Mitigating the pilot contamination for uplink massive MIMO systems

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Abstract:

Multi-cell Massive MIMO System utilizes a large number of antennas in a base station that serves a group of users at the same time, suffers from pilot contamination(PC) due to the reuse of pilots in adjacent cells that isn't able to avoid. In this paper, mitigating the pilot contamination based on soft pilot reuse scheme and weighted graph coloring scheme. All users in a cell are foremost divided into cell-center users and cell-edged users. By choosing the best pilots we tend to propose a suboptimal allocation algorithm by exploitation with optimum conditions and weighted graph color methodology is applied. Simulation results show that the proposed scheme alleviating the pilot contamination significantly compared with existing schemes.

Keywords: Pilot contamination, Massive MIMO, Soft pilot reuse, weighted graph coloring

1. INTRODUCTION:

Massive Multiple Input Multiple Output (MIMO) is an extension of MIMO. In Massive MIMO, a massive number of antenna groups together at the transmitter and receiver to maintain better throughput and spectral efficiency. The future generation of wireless data network meets the development of capacity and reliability, investigate the massive MIMO system that is badly suffering from the pilot contamination problem because of reusing the limited pilots in adjacent cells.

Much effort had been made to solve this challenging pilot contamination problem. The condition of pilot contamination and channel estimation (CE) performance in a massive MIMO system are analyzed[2,3]. The time-shifted pilot scheme was good resolution exploitation with asynchronous transmission among adjacent cells however it creates mutual interferences between pilot and data[1]. A data-aided minimum mean square error (MMSE) estimator and practical channel estimator addresses the performance under serious pilot contamination (PC) without previous knowledge[5,6]. These techniques haven't contemplated the pilot reuse scheme. A modified pilot reuse scheme to alleviate PC is necessary why because CE requires pilot resources but those resources are limited which are reused in multi-cell situations this leads to PC. Pilot sequences employed by every user ought to be orthogonal and assigned to single-cell and neighbor cell[4]. Pilot allocation schemes are proposed which are based on coloring graph and weighted coloring graph[7,8]. These methods are reducing the PC and also improve the uplink rate. Soft Pilot Reuse Scheme (SPRS) is proposed which separates the users into cell-centered users and cell edged users. The cell-centered users (having slight PC) using the same pilot resources and cell edged users (having serious PC) using cell-edge pilot subgroups in adjacent cells[9].

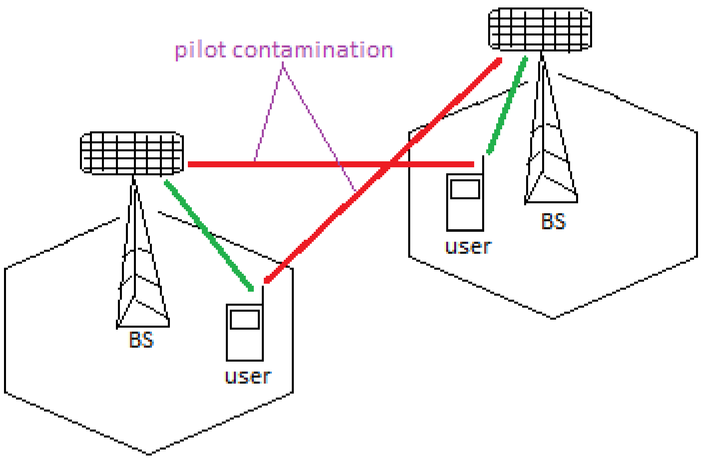

Fig.1. Pilot contamination problem

In this paper, to mitigate pilot contamination SPRS and Weighted-Graph-Coloring-Based Pilot Decontamination (WGC-PD) are proposed. Cells and users are divided by using SPRS, for pilot decontamination use a sub-optimal algorithm which is used to select the best pilots and given to the WGC-PD scheme to get better performance in uplink massive MIMO.

