Etude de la Corrélation des Canaux Massive MIMO pour l'Optimisation d'Algorithmes d'Allocation de Ressources Multi-Users 5G

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L'allocation de ressources est un domaine de recherche majeur des réseaux sans fil. L'enjeu est de trouver l'utilisateur pour chaque ressource temps-fréquence permettant d'atteindre les objectifs de Qualité de Service fixés. Or, la nécessité d'accroître toujours plus la capacité oriente les systèmes vers toujours plus d'antennes. Notamment, l'emploi du Massive-MIMO (Multiple Input Multiple Output) autorise désormais l'utilisation de la même ressource fréquentielle pour plusieurs utilisateurs simultanément, changeant ainsi le paradigme de l'allocation de ressources. Dans ce contexte, les algorithmes d'allocation de ressources doivent ajouter, à leur processus de décision, le choix de quels utilisateurs réunir ensemble sur une même ressource temps-fréquence. Une stratégie possible, utilisée dans l'état de l'art, est de baser ce groupage d'utilisateurs sur la corrélation de leurs matrices de canal afin de minimiser le niveau d'interférences. Dans cet article, nous montrons l'utilité limitée de cette approche dans le cas d'utilisation d'un précodeur bloc diagonal.

Mots-clefs : 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 $\mathbf{H}_i$. The precoding matrix at the BS is represented by matrix $\mathbf{F}_i$ and the digital combining matrix at UE i is represented by $\mathbf{W}_i^*$. The white noise average power is denoted by σ_N^2. Note that the interference from neighbour base stations can be integrated in σ_N^2.

Scheduling at a given slot can be viewed as an indicator function δ_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 :

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

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] :

$$R_i = B \log_2 \left| \mathbb{1}_{n_r} + \frac{\mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i \, (\mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i)^*}{\mathbf{W}_i^* \, (\sigma^2 \mathbb{1}_{n_r} + \sum\limits_{j \neq i, \delta_j > 0} \mathbf{H}_i \mathbf{F}_j \, (\mathbf{H}_i \mathbf{F}_j)^*) \mathbf{W}_i} \right| \tag{2}$$

where $\mathbb{1}_{n_r}$ is an identity matrix of size n_r.

In the SU mode, δ_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 :

$$C_i = B \log_2 \left| \mathbb{1}_{n_r} + \frac{\mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i \, (\mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i)^*}{\mathbf{W}_i^* \, (\sigma^2 \mathbb{1}_{n_r}) \mathbf{W}_i} \right| \tag{3}$$

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 χ is :

$$\chi = E \left[\sum_{i=1}^{n_s} R_i \Big/ \sum_{i=1}^{n_s} C_i / n_s \right], \tag{4}$$

where E is the mathematical expectation. We consider a large set of random deployments of terminals. Thus, $\mathbf{H}_i$ is a random matrix. In the following, for different configurations, we study χ, 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] :

$$\xi(i, j) = \frac{|\mathbf{tr}(\mathbf{H}_i \mathbf{H}_j^*)|}{||\mathbf{H}_i||_F \, ||\mathbf{H}_j||_F} \tag{5}$$

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.

Λ	5	ns	Cluster arrival rate
λ	1	ns	Ray arrival rate
Γ	8.7	ns	Cluster decay rate
γ	4.7	ns	Ray decay rate
σ	0.1	rad	Intra-cluster angles standard deviation

TABLE 1: Channel model parameters, from [G+14]

We consider one sector in a typical 3-sector configuration : the angle between the terminal and the base station is between 0° and 120° horizontally and between −45° and 45° 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.

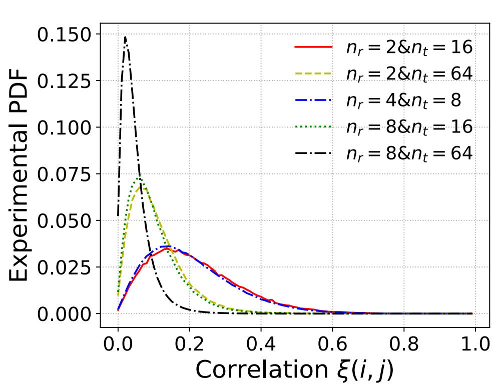

FIGURE 1: Correlation repartition depending on antenna numbers

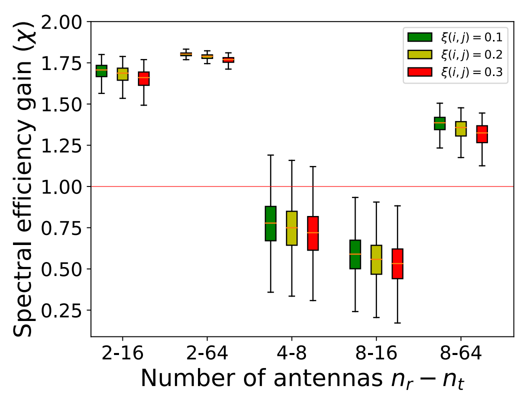

FIGURE 2: Spectral efficiency gain of MU-MIMO over SU-MIMO

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 $n_r = 2\&n_t = 64$ and $n_r = 8\&n_t = 16$ 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 $n_r = 8\&n_t = 64$ there is a larger number of low correlation than with $n_r = 2\&n_t = 16$.

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 χ values, computed in (4), for different antenna configurations. Each antenna configuration is represented 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 loosing 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

[A+18] Adam Mohamed Ahmed Abdo et al. MU-MIMO Downlink Capacity Analysis and Optimum Code Weight Vector Design for 5G Big Data Massive Antenna Millimeter Wave Communication. *Wireless Communications and Mobile Computing*, 2018 :1–12, 2018.

[C+09] Nicolai Czink et al. Spatial separation of multi-user MIMO channels. In *Personal, Indoor and Mobile Radio Communications, 2009 IEEE 20th International Symposium on*, pages 1059–1063. IEEE, 2009.

[G+14] Carl Gustafson et al. On mm-Wave Multipath Clustering and Channel Modeling. *IEEE Transactions on Antennas and Propagation*, 62(3) :1445–1455, March 2014.

[J+07] Tianxiong Ji et al. Low Complex User Selection Strategies for Multi-User MIMO Downlink Scenario. In *2007 IEEE Wireless Communications and Networking Conference*, pages 1532–1537, Kowloon, China, 2007. IEEE.

[K+14] Md Hashem Ali Khan et al. A simple block diagonal precoding for multi-user MIMO broadcast channels. *EURASIP Journal on Wireless Communications and Networking*, 2014(1) :95, 2014.

[L+14] Zhao Li et al. MU-MIMO downlink scheduling based on users' correlation and fairness. In *2014 IEEE 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication (PIMRC)*, pages 407–412, Washington DC, USA, September 2014. IEEE.

[Tel99] Emre Telatar. Capacity of Multi-antenna Gaussian Channels : Capacity of Multi-antenna Gaussian Channels. *European Transactions on Telecommunications*, 10(6) :585–595, November 1999.

[W+14] Cheng-Xiang Wang et al. Cellular architecture and key technologies for 5g wireless communication networks. *IEEE Communications Magazine*, 52(2) :122–130, February 2014.