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Performances of Massive MIMO Uplink Pilot Decontamination Based On SPR Combined With WGC-PA

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Abstract:
Background:
Massive MIMO technology is a wireless, multi-user communication technology. It has generated enormous research interest in recent years.
Materials and Methods: This article is dedicated to the study of uplink pilot decontamination in Massive MIMO system. Pilot contamination occurs during the transmission phase of training sequences to Base Stations. The reuse of same sequence of drivers from a given cell in adjacent cells is the source of this problem. It generates errors in the channel estimation and reduces the performance of the system. In this study, the combination of SPR and WGC-PA is proposed as a method for pilot decontamination. An algorithm is proposed to allocate the pilots to the users of the edge and also to those of the center.
Results: The results demonstrate the performance of this method compared to methods in a Massive MIMO system where the number of antennas is very high and also in case the uplink transmission power is high.
Conclusion: The proposed algorithm offers better performance especially in the uplink of the Massive MIMO system. We demonstrated in this article these results at the level of performance especially in the case of the spectral efficiency
.**Key Word**: SPR, WGC-PA, MIMO, Decontamination, Pilot.

I. INTRODUCTION

In an effort to meet the escalating demand for increasingly higher-capacity and improved-reliability wireless systems, the massive multiple-input multiple-output (MIMO) concept has been proposed, where typically each base station (BS) is equipped with a large number of antenna elements (AEs) to serve a much smaller number of single-AE users. This way each user may have access to several AEs. This large-scale MIMO technology offers several significant advantages in comparison to the conventional MIMO concept having a moderate number of AEs. Firstly, asymptotic analysis based on random matrix theory demonstrates that both the intra-cell interference and the uncorrelated noise effects can be efficiently mitigated, as the number of AEs tends to infinity. Furthermore, the energy consumption of cellular BSs can be substantially reduced and the Massive MIMO systems are robust, since the failure of one or a few of the AEs and radio frequency (RF) chains would not appreciably affect the resultant system performance. Additionally, low complexity signal-processing relying on matched-filter (MF) based transmit precoding (TPC) and detection can be used to for approaching the optimal performance, when the number of AEs at the BS tends to infinity.

Although Massive MIMO technology removes many traditional research problems, there are still challenges to realize the full potential of the technology, such as computational complexity, realization of distributed processing algorithms, problem of inter and intracellular interference and also pilot contamination.

Pilot contamination is the result of the reuse of pilot sequences from a given cell in adjacent cells. The limitation in number of pilots which must be respected to avoid exceeding the coherence interval, obliges us to reuse its sequences in the adjacent cells.
In this article, some studies will be done to seek solutions to Pilot contamination.

II. MATERIAL AND METHODS

Massive MIMO uplink pilot decontamination:

1. System model

Let us consider as a model, a system composed of L cells each containing a Base Station (BS). Each BS is assigned M antennas and K users randomly positioned in each cell, with K<< M. Then, we take as S the total number of pilot Ø available in each cell.

The pilots are orthogonal to each other in one cell but the same Ø pilot group is also used in other cells because the number of pilots used is limited. Different pilots are randomly assigned to different users for a given cell.

In this model of the system, h_{ijk} is the channel matrix between the kth user in the jth cell and the base station in the ith cell:

$$h_{ijk} = g_{ijk}\sqrt{\beta_{ijk}} \tag{1}$$

Where

- β_{ijk} represents the large-scale fading coefficient due to path loss and maskingeffect;
- $\beta_{ijk} = \frac{z_{ijk}}{\left({r_{ijk}}/{R}\right)^{\alpha}}$ where z_{ijk} represents the mask effect ; r_{ijk} the distance between user k in the jth cell and the base station in the ith cell; R the radius of the cell ; α exponent for path loss.
- g_{ijk} represents the small-scale fading vector.

In uplink, at the beginning of the coherence interval, all users in each cell send pilot symbols at the same time. The Base Stations in turn perform the corresponding channel estimation for these users.

The signal received at the base station can be written as :

$$Y_i^u = \sqrt{\rho_u}\sum_{j=1}^{L}\sum_{k=1}^{K} h_{ijk}\Psi_k + N_i^u \tag{2}$$

With

ρ_u: power transmission of the pilot.

N_i^u: white Gaussian noise.

Ψ_k^T : symbols transmitted from the kth user .

By separating the signal from users in the same cell as the BS and the signal fromother users in adjacent cells, Y_i^u becomes :

$$Y_i^u = \sqrt{\rho_u}\sum_{k=1}^{K} h_{iik}\Psi_k + \sqrt{\rho_u}\sum_{l=1,l\neq i}^{L}\sum_{k=1}^{K} h_{ijk}\Psi_k + N_i^u \tag{3}$$

The part of the equation :

$$\sqrt{\rho_u}\sum_{l=1,l\neq i}^{L}\sum_{k=1}^{K} h_{ijk}\Psi_k$$

represents the transmitted pilots from users in adjacent cells, while using the samepilot group. Hence the pilot contamination.

