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Study of MIMO Channel Matrices Correlation to Optimize Resource Allocation Algorithms in Multi-Users 5G

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Abstract—Resource allocation is a major research field in wireless networks. The main challenge is to find the most suitable user for each time and frequency resource to reach the quality of service requirements. The necessity to always increase the capacity of wireless networks leads to systems using more and more antennas. Namely, the use of Massive-MIMO (Multiple Input Multiple Output) allows to simultaneously schedule several users on the same frequency resource. This is a new paradigm for resource scheduling. In this context, resource allocation algorithms have to include in their decision mechanism the choice of users association on the same time and frequency resource. A possible strategy, seen in the state of the art, is to base this user grouping on their channel-matrix correlation to minimize the interference level. In this paper we show the limited use of this approach in a system using block diagonal precoder.

Index Terms—5G, Massive-MU-MIMO, Channel correlation, Resources allocation.

I. INTRODUCTION

One of the key technologies for 5G radio transmission is Massive-MIMO (Multiple Input Multiple Output) [1]. Having a larger number of antennas at the base station can significantly improve the link budget by focusing the energy in the chosen direction [2]. 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 [3], [4], [5]. Our secondary objective is to check whether the correlation is a good indicator of the total system rate or not.

II. SYSTEM DESCRIPTION

We consider one base station (BS) and several user equipment (UE) and we study the downlink transmission of one resource block (RB). 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, \mathcal{I} as the set of all UE using simultaneously the same RB, 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 .

The channel matrix of a UE i is given by $\mathbf{H}_i[t] \in \mathbb{C}^{n_r \times n_t}$ and is perfectly known at the eNB. Different models can be used to compute the $\mathbf{H}_i[t]$ matrix, such as the "one-ring" model [6] or extended Saleh-Valenzuela model [7]. The total number of parallel transmissions that can be made on the same RB by one eNB is given by n_t . The maximum number of transmissions on the same RB to a given UE is $\min(n_t, n_r)$. The time is considered discrete and Δt is equivalent to a timeslot. We suppose the coherence time of the channel greater than Δt and therefore the scheduling time.

1) *Transmission model*: At a given time, scheduling can be viewed as an indicator function: $\delta_i(t)$ where i is the UE index, k the RB index and $\delta_i(t) \in [0, \min(n_t, n_r)]$ gives the number of streams on resource k allocated to i .

We have the following constraint:

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

The potential number of usable resources is given by $n_t \times K$, where K is number of resource blocks. We assume that there is no limitation regarding the number of RF chains and the processing capacity. To illustrate the previous equation, we can consider a number of UEs equal to $n_t \times K$, for example $n_t \times K = 100$. In this case UEs will only have 1 RB among 100 on average per timeslot. It is then safe to say that in most cases, $\delta_i(t) = 0$.

For the sake of clarity we omit t for this part. We denote the precoding matrix associated to channel \mathbf{H}_i as $\mathbf{F}_i \in \mathbb{C}^{n_t \times \delta_{i,k}}$. The dimension of \mathbf{F}_i depends on the number of antennas at the eNB and the selected streams. The signal transmitted to UE i is :

$$\mathbf{x}_i = \mathbf{F}_i \mathbf{s}_i \quad (2)$$

where $i \in \mathcal{U}$ and $\mathbf{s}_i[k]$ is the $\delta_i \times 1$ transmitted vector of symbols at subcarrier k . Note that $\mathbf{s}_i[k]$ is null if $\delta_i = 0$. The global signal transmitted by the base station is:

$$\mathbf{X} = \sum_{j \in \mathcal{U}, \delta_j > 0} \mathbf{F}_j \mathbf{s}_j \quad (3)$$

At the receiver, the signal is affected by the channel matrix \mathbf{H}_i , noise corrupting the received signal \mathbf{n} of power σ^2 and \mathbf{I} external cell interferences:

$$\mathbf{y}_i = \underbrace{\mathbf{H}_i \mathbf{X}}_{\text{signal}} + \underbrace{\mathbf{I} + \mathbf{n}}_{\text{external interferences+noise}} \quad (4)$$

Due to the fact that we are considering a Multi-User transmission (MU-MIMO) the transmitted signal for other UEs scheduled on the same resource block has to be considered as internal interference:

$$\mathbf{y}_i = \underbrace{\mathbf{H}_i \mathbf{F}_i \mathbf{s}_i}_{\text{signal}} + \underbrace{\sum_{j \neq i, \delta_j > 0} \mathbf{H}_i \mathbf{F}_j \mathbf{s}_j}_{\text{interferences+noise}} + (\mathbf{I} + \mathbf{n}) \quad (5)$$