2. Experimental and Computational Details:

2.1. System model:

Consider an uplink massive MIMO system, which includes J cells. Each cell contains a base station which has M antennas and K (K<<M) single-antenna users. The kth user in the jth cell to the BS of the ith cell can be connected by channel impulse response vector are often written as

$$h_{i,j,k} = b_{i,j,k}\sqrt{\beta_{i,j,k}} \qquad (1)$$

Where $\beta_{i,j,k}$ represents the coefficient vector of small scale fading and $b_{i,j,k}$ with distribution $CN(0, I_M)$ represents the large scale fading vector.

Hence, the available S (S≥K) pilots' matrix is Φ=$[\varphi_1, \varphi_2, \dots \dots \dots, \varphi_O] \in \mathbf{C}^{S\times l}$, l is the length used in one cell which is orthogonal to each other so that $\Phi\Phi^H$=I.

In communication, the uplink system can be written as

$$X_i^p = \sqrt{\gamma_p}\sum_{j=1}^{J} H_{i,j}\Phi + N \qquad (2)$$

Where X_i^p represents the signal of pilot sequences received at the ith base station (BS), $H_{i,j}$ represents the channel matrix collected from (1), N is the noise matrix, and γ_p represents the transmission power. The uplink signal-to-interference-plus-noise ratio (SINR) of a user $\langle j, k\rangle$ after pilot assignment can be formulated as

$$SINR = \frac{\left\|h^H_{\langle j,k\rangle,j}\right\|^4}{\sum_{\langle j\prime,k\prime\rangle\in\Gamma\langle j,k\rangle}\left\|h^H_{\langle j,k\rangle,j}\right\|^4 + \frac{\rho^2_{\langle j,k\rangle}}{\gamma^2}}$$

$$\approx \frac{\beta^2_{\langle j,k\rangle,j}}{\sum_{\langle j\prime,k\prime\rangle\in\Gamma\langle j,k\rangle}\beta^2_{\langle j\prime,k\prime\rangle,j}} \qquad (3)$$

Where $\langle j', k' \rangle \in \Gamma'_{\langle j,k \rangle}$denotes the different cell users using the same pilot as $\langle j, k \rangle$, $\rho^2_{\langle j,k \rangle}$ represents the uncorrelated interference and noise, and $\sum_{\langle j\prime,k\prime \rangle \in \Gamma \langle j,k \rangle} \beta^2_{\langle j\prime,k\prime \rangle,j}$is the pilot contamination. Uplink user $\langle j, k \rangle$ average achievable rate R can be calculated as

$$R = (1 - m_0)E\{\log2 (1 + \text{SINR})\} \qquad (4)$$

Where m_0 is the fraction of spectral efficiency loss allocated to channel estimation and our mission is to maximize the total communication rate R.

So, the optimization problem P1 is:

$$\max_{p_{\langle j,k \rangle}} \{\textstyle\sum_{\langle j,k \rangle} \log_2(1 + SINR)\} \qquad (5)$$

$$\max_{p_{\langle j,k \rangle}} \left\{\textstyle\sum_{\langle j,k \rangle} \log_2 \left(1 + \frac{\beta^2_{\langle j,k \rangle,j}}{\sum_{\langle j\prime,k\prime \rangle \in \Gamma \langle j,k \rangle} \beta^2_{\langle j\prime,k\prime \rangle,j}}\right)\right\} \qquad (6)$$

Thus, P_1 can be approached by P_2, i.e.,

The exhaustive search method of P2 is as follows: the number of different kinds of pilot allocations in the jth cell for K users and S pilots is $P_S^k = \frac{S!}{(S-K)!}$, but considering all the cells, the assignment can be as huge as $(P_S^K)^{J-1}$, which is infeasible in reality. So, an optimized scheme is desired.

2.2. The proposed scheme:

The K_i users in the ith cell are divided into cell-centered users and cell-edged users by using the coefficient $\beta_{i,j,k}$, which is

$$\beta^2_{i,j,k} > \sigma_i \rightarrow \begin{cases} Yes \rightarrow center\ users \\ NO \rightarrow edge\ users \end{cases} \qquad (7)$$

and threshold value σ_i can be formulated as

$$\sigma_i = \frac{\theta}{K} \sum_{k=1}^{K} \beta^2_{i,j,k} \qquad (8)$$

where θ is adjustable according to configuration.

$$K_i = K_{i,c} + K_{i,e} \qquad (9)$$

In the ith cell $K_{i,e}$ and $K_{i,c}$ are the cell edged users and cell-centered users.