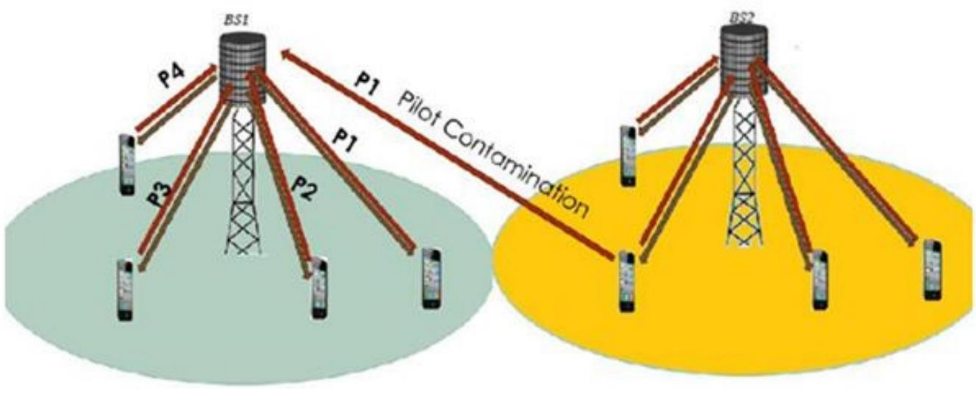

Figure no1 : Pilot contamination

2. Pilot decontamination

Pilot contamination greatly reduces system performance and generates inter-cellinterference. Furthermore, pilot decontamination is the study of techniques to reduce or mitigate pilot contamination in massive MIMO systems. There is a lot of research into how to eliminate pilot contamination.

In this study, the FM receiver is used and the SINR (Signal to Interference plus Noise Ratio) to measure the performance of the pilot decontamination methods is obtained by the relation (4)

$$SINR_{ik}^{u} = \frac{|h_{iik}^{H} h_{iik}|^2}{\sum_{j\neq i}|h_{ijk}^{H} h_{ijk}|^2 + \frac{|\varepsilon_{ik}^{u}|^2}{\rho_u}} \quad (4)$$

With ε_{ik}^{u} intra-cell interference and noise.

Then the spectral efficiency obtained in the uplink is given by :

$$ES^{u} = (1 - u_s)E\{log_2(1 + SINR_{ik}^{u})\} \quad (5)$$

With $u_s = \left(\frac{S}{K}\right)u_0$ where u_0 : $0 \leq u_0 \leq 1$

3. Pilot Decontamination methods with SPR and WGC-PA

In order to make pilot decontamination more concrete, the study focuses on two pilot allocation methods: SPR (Soft Pilot Reuse) and WGC-PA (Weighted Graph Coloration-Pilot Assignment).

SPR relies on dividing cell users into 2 groups while WGC-PA uses graph theory to overcome the problem of pilot contamination.

4. SPR or Soft Pilot Reuse

In a given cell, users closer to the BS are less affected by pilot contamination than users atthe edge of the cell. With SPR, it is suggested to divide the K users of the ith cell into two groups: users at the center and users at the edge, according to the following threshold

$$\rho_i = \frac{\lambda}{K}\sum_{k=1}^{K}\beta_{iik}^{2} \quad (6)$$

With λ an adjustable parameter depending on the system.

If $\beta^2 > \rho_I$ then the user is at the centre.

If $\beta^2 < \rho_I$ then the user is at the edge.

Then all users at the edge of all cells must be assigned to orthogonal pilots. The group of pilots assigned to the users in the centre of a cell i must be reassigned to the central users inall adjacent cells.

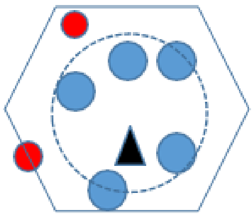

Figure no2 : Principle of SPR

5. WGC-PA or Weighted Graph Coloration Pilot Assignment

With the WGC-PA method, the following two steps should be taken to reduce pilotcontamination: The construction of the Edge-Weighted Interference Graph (EWIG) whichdetermines the interference that may exist between users.

