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doi:10.15199/48.2021.01.09

Performance of Massive MIMO Systems under the Effect of Fading Channel

***Abstract**. This paper evaluates the performance of an uplink OFDM-based communication system considering multipath propagation environment where a Massive MIMO approach is exploited. In this context, Zero Forcing detector is used and assessed. Numerical analysis of the mathematical model was conducted on MATLAB. The results presented in this paper include Bit Error rate (BER) and the channel capacity of QPSK/OFDM transmission through a fading channel. Performance results verify the positive effect of Massive MIMO even when reduced complexity detection technique is used.*

*Streszczenie. Analizowano właściwości systemu komunikacyjnego bazującego na OFDM. Uwzględniono wielostrumieniowy rozsył z eksploatacja dużego MIMO. Opracowano model matematyczny I przeprowadzono symulację określającą BER I pojemność kanału dla przesyłu QPSK/OFDM. (**Właściwości systemu komunikacji MIMO z uwzględnieniem efektu zaniku kanału**)*

Keywords: Massive MIMO, OFDM, Multipath, BER, QPSK
Słowa kluczowe: system komunikacyjny, MIMO, BER

Introduction

Since the invention of wireless communications, data trafficking has been doubling almost every two years and a half [1]. Although electromagnetic spectrum is a limited resource, the need for more enhanced wireless services will always be increasing [2][3]. Hence, it is essential that new technologies are developed all the time to use these limited resources in an effective way. Therefore, as the demand increases, technologies that can improve spectrum efficiency, cellular network densification methods will be improved.

During the last two decades, the development of wireless communications has been led by the MIMO technology [4][4] [5]. Thus, Recent communication systems which are MIMO based have become very bandwidth efficient and reliable due to the numerus detection techniques that reduce complexity and enhance performance [1], [6]–[8].

In modern wireless communications, multi-users MIMO (MU-MIMO) is used to increase the efficiency. Therefore, MU-MIMO has become an essential part of recent communication standards [9]. Recently, it has been shown that serving large number of users by increasing the number of antennas in the base station (BS) is possible [10]. Therefore, Massive MIMO technology has been introduced[11] [12][13]. The main concept of Massive MIMO is that the number of antennas at the BS is much larger than the number of users. Therefore, cells would become smaller and the BS would have large antenna arrays. Hence, 5G New radio (5G NR) has already adopted Massive MIMO for 5G mobile networks where antenna arrays at the BS is used because of its robustness against small scale fading and interferences [14].

This paper studies Massive MIMO systems under the effect of a fading a channel. An uplink OFDM transmission where a BS is equipped with large number of antennas compared to the number of users have been considered.

The rest of this paper is continuous as the following: the next section shows the mathematical model of the Massive MIMO channel that used in this paper. Next, the detection technique is described. After that, simulation results show BER and the system capacity for BPSK/OFDM transmissions of Massive MIMO under a flat fading channel are presented. Finally, this paper is concluded.

System Model

The Main feature of Massive MIMO is that the BS is contains antenna arrays that makes it capable of severing a large number of users at the same frequency recourse. Communication reliability is achieved through the high multiplexing gain where only linear processing is needed.

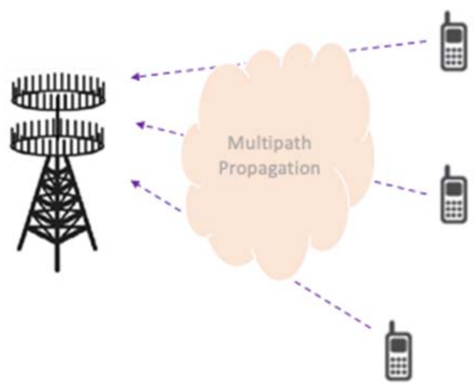


Fig.1 Uplink Massive MIMO with Fading Channel

The system model of an uplink MU-Massive MIMO sudied in this paper is illustrated in fig.1 where *N* single antenna devices are communicating with a BS that have *K* antenna in single cell scenario. If the uplink channel coefficient between the *n*-th user and the *k*-th BS antenna is denoted $h_{n,k}$, then [7].