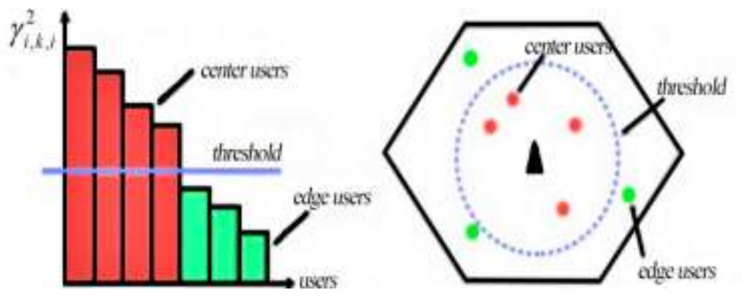

Fig.2. An illustration of the users' division

Define $K_{cu} = max\{K_{i,c}, i = 1,2, \ldots, J\}$ and $K_{eu} = \sum_{i=1}^{J} K_{i,e}$. The total number of the required orthogonal pilot sequences in the proposed scheme is

$$K_{all} = K_{cu} + K_{eu} \quad (10)$$

Then the available Φ can be assigned as

$$\Phi_{all} = [\Phi_{cu}^T \Phi_{eu}^T]^T \quad (11)$$

in which $\Phi_{cu} \in \mathbb{C}^{K_{cu}\times l}$ is the pilots for cell-centered users and $\Phi_{eu} \in \mathbb{C}^{K_{eu}\times l}$ is the pilots for cell edged ones. In addition, the matrix Φ_{eu} can be separated into J row partitions, corresponding to the $K_{i,e}$cell edged users. Thus, the orthogonality of the pilots of all the cell edged users is guaranteed, in order that the quality of the communication service for them is often improved significantly.

So, since the pilot sequences in the single-cell are orthogonal to each other and therefore no PC exists, and the cell edged users are free from very severe PC due to SPRS, the achievable decontamination mainly comes from eliminating the interference among different cell-centered users reusing the same pilot resource. For selecting the best pilots choose a sub-optimal algorithm. A Sub-optimal algorithm is used to select the pilots before assigning them to users.

Looking more broadly, the suboptimal search algorithm has two tasks. The first is finding a solution, and the second is proving that the solution is within the sub-optimality bound.

Improved Optimistic Search is developed that's both simpler than existing algorithms and also has better performance.

$$R_{k,n} = B \times \log_2\left(1 + \frac{(p_n \times CGNR(k,n))}{\Gamma}\right) \quad (12)$$

where $R_{k,n}$ is the data rate of user k for pilot n, p_n is the power for pilot n, Γ is the SNR gap and CGNR is the channel gain to noise ratio.

The existing resource allocation algorithms have high computational complexity. Considering this, in this section, we have proposed a low complexity algorithm. The proposed algorithm is described in Algorithm 1.

Proposed suboptimal algorithm:

1. for k=0 to K-1 do
2. $r_k \leftarrow 0$
3. end for
4. for s=0 to S-1 do
5. $a_n \leftarrow 0$
6. $e_n \leftarrow 0$
7. end for
8. $[p_s]$= water-filling(CGNR',P_T)
9. Calculate $R_{k,n}$from (12)
10. For s=0 to S-1 do
11. $k_{min} \leftarrow \arg\min(r)$
12. $s_{best} \leftarrow \arg\max_{s_n=0}(R_{k_{min,s}})$
13. $r_{k_{min}} \leftarrow r_{k_{min}} + R_{k_{min,s_{best}}}$
14. $e_{s_{best}} \leftarrow k_{min}$
15. $a_{s_{best}} \leftarrow 1$
16. end for
17. Total capacity = $\sum_{k=0}^{K-1} r_k$

In the algorithm, r is the vector containing the data rate of each user. A is also a vector, used to store the position of the pilots already assigned and another vector E is used to store the indexes of the assigned pilots. The size of A and E is 1 × S. Here k_{min} represents the index for minimum data rate user in r and s_{best} indicates the highest data rate (best) subcarrier among remaining unassigned pilots.