Once the EWIG is established, pilots are assigned using the WGC-PA algorithm

- Construction of the EWIG

The EWIG is a graph that is constructed to detect the strength of pilot contamination between users. It is a weighted undirected graph G=(V,E) where V is the set of users:

V = $\{\langle j,k\rangle : 1 \leq j \leq L, 1 \leq k \leq K\}$ and the edges represent the potential pilot contamination between users: $E_{\varsigma_{\langle j,k\rangle,\langle j',k'\rangle}} = \{\varsigma_{\langle j,k\rangle,\langle j',k'\rangle} : j \neq j'\}$ With :

$$\varsigma_{\langle j,k\rangle,\langle j',k'\rangle} = \frac{\beta_{\langle j',k'\rangle,j}^{2}}{\beta_{\langle j,k\rangle,j}^{2}} + \frac{\beta_{\langle j,k\rangle,j'}^{2}}{\beta_{\langle j',k'\rangle,j'}^{2}}$$

is used to measure the strength of potential pilot contamination between 2 users.

- j and j′ are cells : $1 \leq j \leq L, 1 \leq j' \leq L$ where L is the number of cells inthe system
- k is the user: $1 \leq k \leq K$ with K the number of users in a cell.
- $\beta^2_{\langle j',k'\rangle,j}$ indicates user-induced pilot contamination k' in the cell j′ to the base station of cell j.
- $\beta^2_{\langle j,k\rangle,j'}$ indicates the pilot contamination caused by user k in cell j at the cell's base station j'

If $\varsigma_{\langle \mathbf{j},\rangle,\langle \mathbf{j}^F,k^F\rangle}$ is very large, this implies that pilot contamination between users is very severe when they are assigned the same pilot.

In the case where $\varsigma_{\langle j,k\rangle,\langle j',k'\rangle}$ is a small value, the pilot contamination is low even if both users are using the same pilot.

- The WGC-PA scheme

The WGC-PA is based on the classical Dsatur or DSAT (degree saturation) algorithm. It is a graph coloring algorithm created by Daniel Brélaz. It is a heuristic sequential coloring algorithm.

In a non-oriented graph G= (G, E), Dsatur sorts the vertices according to their degrees indescending order and colors them sequentially with reused colors as much as possible.

With WGC-PA, different pilots are assigned to connected users with a high weight in the EWIG graph.

Here are the points to follow in WGC-PA:

- First, two users in different cells with the $\varsigma_{\langle j,k\rangle,\langle j',k'\rangle}$ highest in EWIG are selected and assigned pilots $p_{\langle j_1,k_1\rangle} = 1, p_{\langle j_2,k_2\rangle} = 2$. Then we add the two users $\langle j_1, k_1\rangle$, $\langle j_2, k_2\rangle$ to the set $\Omega = \{\langle j,k\rangle: 1 \leq j \leq L, 1 \leq k \leq K \; et \; pj,k \neq 0$
- we introduced $\delta_{\langle \mathbf{j},k\rangle}$ the sum of $\varsigma_{\langle \mathbf{j},k\rangle,\langle \mathbf{j}^F,k^F\rangle}$ linking user < j,k> and users in other cells in Ω. Then we choose the user $\langle j_0, k_0\rangle$ whose value of $\varsigma_{\langle \mathbf{j},k\rangle,\langle \mathbf{j}^F,k^F\rangle}$ is maximum.
- Subsequently, the set of unused pilots in the j_0 cell to ensure that no pilots are reused in the same cell. 5G describes the strength of pilot contamination between users with pilot s in Ω and $\langle j_0, k_0\rangle$ assuming that $\langle j_0, k_0\rangle$ is assigned pilot s. Finally, the pilot causing the smallest pilot contamination is selected 5_s is selected and assigned to the user $\langle j_0, k_0\rangle$ which is then added to Ω.
- As long as there are users who have not been affected by pilots, the loop will be repeated sequentially.

5. SPR and WGC-PA Combination Algorithm

With the SPR scheme, the orthogonality of the pilots assigned to users at the edge of the cells is guaranteed. On the other hand, it is known that for users at the centre of the cells, the pilots assigned there are also reused by other central users in other adjacent cells. This reducesthe performance of the system. The combination of the two methods, i.e. SPR and WGC-PA, will greatly reduce pilot contamination. This is the combination algorithm:

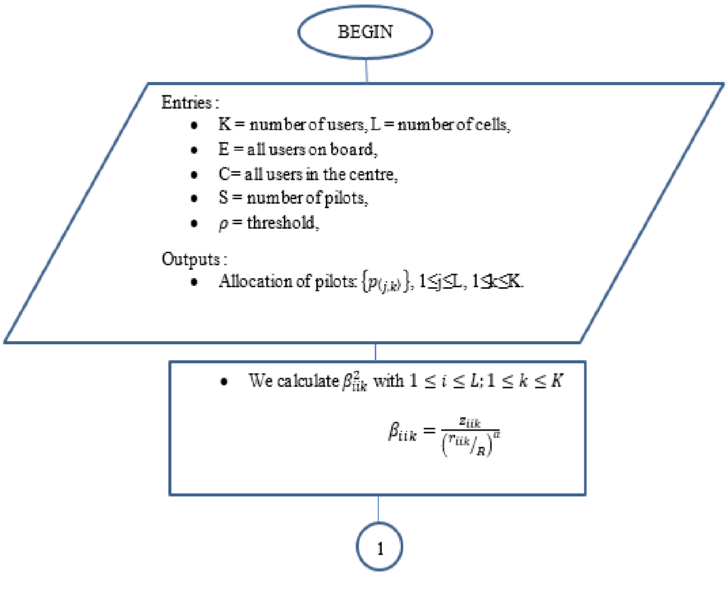

Figure no3 : Algorithm 1

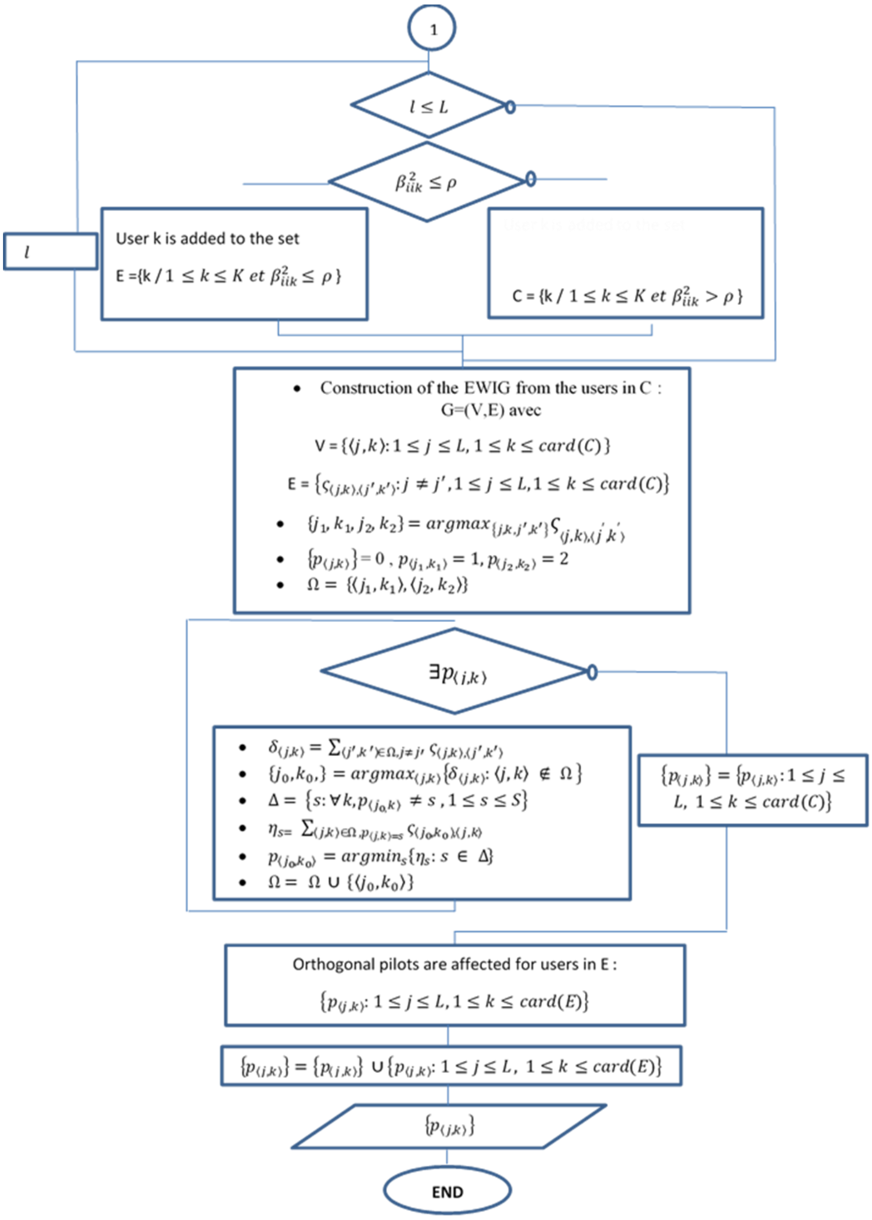

Figure no4 : Algorithm 2

III. RESULT AND DISCUSSION

In this article, the results obtained represent the spectral efficiency as a function ofthe influential parameters of each of the following methods:

- 1ère method: the classic random allocation of pilots to users in each cell of thesystem.
- 2ème method: the allocation of user pilots is based on the principle that the pilots of on-board users are orthogonal while central users use the same pilot group in all cells.
- 3ème method: the allocation of pilots is carried out by calculating the value of the interference between the users and then establishing the EWIG interference graph. With this graph, the WGC-PA pilot allocation algorithm is applied.
- 4ème method: The last method combines the 2 methods mentioned above: SPR + WGC-PA.