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

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

(2) $$\mathbf{H} = \begin{pmatrix} h_{1,1} & \cdots & h_{K,1} \\ \vdots & \ddots & \vdots \\ h_{1,K} & \cdots & h_{N,K} \end{pmatrix} = \mathbf{GD}^{\frac{1}{2}}$$

Therefore,

(3) $$\mathbf{H} = \mathbf{GD}^{\frac{1}{2}}$$

where

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

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

Therefore, $\boldsymbol{y} \in \mathbb{C}^{K\times1}$ represents the uplink received signal which is expressed as

(6) $$\mathbf{y} = \sqrt{\sigma}\mathbf{Hx} + \mathbf{n}$$

where σ denote transmit power, $\mathbf{x} \in \mathbb{C}^{N\times1}$ indicates the vector of the uplink transmitted signal from the users and $\mathbf{n} \in \mathbb{C}^{K\times1}$ is a Gaussian distributed noise vector with zero mean and unit variance. Therefore, the *n*-th user is transmitting the x_n sample which represent the *n*-th element of $\mathbf{x} = [x_1 \ldots x_n]^{\boldsymbol{T}}$. In this paper, data symbols needed to form the OFDM blocks are randomly selected from QPSK alphabet with a normalized energy.

While the coefficients of the small scale fading for different users are assumed to be i.i.d, the channel vectors of the users become asymptotically orthogonal when the number of antennas at the BS grows to a very large number [15].

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

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

Experimental measurements in [2] confirm the favorable propagation features of massive MIMO which supports the assumption made in (7). hence, the uplink channel capacity of the Massive MIMO system is

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

Signal Detection

Data streams of the different signals sent by the various users in the Massive MIMO system must be separated via a number of detection techniques. Maximum likelihood (ML) detector cam be used but the issue. with this kind of detection is the exponential computational complexity as the number of antennas is increased which considerably reduce its viability for Massive MIMO [16]. Thus, ZF which is a linear sub-optimal detector with low complexity is one alternative that have been used in this paper.

The received uplink MIMO signal can be demultiplexed at the BS as the following

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

where r is $N \times 1$ vector that contains the signals sent by N users and U is the $K \times N$ linear detection matrix given in equation (10) which represents the zero forcing (ZF) estimator.

(9) $$\mathbf{U} = \mathbf{H}(\mathbf{H}^{\mathrm{H}}\mathbf{H})^{-1}$$

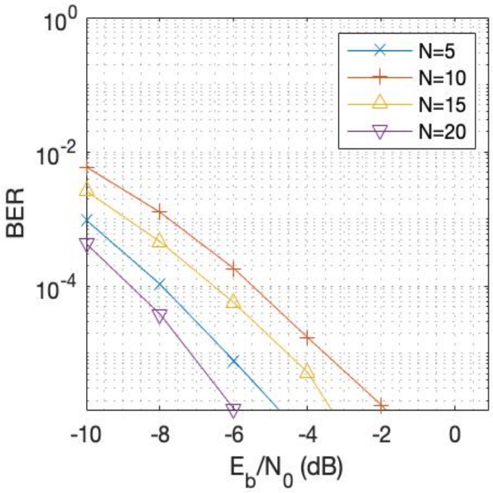
ZF select the matrix **U** that cancel interference. In particular , ZF linear detector chooses U so that UH = I. U. However, It removes any desired signal energy that lies in the interference subspace.