The algorithm provides the suboptimal assignment of the S pilots to K users. It aims to maximize the sum capacity under total power constraint while maintaining fairness among the users. The proposed algorithm does not assure the minimum rate requirement; it just optimizes the data rate of the users so that the data rate of the poor user can be maximized to maintain fairness among the users. The algorithm performs both the tasks jointly, vector $r = [r_1, r_2, r_3, \dots, r_k]_{K\times 1}^T$ has the data rate of each user k considering the assigning of a specific set of pilots. A_s takes the value of 1 when the pilot s is assigned. E received the column index of the best pilot (sbest).

After selecting the best pilots from a suboptimal algorithm, assigning them to users by using the WGC-PD scheme. The metric $\xi_{\langle j,k\rangle,\langle j\prime,k\prime\rangle}$ measures the Pilot contamination strength (PCS) between the user $\langle j,k\rangle$ and $\langle j',k'\rangle$ with the same pilot.

$$\xi_{\langle j,k\rangle,\langle j',k'\rangle} = \frac{\beta^2_{\langle j',k'\rangle,j}}{\beta^2_{\langle j,k\rangle,j}} + \frac{\beta^2_{\langle j,k\rangle,j'}}{\beta^2_{\langle j',k'\rangle,j'}} \qquad (13)$$

Here $\xi_{\langle j,k\rangle,\langle j\prime,k\prime\rangle}$ is the ratio between interference channel strength and effective channel strength.

Algorithm of WGC-PD scheme

Input: parameter: K, J and S;
WG = (U,E)
Output: pilot allocation: $\{p_{\langle j,k\rangle}\}$
$1 \le j \le J,\ 1 \le k \le K$
Initialization:

1. $\{j_1, k_1, j_2, k_2\} = arg \max_{\{j,k,j\prime,k\prime,j\neq j\prime\}} \xi_{\langle j,k\rangle\langle j\prime,k\prime\rangle}$
2. $\{p_{j,k}\} = 0, p_{j_1k_1} = 1, p_{j_2k_2} = 2$
3. $\Omega = \{\langle j_1, k_1\rangle, \langle j_2, k_2\rangle\}$
4. **while** $\exists p_{j,k} = 0$ **do**

5. $\delta_{j,k} = \sum_{\langle j\prime,k\prime\rangle \in \Omega, j \neq j\prime} \xi_{\langle j,k\rangle\langle j\prime,k\prime\rangle}$
6. $\langle j_0, k_0\rangle = arg \max_{\langle j,k\rangle}\{\delta_{\langle j,k\rangle}: \langle j,k\rangle \notin \Omega\}$
7. $\wedge = \{s : \forall k, p_{j_0,k} \neq s, 1 \leq s \leq S\}$
8. $\eta_S = \sum_{\langle J,K\rangle \in \Omega, p_{j,k}=s} \xi_{\langle j_0,k_0\rangle,\langle j,k\rangle}$
9. $p_{j_0 k_0} = arg \min_s\{\eta_s: s \in \wedge\}$
10. $\Omega = \Omega \cap \{\langle j_0, k_0\rangle\}$
11. **end and return** $\{p_{j,k}\}$.

Step 1-3: Two users with the largest weighted edge in different cells are selected. Those two users are assigned with pilots $\varphi_1 and\ \varphi_2$ and other users are assigned with pilots in a sequential way until $\nexists p_{j,k} = 0$. Step 5: $\delta_{\langle j,k\rangle}$denotes the sum of weighted edges connecting the user $\langle j,k\rangle$ with users in different cells within Ω. Step 6: Select the user $\langle j_0, k_0\rangle$ with large pilot contamination severity PCS) in the assigned set Ω. Step 7: ensure that different pilot used in the same cell and select the unused pilots in a cell. Step 8: define η_s to describe the PCS between the users. Step 9: Finally, the pilot with the smallest potential PCS η_s selected and assigned to the $\langle j_0, k_0\rangle$ user. Then this loop will continue until all users are assigned to their corresponding pilots.