The simulation parameters are as follows:

Table no1: Simulation parameters

Parameter	**Value**
Number of users K	10 20
Number of cells L	15 20 30
Number of pilots	K≤S≤KL / 15 if fixed

μ_0	0,05
Number of antennas on each BS M	10≤M≤2048 / 512 if fixed
Threshold ρ_i	0.1
Transmitter power ρ_u	5dB≤ρ_u≤30dB / 15dB if fixed
Shadow Fading	8dB

In the first results, shown in Figures 5 and 6, the number of cells is set to the following values: L=15, L=20, L=30, the number of users is set to 10 and the transmit power is also set to 15dB. Then 10≤M≤2048.

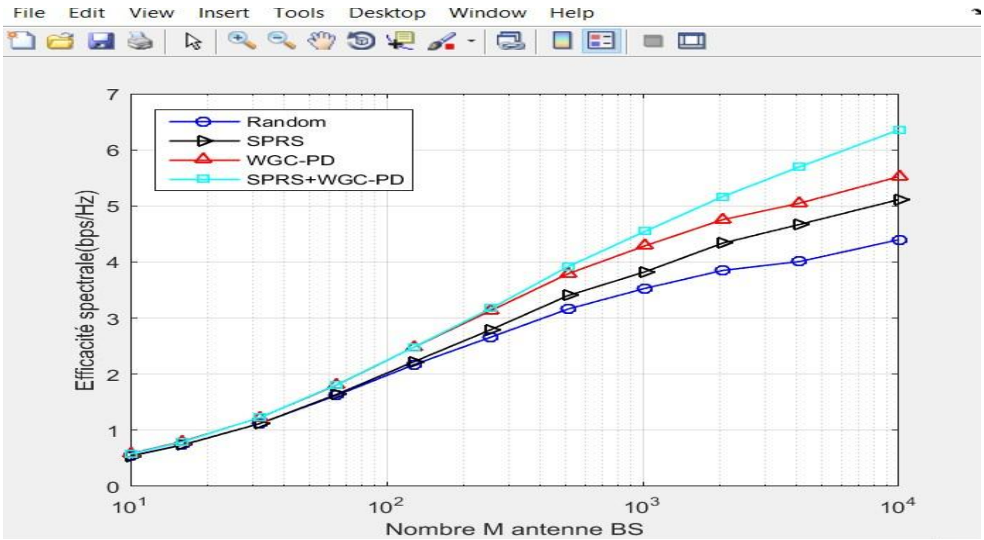

Figure no5 : Spectral efficiency /M with L=15, K=10 , ρ = 15dB

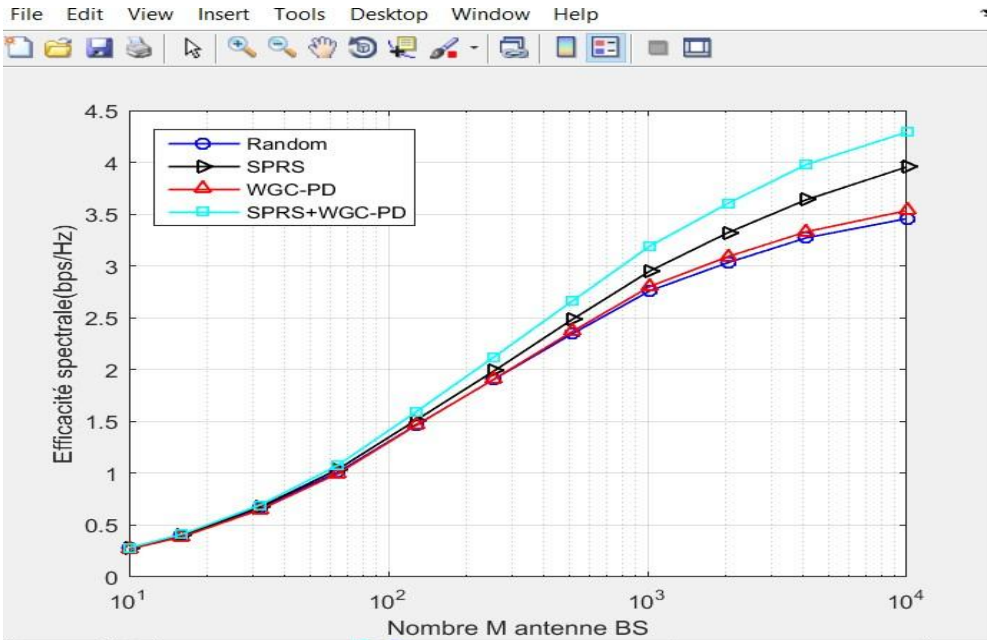

Figure no6 : Spectral efficiency / M with L=30, K=10 , = 15dB

The following tables compare the spectral efficiency values obtained for each pilot allocation method with respect to the number of antennas M. The numbers of M taken from the table are 64,512,1024 and 2048 :