Those internal interferences depend on the precoders \mathbf{F}_j orthogonality to the channel matrix \mathbf{H}_i . The signal at the receiver after combining is finally given by:

$$\mathbf{z}_i = \mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i \mathbf{s}_i + \mathbf{W}_i^* \sum_{j \neq i, \delta_j > 0} \mathbf{H}_i \mathbf{F}_j \mathbf{s}_j + \mathbf{W}_i^* (\mathbf{n} + \mathbf{I}) \quad (6)$$

where $\mathbf{W}_i^*[k]$ is the digital combining matrix [8] and $(\cdot)^*$ the conjugate transpose of a complex matrix.

2) *Precoding techniques*: Two precoding mechanisms are considered:

a) *SVD*: A MIMO channel \mathbf{H}_i of a user i can be decomposed using the singular-value decomposition (SVD) as follow:

$$\mathbf{H}_i = U_i \Sigma_i V_i^* \quad (7)$$

The optimal precoder in SU-MIMO for i is $\mathbf{F}_i[2]$:

$$\mathbf{F}_i = V_i \Lambda^{1/2} \quad (8)$$

where $\Lambda^{1/2}$ is a diagonal matrix of which the element λ_i scales the power transmitted.

b) *Block Diagonal precoding* [9][10]: In MU-MIMO several users can be scheduled simultaneously on the same resource block. In such condition, users can experience interferences from other users. The objective of the Block Diagonal precoder is to eliminate UEs interferences when they are scheduled in a MU-MIMO context. Therefore, all users that are simultaneously scheduled have to be consider in the precoding process.

We define $\tilde{\mathbf{H}}_i^T$ the concatenation of channel matrices of all users in \mathcal{I} except i :

$$\tilde{\mathbf{H}}_i^T = [\mathbf{H}_1^* \dots \mathbf{H}_{i-1}^* \mathbf{H}_{i+1}^* \dots \mathbf{H}_I^*]^* \quad (9)$$

where $I = \text{card}(\mathcal{I})$. Note that $\tilde{\mathbf{H}}_i^T$ is a $n_r \times (I-1)$ rows and n_t columns complex matrix. We are using the singular-value decomposition on $\tilde{\mathbf{H}}_i^T$.

$$\tilde{\mathbf{H}}_i^T = U_i^T \Sigma_i [V_i^{(1)} V_i^{(0)}]^* \quad (10)$$

where $[V_i^{(1)} V_i^{(0)}]$ is a $n_t \times n_t$ matrix. $V_i^{(1)}$ contains vectors corresponding to nonzero singular values and $V_i^{(0)}$ contains vectors corresponding to zero singular values.

$$\tilde{\mathbf{H}}_i^T \tilde{V}_i^{(0)} = \tilde{U}_i \tilde{\Sigma}_i [\tilde{V}_i^{(1)} \tilde{V}_i^{(0)}]^* \quad (11)$$

The total precoding matrix is given by:

$$T^{BD} = [\tilde{V}_1^{(0)} V_1^{(1)} \tilde{V}_2^{(0)} V_2^{(1)} \dots \tilde{V}_I^{(0)} V_I^{(1)}] \Lambda^{1/2} \quad (12)$$

where $\Lambda^{1/2}$ is a diagonal matrix of which the element λ_i scales the power transmitted.

3) *User Equipment throughput*: For the MU mode, we consider the Block Diagonal (BD) precoding technique [10] 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 [11] :

$$R_i = B \log_2 \left| \mathbb{1}_{n_r} + \frac{\mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i (\mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i)^*}{\mathbf{W}_i^* (\sigma^2 \mathbb{1}_{n_r} + \sum_{j \neq i, \delta_j > 0} \mathbf{H}_i \mathbf{F}_j (\mathbf{H}_i \mathbf{F}_j)^*) \mathbf{W}_i} \right| \quad (13)$$

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 (13) is simplified as:

$$C_i = B \log_2 \left| \mathbb{1}_{n_r} + \frac{\mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i (\mathbf{W}_i^* \mathbf{H}_i \mathbf{F}_i)^*}{\mathbf{W}_i^* (\sigma^2 \mathbb{1}_{n_r}) \mathbf{W}_i} \right| \quad (14)$$

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:

$$\chi = E \left[\frac{\sum_{i=1}^{n_s} R_i}{\sum_{i=1}^{n_s} C_i/n_s} \right], \quad (15)$$

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 is thus our main performance indicator.