Simulation Results

The simulation results of a QPSK/OFDM transmission with IFFT size = 2048 and cyclic prefix size = 128 through a Massive MU- MIMO $N \times K$ are discussed in this part. Simulation pararemters that was performered in MATLAB are shown in Table 1. Monte-Carlo simulation was utilized after randomly generating a large number of channels and QPSK/OFDM symbol realizations. Within the Massive MU-MIMO $N \times K$ flat Rayleigh fading channel, all the paths between the transmitter and the receiver are modeled as an FIR filter with a Gaussian complex coefficient of zero mean and unit variance.

Table.1 Simulation Parameters of the system

Parameter	**Specification**
Signal Constellation	QPSK
Number Frames	1000
Bits per Frame	10000
IFFT Size	2048
Channel	Rayleigh Fading
Cyclic Prefix	128
Equalizer	ZF
Simulation Tool	MATLAB



Fg.2 BER vs. K=50 for different number of users N

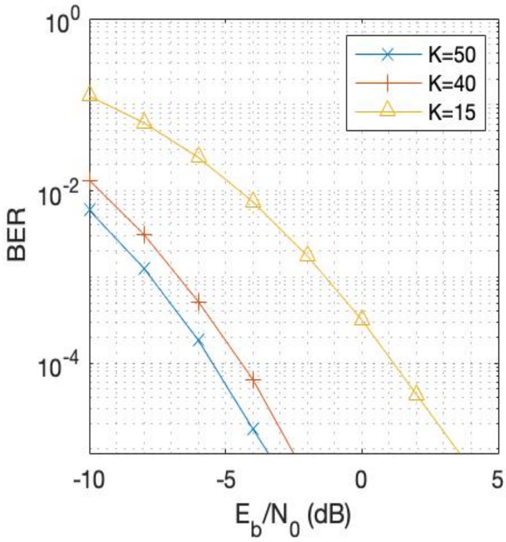


Fig.3 BER vs. users *N*=10 for different BS Antennas K

BER for several number of users *N* while the number of BS antennas is fixed at *K*=50 are shown in Fig. 2. An improvement in the performance of the system is observed as the number of users increases. The improvement is noticeable when the entire Eb/No range is considered. The effect of of fixing the number of users while varying the number of antennas at the BS is shown In Fig. 3 the BER performance of the same system. Increasing the number of antennas *K* at the BS improve the 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 $K \gg N$.

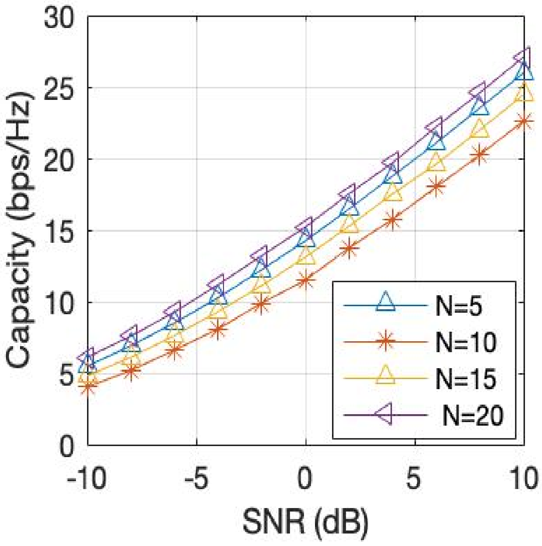


Fig.4 Uplink Capacity for different users *N* VS BS with *K*=50

The capacity of channel considering different number of users is shown in Fig. 4. Results shows the positive effect of increasing the number of users on capacity of the system even when the channel is fading. Hence, the uplink channel capacity is improved as more users are active. Hence, spectral efficiency is proportional to the number of users .

Conclusion

The performance of a Massive MIMO under a fading channel was investigated in this paper. The system consists of a single cell served through one BS. linear detection techniques to process the uplink OFDM transmission were used. The positive effect of leting the number antennas at the BS greater than the transmit antennas has been verified through BER results. Also, this paper confirms that Massive MIMO enhance spectral efficiency even through fading environment.

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