Etude de la Corrélation des Canaux Massive MIMO pour l’Optimisation d’Algorithmes d’Allocation de Ressources Multi-Users 5G
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Mots-clés : 5G, Massive-MU-MIMO, Corrélation de canal, Allocation de ressources

1 Introduction

One of the key technologies for 5G radio transmission is Massive-MIMO (Multiple Input Multiple Output) [W+14]. Having a larger number of antennas at the base station can significantly improve the link budget by focusing the energy in the chosen direction [Tel99]. Focusing the energy can also be used to serve multiple users (MU) on the same time and frequency resource. This opens the way to conceiving new scheduling algorithms in order to take a real advantage from Massive-MIMO. The objective of this paper is to provide a better understanding of the MU mode in a massive MIMO context by comparing its total system rate with the one given by a traditional single-user (SU) approach.

More precisely, we compare two strategies. In the SU mode, only one user is served on a given time-frequency resource unit. There is no intracell interference. Several users are served by a classical round-robin scheduler. In the MU mode, several users are served on the same time-frequency unit. The total system rate is expected to be higher. However, there is intracell interference, which reduces the bit rate. A standard approach to estimate the interference level is to consider the correlation between the user-channel matrices [J+07, L+14]. Our secondary objective is to check whether the correlation is a good indicator of the total system rate.

2 System description

We consider one base station (BS) and several user equipment (UE) and we study the downlink transmission of one resource block. The channel is assumed to be constant for all sub-carriers within a resource block. We define $B$ as the bandwidth of the resource block, $\mathcal{U}$ as the set of all UEs in the cell, and $n_t$, $n_r$ the number of antennas at the transmitter (BS) and at the receiver (UE), respectively. The channel between the
set of antennas at the BS and the set of antennas at UE $i$ is modelled by complex matrix $H_i$. The precoding matrix at the BS is represented by matrix $F_i$ and the digital combining matrix at UE $i$ is represented by $W_i^*$. The white noise average power is denoted by $\sigma_N^2$. Note that the interference from neighbour base stations can be integrated in $\sigma_N^2$.

Scheduling at a given slot can be viewed as an indicator function $\delta_i$ where $\delta_i \in [0, \min(n_t, n_r)]$ gives the number of streams allocated to UE $i$. We have the following constraint:

$$\sum_{i \in \mathcal{U}} \delta_i(t) \leq n_t. \quad (1)$$

For the MU mode, we consider the Block Diagonal (BD) precoding technique [K+14] because the BD precoder is focused on interference management and therefore limits the reduction of the bit rate due to the intracell interference. The bit rate for UE $i$ is given by [A+18]:

$$R_i = B \log_2 \left| \frac{W_i^* H_i F_i (W_i^* H_i F_i)^*}{\sigma_N^2 (\mathbb{I}_{n_r} + \sum_{j \neq i, \delta_j > 0} \mathbb{I}_{n_r})} \right|. \quad (2)$$

where $\mathbb{I}_{n_r}$ is an identity matrix of size $n_r$.

In the SU mode, $\delta_i$ is non-zero for only one value of $i$. Thus, there is no intracell interference and the rate $C_i$ is maximized. Equation (2) is simplified as:

$$C_i = B \log_2 \left| \frac{W_i^* H_i F_i (W_i^* H_i F_i)^*}{\sigma_N^2 (\mathbb{I}_{n_r})} \right|. \quad (3)$$

Our objective is to compare the total system rate for MU and SU strategies. With MU, $n_t/n_r$ are served at the same time. With SU, only one user is served. Serving $n_t/n_r$ users is done by considering $n_t/n_r$ successive slots. We define $n_s$ as the number of simultaneously scheduled users, where $n_s \leq n_t/n_r$. The spectral efficiency gain $\chi$ is:

$$\chi = E \left[ \frac{n_s}{\sum_{i=1}^{n_t} R_i} / \frac{n_s}{\sum_{i=1}^{n_t} C_i} \right], \quad (4)$$

where $E$ is the mathematical expectation. We consider a large set of random deployments of terminals. Thus, $H_i$ is a random matrix. In the following, for different configurations, we study $\chi$, which thus is our main performance indicator.

In MU-MIMO a good interference management is crucial to fully profit from the technique. As seen in [L+14] and [J+07] the channels matrices correlation is commonly used as an indicator for interferences level between UEs. The correlation of two UEs channel matrices indicates the interference level if they are using simultaneously the same resource block. The correlation of two UEs is defined by [C+09]:

$$\xi(i, j) = \frac{\left| \text{tr}(H_i H_j^*) \right|}{\|H_i\|_F \|H_j\|_F} \quad (5)$$

where $(.)^*$ denotes the conjugate transpose operation and $\|.|_F$ the Forbenius norm of a matrix.