In MU-MIMO a good interference management is crucial to fully profit from the technique. As seen in [4] and [3] 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 [12]:

$$\xi(i, j) = \frac{|\text{tr}(\mathbf{H}_i \mathbf{H}_j^*)|}{\|\mathbf{H}_i\|_F \|\mathbf{H}_j\|_F} \quad (16)$$

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

III. 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 [7] where the obstructed-line-of-sight (OLOS) parameters are given in table I.

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 I: Channel model parameters, from [7]

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.

IV. 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 fixes the number of antennas at the transmitter and at the receiver in the system evaluation framework. 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 shows the empirical PDF of the correlation. The CDF can be easily deduced from the PDF but is not shown due to space constraints. Several observations can be highlighted

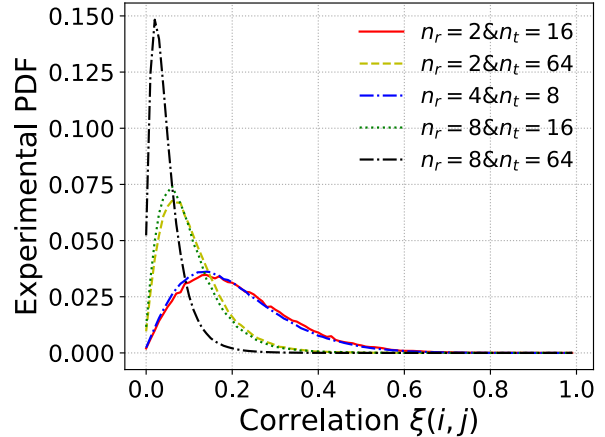


Fig. 1: Correlation repartition depending on antenna numbers

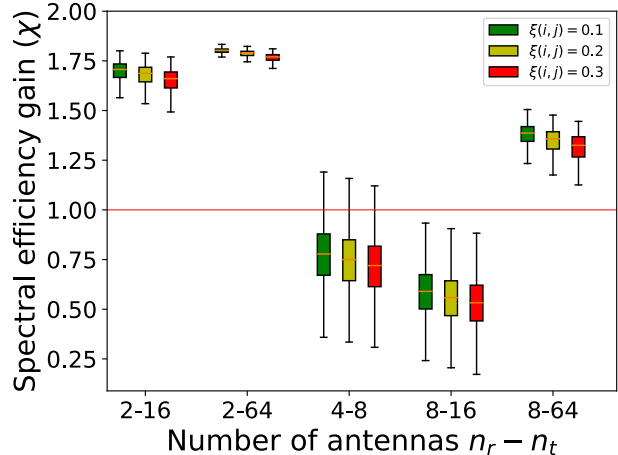


Fig. 2: Spectral efficiency gain of MU-MIMO over SU-MIMO

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 have more narrow beams, resulting in a lower average correlation. With $n_r = 8 \& n_t = 64$ there is a larger number of low correlation than with $n_r = 2 \& n_t = 16$.

V. 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. For each sample, we calculate the throughput gain from the MU-MIMO allocation, that is given by 15.

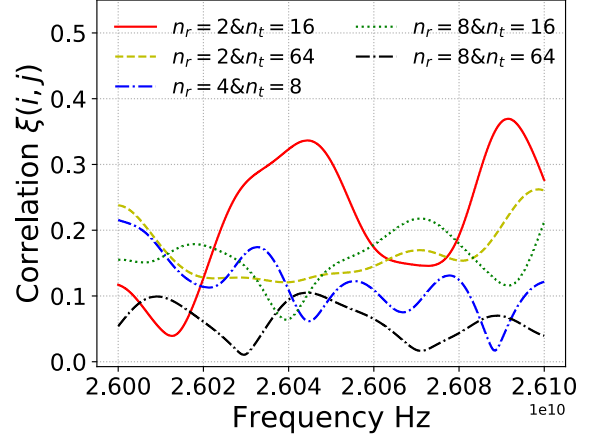
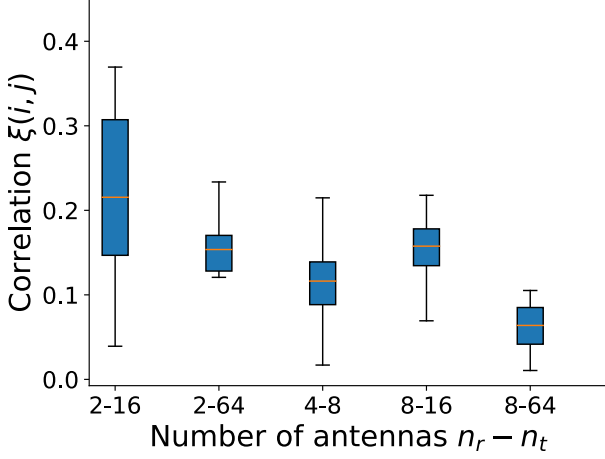