3. RESULTS AND DISCUSSION:

Number of users in one cell K_i	10
Number of cells J	19
Number of pilot sequences S	K≤Q≤KJ 15 if fixed
Loss of spectral efficiency m_0	0.05
Antenna's number in a BS M	32~2048 512 if fixed
The threshold parameter ϑ	0.05≤θ≤1 0.1 if fixed
Transmission power γ_p	5~30 dB 15 if fixed
The shadowing fading ρ	8 dB

Table 1: Simulation Parameters

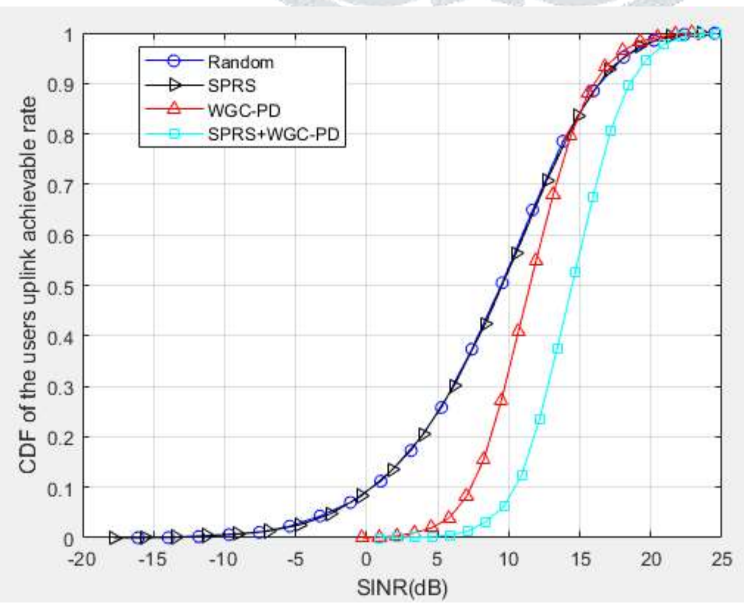

Fig 3. CDF of uplink SINR for different schemes

In fig.3 SPRS+WGC-PD attains a fairly higher SINR for uplink users than others scheme respectively. The values of CDF is Random>SPRS>WGC-PD>SPRS+WGC-PD, which means the proposed SPRS+WGC-PD scheme has the least users whose SINR are less than $SINR_0$.

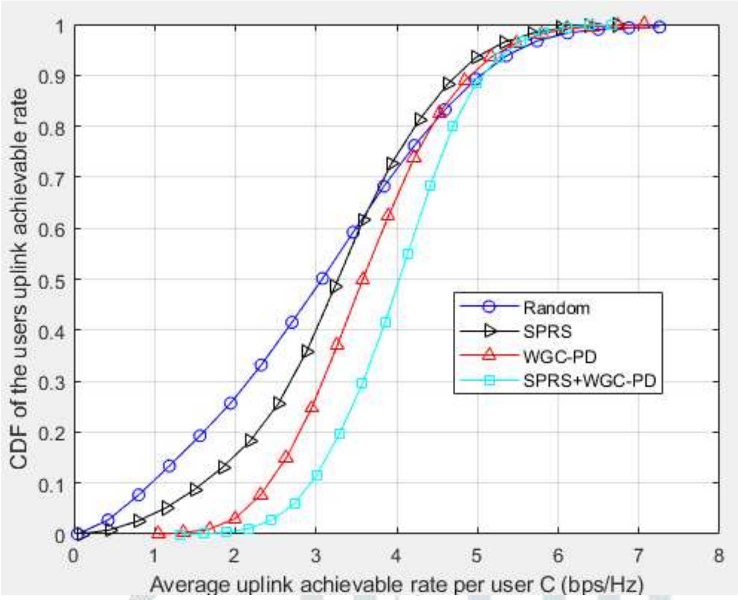

Fig 4. CDF of uplink achievable rate for different schemes

Fig.4 shows the relationship between CDF and rate C. It can be concluded that the proposed scheme is superior to the existing schemes and when C comes to about 6 bps/Hz, the CDF curves are all nearly reaching 1.