### 3 Simulation set up

Two user equipment (UE) are considered. The channels of the UEs are mutually independent. A channel for a user $i$ is generated using the extended Saleh-Valenzuela model [G+14] where the obstructed-line-of-sight (OLOS) parameters are given in table 1.
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| \( \Lambda \) | 5 ns | Cluster arrival rate |
| \( \lambda \) | 1 ns | Ray arrival rate |
| \( \Gamma \) | 8.7 ns | Cluster decay rate |
| \( \gamma \) | 4.7 ns | Ray decay rate |
| \( \sigma \) | 0.1 rad | Intra-cluster angles standard deviation |

Table 1: Channel model parameters, from [G\textsuperscript{+}14]

We consider one sector in a typical 3-sector configuration: the angle between the terminal and the base station is between 0\(^\circ\) and 120\(^\circ\) horizontally and between −45\(^\circ\) and 45\(^\circ\) vertically. We assume that the transmitter has a full knowledge of the channel for each UE. Each antenna settings is tested over an average of 1 million configurations, where each configuration is a new independent set of random variables. When scheduled alone the capacity achievable for a user will be calculated as fallow.

4 Impact of the number of antennas on the correlation distribution

The number of antennas is a main strength of Massive-MIMO. The more antennas there are, the more precise the spatial separation will be. However, due to technical limitations, such as precoding complexity or room space available for mobile devices, the number of antennas is limited. 3GPP proposed to fix the number of antennas at the transmitter and at the receiver for system evaluation. In our performance evaluation, we study different configurations to understand the impact on the correlation. In the following example we show the impact of the number of antennas, at the transmitter \( n_t \) and at the receiver \( n_r \), on UEs correlation repartition. For each sample we compute the channel correlations of two UEs.

Figure 1: Correlation repartition depending on antenna numbers

Figure 2: Spectral efficiency gain of MU-MIMO over SU-MIMO

Figure 1 shows the empirical PDF of the correlation. The CDF can be easily deduced from the PDF but is not shown for space constraints. Several observations can be highlighted from figure 1. The product of the number of antennas determines the correlation repartition. Two antenna configurations having the same product have a close correlation repartition: configurations \( n_r = 2 \times n_t = 16 \) and \( n_r = 8 \times n_t = 64 \) have a nearly similar correlation distribution. Having a greater number of antennas allows the system to be more accurate in the beamforming, resulting in a lower average correlation. With \( n_r = 8 \times n_t = 64 \) there is a larger number of low correlation than with \( n_r = 2 \times n_t = 16 \).

5 Impact of the correlation on throughput

The main objective when designing a resource allocation algorithm is to increase the capacity of the system. To understand if the correlation is a good indicator for a scheduling process, we study the correlation
impact on throughput. Using the previous example, for each sample, we calculate the throughput gain from the MU-MIMO allocation, that is expressed by:

Figure 2 shows $\chi$ values, computed in (4), for different antenna configurations. Each antenna configuration is represented by tree boxes with 0.1, 0.2 and 0.3 of correlation. Concerning the throughput gain, for example, with $n_r = 2$ & $n_t = 16$, between 0.1 and 0.3 of correlation, we are only losing less than 3% of capacity in mean. The Block Diagonal precoding technique is built to withstand the increase of interferences. When the correlation increases, even if the spectral efficiency decreases, the precoder is able to contain the degradation. With an antenna configuration of $n_r = 2$ & $n_t = 16$ at a correlation of 0.2 they may be more than 10% between the highest and lowest value of throughput. This difference depends on the degree of freedom available in the precoding process. To reduce the deviation the ratio $\frac{n_t}{n_r}$ should be larger. The main issue in this example, is the ability to predict the gain. In all configurations there is an intersection between throughput values, meaning that the same throughput gain can be experienced with different correlation values. Note that in the case of $n_r = 8$ & $n_t = 16$ and $n_r = 4$ & $n_t = 8$, it is not even profitable to schedule two UEs at the same time. They will both experience a smaller throughput than if they were scheduled in Single-User mode.

6 Conclusion

Correlation is often used in the user selection process as an indicator to maximize the global throughput. In this study, we show the correlation repartition and the relation between correlation and throughput when using a Block Diagonal precoder. The repartition of the correlation depends on the product of the number of antennas at the transmitter and at the receiver. A higher product reduces the probabilities of high correlation values and diversity. The ratio between receive and transmit antennas determines the variability of the throughput gain. A large number of transmit antennas compares to number of receiver antennas makes the throughput gain more predictable. As a summary, a user selection process, using Block Diagonal precoding, can benefit from a correlation indicator in different configurations. With small product of the number of antennas, where their is still some variability in correlation. Also, when there is a large ratio between the number of antennas at the transmitter and at the receiver, the gain is more predictable. In future works, we will study how more than two users simultaneously scheduled impact the correlation and therefore the throughput. We will also investigate the use of a compensation factor to being able to use the correlation as an indicator in all antennas configurations.

Références


