=50$.

To further study the effect of the number of users on the uplink channel capacity in massive MIMO systems, BSs with

50 and 100 antennas were considered. The optimal capacities of the system depend on the number of antennas in the BS and the number of the users in the cell as shown in Figure 6. When the BS is equipped with $K=50$ antennas, the capacity gradually grows until 40 active users are reached. After that, it starts degrading as the number of users increases. If the BS is equipped with $K=100$ antennas, the maximum capacity is around 125bits/s/Hz at 64 users. Therefore, the BS with a large number of antennas outperforms the one with a smaller number of antennas. Different estimation techniques have been used in [9] to investigate the influence of the number of active users on the channel capacity and their results show that channel capacity starts degrading after a certain point.

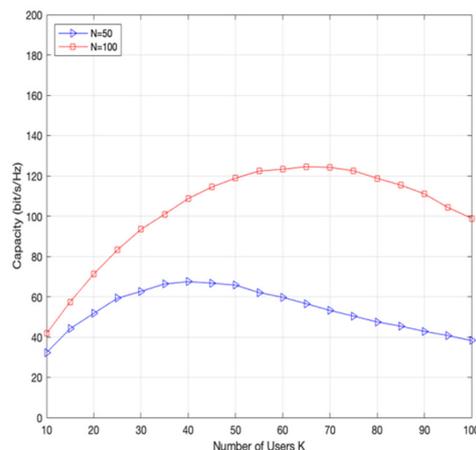


Fig. 6. Uplink capacity vs. number of users.

VI. CONCLUSION

Massive MIMO is a wireless communication technology with many issues and aspects that must be investigated. The performance of a massive MIMO was studied in this paper. The studied scenario consists of a single cell that contains multiple users served through a single BS where linear detection techniques that process the uplink OFDM transmission were used. The BER results confirm the positive impact of making the number of receive antennas at the BS much larger than the transmit antennas which represent the number of users. Hence, increasing the number of antennas in the BS is recommended if the number of users is large. It was shown that massive MIMO improves spectral efficiency. It has been shown that the channel capacity increases by increasing the number of users, the number of BS antennas or both.

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