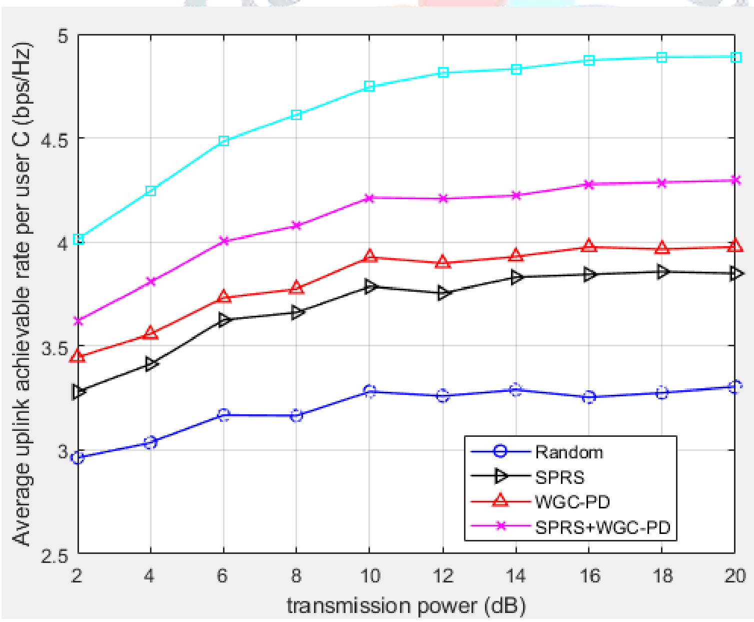

Fig 5. Average uplink achievable rate C against δ for different schemes

All the considered schemes can improve the rate C when δ increases. At the same time, obviously, the effect of the SPRS+WCG-PD scheme is the best.

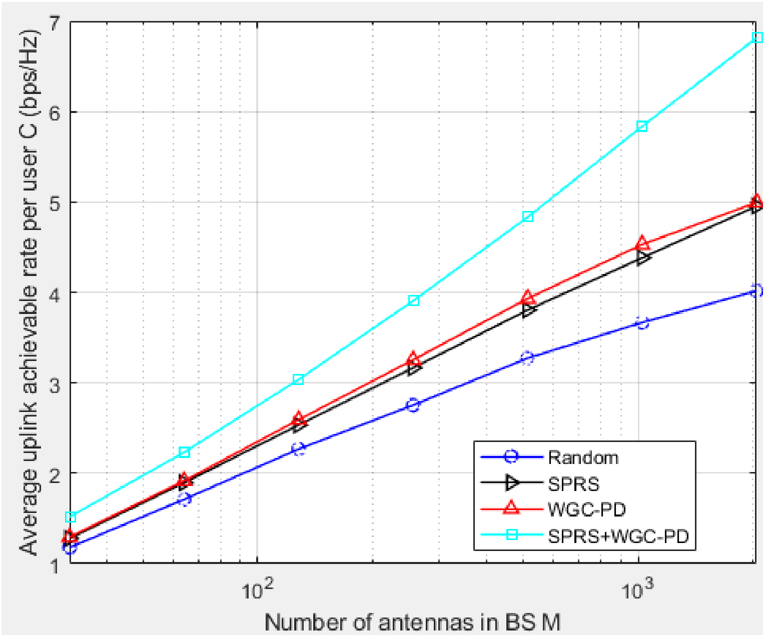

Fig 6. Average uplink achievable rate C against M for different schemes

It is obvious that with the increase of M, the rates of these four schemes all rise. But the proposed scheme's curve rises fastest.

4. CONCLUSION:

In this paper, we proposed a pilot decontamination scheme based on the SPRS and WGC-PD schemes. The uplink massive MIMO users are separated into cell-centered users and cell-edged users and the assigning of pilots is determined from SPRS and the Sub-optimal algorithm is used to select the best pilots. Furthermore, WGC-PD is introduced to improve the decontamination of pilots. Then, in accordance with the simulation results, this combination scheme outperforming than existing schemes in many aspects. Thus, the proposed scheme has a good prospect for application in the massive MIMO system.

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