Table no2: result for L=15, K=10, rho=15db

L=15	Method	Random	SPR	WGC-PA	SPR+WGC-PA
K=10	64	1.6451	1.6598	1.8331	1.8228
rho=15db	512	3.0861	3.3219	3.7294	3.8371
	1024	3.5158	3.8903	4.3068	4.5628
	2048	3.8237	4.3062	4.7321	5.1782

Table no3: result for L=20, K=10, rho=15db

L=20	Method	Random	SPR	WGC-PA	SPR+WGC-PA
K=10	64	1.4730	1.5068	1.6525	1.6834
rho=15db	512	2.8265	3.0966	3.4263	3.6399
	1024	3.2074	3.5699	3.9824	4.2895
	2048	3.4641	3.9750	4.3356	4.8543

Table no4: result for L=30, K=10, rho=15db

L=30	Method	Random	SPR	WGC-PA	SPR+WGC-PA
K=10	64	0.8075	0.8559	0.8893	0.9340
rho=15db	512	1.6262	1.8117	1.8949	2.1020
	1024	1.8336	2.1294	2.1718	2.4808
	2048	1.9946	2.3632	2.3825	2.8074

According to these tables :
- If M increases, the spectral efficiency values also increase for all methods.However, as the number L increases, the values decrease.

- For the SPR + WGC-PA method for example:

Table no5: result SPR+WGC-PA by modifying M and L

M/L	L=15	L=20	L=30
64	1.8228	1.6834	0.9340
512	3.8371	3.6399	2.1020
1024	4.5628	4.2895	2.4808
2048	5.1782	4.8543	2.8074

For L=15 : The ES value increases from 1.8228 bps/Hz for M=64to 5.1782 bps/Hz for M=2048;
For L= 20 : The ES value increases from 1.6834 bps/Hz for M=64 to 4.8543 bps/Hz for M=2048;
For L=30 : The ES value increases from 0.9340 bps/Hz for M=64 to 2.8074 bps/Hz for M=2048;
Similarly for the other three methods, for L=15, L=20, L=30 the value of the Spectral efficiency increases when the number of antennas is increased from M=64 to M=2048.
- Here is the comparison, in terms of spectral efficiency, of the SPR+WGC-PA method with the other three methods.

Table no6: Comparaison spectral efficiency between SPR+WGC-PA and Classical Random

Classical Random	SPR+WGC-PA	Difference D
1,6451	1,8228	*0,1777*
3,0861	3,8371	*0,7510*
3,5158	4,5628	*1,0470*
3,8237	5,1782	*1,3545*

Table no7: Comparaison spectral efficiency between SPR+WGC-PA and SPR

SPR	SPR+WGC-PA	Difference D
1,5068	**1,6834**	***0,1766***
3,0966	**3,6399**	***0,5433***
3,5699	**4,2895**	***0,7196***
3,975	**4,8543**	***0,8793***

The third column entitled "Difference D" represents the difference between the Spectral efficiency value if SPR + WGC-PA is used and the SE value of the other methods. The resulting values are all positive: D>0. This implies that SPR + WGC-PA performsbetter than the other three methods.

Table no8: Comparaison spectral efficiency between SPR+WGC-PA and WGC-PA

WGC-PA	SPR+WGC-PA	Difference D
0,8893	**0,9340**	***0,0447***
1,8949	**2,102**	***0,2071***
2,1718	**2,4808**	***0,3090***
2,3825	**2,8074**	***0,4249***

- For M < 512, the ES curve merges with the other curves with a slight positive difference. But when the number of antennas M is equal to 512, the curve representing the SPR+WGC-PA method starts to deviate from the other curves andwhen M tends to 10000 the value of the corresponding SE keeps increasing.
In the second results, the number of cells always takes the following values: L=15, L=20, L=30, the number of users is set to 10 and M is set to 512. Then the transmission power 5dB≤ρ_u≤20dB.