Fig. 3: Correlation over 100 MHz bandwidth at 26GHz

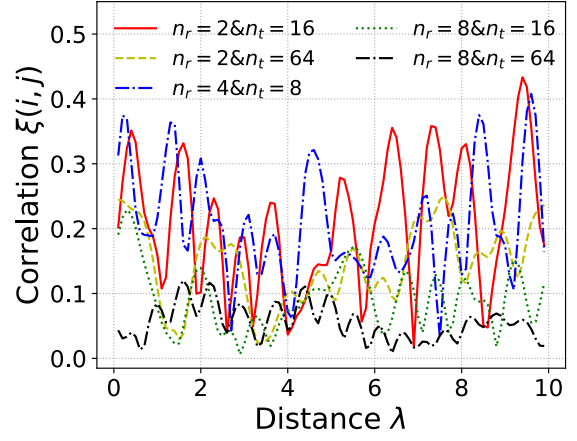
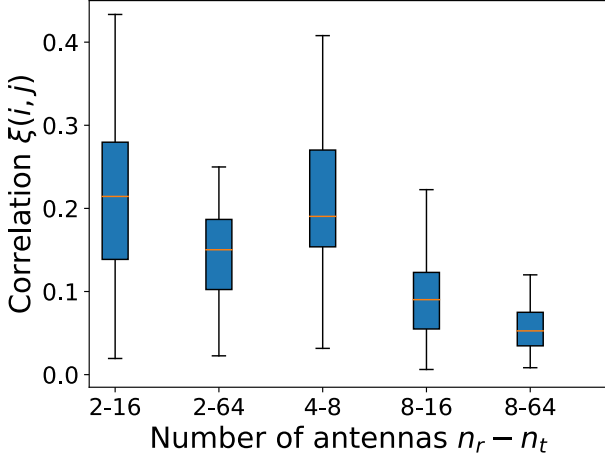


Fig. 4: Correlation over 10λ

Figure 2 shows χ values, computed in (15), for different antenna configurations. Each antenna configuration is represented tree boxes with 0.1, 0.2 and 0.3 correlations. Concerning the throughput gain, for example, with $n_r = 2 \& n_t = 16$, between 0.1 and 0.3 correlations, less than 3% of capacity is lost on average. 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 $n_r = 2 \& n_t = 16$ 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 $\frac{n_r}{n_t}$ 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.

VI. MOBILITY IMPACT ON THE CORRELATION BETWEEN UES

In order to be able to use the correlation as an indicator, the correlation should be stable in frequency and in time when users are moving. The more variable the channel, the more frequent the correlation should be updated. There is thus a feasibility issue: requiring more Channel State Information feedbacks and more CPU resources. As seen in the simulation setup, we are considering two users with independent channel

matrices. The results are computed on one snapshot in each configuration. One user is static during the simulation, while the other user is moving and its channel adjusts accordingly. The purpose of this experiment is to determine if the correlation is stable enough to be calculated as often as possible for two UEs during a period of time and over a given bandwidth.

Figure 3 shows the correlation evolution between two users depending on the frequency. Over 100 MHz bandwidth, the correlation significantly varies in amplitude but slowly in time. This shows that the variation of phase offset is not negligible over a large bandwidth. However, the rate variation is slow enough and only a few correlation calculations are needed by timeslot. Another variable factor is the displacement over time. Figure 4 shows the correlation evolution when a user moves from its original position. Distance is represented in λ , which is the wavelength, and 10λ at 26 GHz is travelled in roughly 84 ms. We can observe a high variability of the correlation with the distance changes, with a similar amplitude gap compares to figure 3. When the variation in frequency and distance are combined, the correlation stability might not be sufficient for an accurate calculation between scheduling decisions.

VII. 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, the relation between correlation and throughput and the mobility impact on the correlation 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 probability of high correlation values and diversity. The ratio between the number of receive and transmit antennas determines the variability of the throughput gain. A large number of transmitting antennas compared to number of receiver antennas makes the throughput gain more predictable. Finally, the correlation variability quickly changes over frequency and time, when a user is mobile. There is a substantial number of correlation calculations needed over time. As a summary, a user selection process, using Block Diagonal precoding, can barely benefit from a correlation indicator in different configurations, due to high variability with minimum effect on the throughput. MU-MIMO allows more than two users sharing the same resource block. In future works, we will study how a higher number of simultaneously scheduled users impacts the correlation and the corresponding throughput.

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