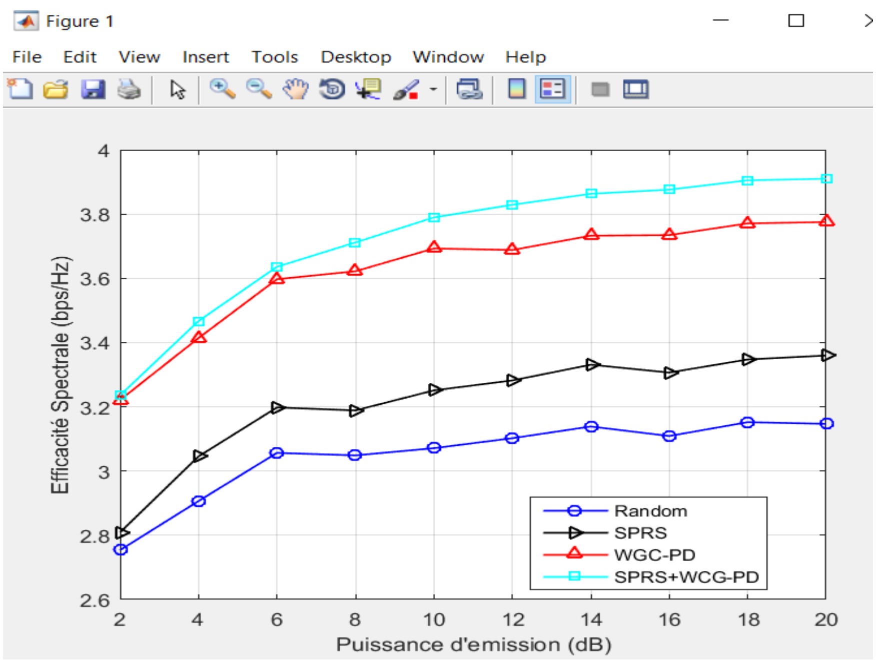

Figure no7 : Spectral efficiency/emission power with M= 512 , L= 15

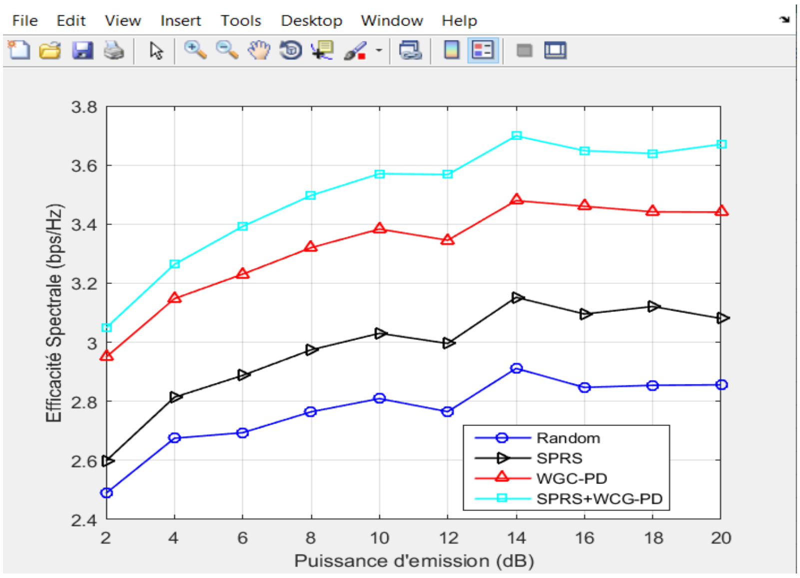

Figure no8 : Spectral efficiency/emission power with M= 512 , L= 15

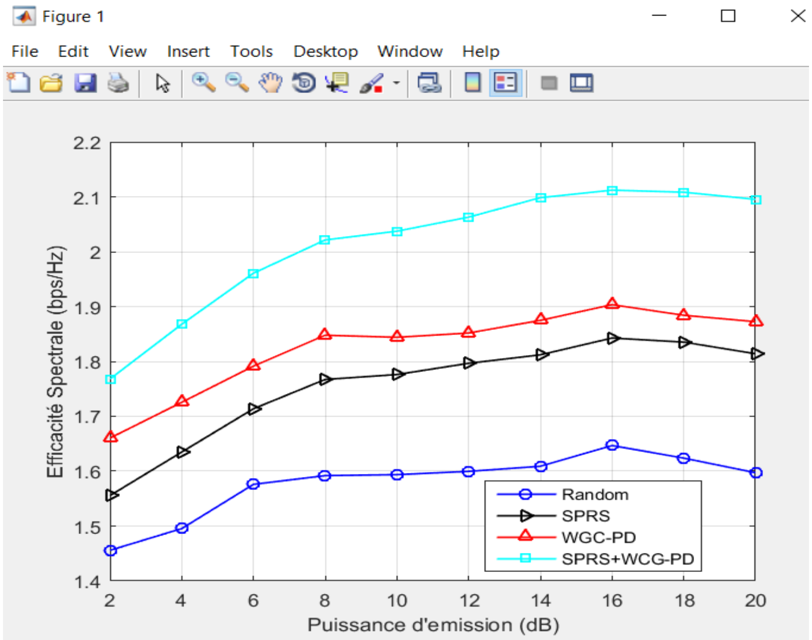

Figure no9 : Spectral efficiency/emission power with M= 512 , L= 30

Here are the comparative tables for each result:

Table no9: Comparaison spectral efficiency M=512 and L=15

M=512	Rho/Method	Random	SPR	WGC-PA	SPR+WGC-PA
L=15	6	2.8694	3.0296	3.4080	3.5112
	8	2.9603	3.1598	3.5545	3.6581
	10	3.0030	3.2023	3.6152	3.7279
	12	3.0094	3.2515	3.6566	3.7927
	16	3.0374	3.2739	3.6899	3.8292

Table no10: Comparaison spectral efficiency M=512 and L=20

M=512	Rho/Method	Random	SPR	WGC-PA	SPR+WGC-PA
L=20	6	2.7211	2.8967	3.2449	3.4005
	8	2.7709	2.9721	3.3348	3.4993

	10	**2.7780**	**2.9684**	**3.3377**	**3.5378**
	12	**2.7972**	**3.0691**	**3.3867**	**3.5958**
	16	**2.8311**	**3.0953**	**3.4291**	**3.6626**

Table no11: Comparaison spectral efficiency M=512 and L=30

M=512	**Rho/Method**	**Random**	**SPR**	**WGC-PA**	**SPR+WGC-PA**
L=30	**6**	**1.5760**	**1.7137**	**1.7914**	**1.9607**
	8	**1.5919**	**1.7671**	**1.8477**	**2.0213**
	10	**1.5937**	**1.7761**	**1.8440**	**2.0373**
	12	**1.5996**	**1.7966**	**1.8518**	**2.0629**
	16	**1.6467**	**1.8426**	**1.9034**	**2.1121**

According to these curves and tables :

- If the transmit power increases, the spectral efficiency also increases for all four pilot allocation methods. However, increasing the number of cells decreases the system performance. For SPR+WGC-PA :

Table no12: emission power/L

emission power/L	**L=15**	**L=20**	**L=30**
6	**3.5112**	**3.4005**	**1.9607**
8	**3.6581**	**3.4993**	**2.0213**
10	**3.7279**	**3.5378**	**2.0373**
12	**3.7927**	**3.5958**	**2.0629**
16	**3.8292**	**3.6626**	**2.1121**

- The SPR + WGC-PA combination is more effective in reducing pilot contamination than the other methods. Taking L=15, here is a table demonstrating this effectiveness:

Table no13: method of power emission

MethodEmission power	**6**	**8**	**10**	**12**	**16**
Random	**2.8694**	**2.9603**	**3.0030**	**3.0094**	**3.0374**
SPR	**3.0296**	**3.1598**	**3.2023**	**3.2515**	**3.2739**
WGC-PA	**3.4080**	**3.5545**	**3.6152**	**3.6566**	**3.6899**
SPR+WGC-PA	**3.5112**	**3.6581**	**3.7279**	**3.7927**	**3.8292**

IV. CONCLUSION

The proposed algorithm offers better performance especially in the uplink of the Massive MIMO system. We demonstrated in the article these results at the level of performance especially in the case of the spectral efficiency.

This article allowed to compare the efficiency of different driver allocation methods in a Massive MIMO system. By increasing the number of antenna M, the combination of the WGC-PA method with the SPR method gives the system more performance compared to other methods. Similarly, when the transmission power ρ is increased, this combination is always more efficient compared to the other methods. Increasing the number of cells from L=15 to L=30 decreases the performance of each method. In this study, the best solution for uplink driver decontamination in Massive MIMO is then the proposal to combine the SPR and WGC-PA method.

REFERENCES

[1]. T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," *IEEE Trans. Wirel. Commun.*, vol. 9, no. 11, pp. 3590–3600, Nov. 2010.

[2]. F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson, "Scaling up MIMO: Opportunities and challenges with very large arrays," *IEEE Signal Process. Mag.*, vol. 30, no. 1, pp. 40–60, Jan 2013.

[3]. L. Lu, G. Y. Li, A. L. Swindlehurst, A. Ashikhmin, and R. Zhang, "An overview of massive MIMO: Benefits and challenges," *IEEE J. Sel. Top. Signal Process.*, vol. 8, no. 5, pp. 742–758, Oct. 2014.
[4]. H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," IEEE Trans. Commun., vol. 61, pp. 1436–1449, Apr. 2013.

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