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Worst Cell Based Pilot Allocation in Massive MIMO Systems

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Abstract: Massive multiple-input multiple-output (MIMO) has been viewed as an advanced technique in future 5G networks. Conventional massive MIMO systems consist of cellular base stations (BS) equipped with a very large number of antennas to simultaneously serve many single-antenna users. Unfortunately, massive MIMO system's performance is limited by pilot contamination (PC) problem. Conventionally, all users in massive MIMO systems are assigned pilot randomly. In this paper, we propose a pilot allocation algorithm based on a cell with the worst channel quality (WCPA) algorithm to improve the uplink achievable sum rate of the system. Specifically, WCPA exploits the large-scale coefficients of fading channels between the BSs and users. According to the number of available orthogonal pilot sequences, we choose some of the highest inter-cell interfering users and assign each of them a unique pilot sequence if the number of pilot sequences is more than the number of users in a cell. Next, we choose a target cell with the worst channel quality, and gather the highest channel gain user in the target cell and the lowest interfering user in the other cells in the same group in a sequential way by assigning them the same pilot sequence. The simulation results show the outperformance of the proposed algorithm compared to the conventional pilot allocation schemes.

Keywords: 5G wireless networks; massive MIMO; pilot contamination; pilot assignment; channel estimation

1. Introduction

Massive multiple-input multiple-output (MIMO) techniques have been broadly investigated over the last two decades to keep up with the exponential increases in mobile data traffic in future 5G wireless systems [1–6], whereby a base station (BS) endowed with a very huge number of antennas serving many users concurrently. Massive MIMO has been considered as one of the main techniques which provide reliable and green communication [7,8], especially in smart cities networks. Within a few recent decades, global wireless data has been increasing significantly and rapidly due to the explosion of smart devices, Internet-of-Things (IoT) devices, high-data-rate applications and smart cities which contains the huge number of smart gadgets, sensors and embedded systems. For those reasons, the demands for reliable and green communication or in other words, energy-efficient communications, are inevitable [7–9]. It is well-known that massive MIMO makes a huge break with current MIMO by using a large number of BS antennas to efficiently focus energy into small regions of space to bring significant improvement in energy efficiency and spectral efficiency [2–4], which is the main target of green communication networks.

Assuming time division duplex (TDD) mode is used, users in every cell send their pilot sequences to the corresponding BS in multi-cell multi-user massive MIMO systems. Since the BS already know all pilot sequences, which are orthogonal to each other, the BS is able to estimate the uplink channels by using the received pilot data. Based on the estimated uplink channels, the BS creates the signal detector for uplink and precoding matrix for downlink. It is known that interference between users in the same cell and white noise can be completely canceled out if the number of BS antennas goes to infinity [2,3]. However, since the resources is inadequate, only one group of orthogonal pilot sequences is reused in every cells in the systems. Reusing orthogonal pilot sequences results in a problem called pilot contamination (PC). PC causes major limitations in the performance of massive MIMO systems, even though the number of BS antennas goes to infinity, and thus PC has become one of the main research topics in massive MIMO systems [4,5]. A lot of efforts have been made to overcome this challenging issue of PC [10–19]. A MMSE-based multi-cell precoding technique was proposed in [10], where each BS creates its own precoding matrix to minimize the total of squared errors of its users and the interference with other cells users. The disadvantage of this precoding technique [10] is that it has high computational complexity because of large matrix inversion. The time-shifted pilot scheme in [11] was proposed by dividing the whole system into smaller divisions, and asynchronously transmitting data or pilot among these divisions. The transmission scheme in [11] ensures that pilot contamination does not happen among users from different divisions when we increase the BS antennas to infinite number, but it causes the mutual interference between users data and pilot data in non-asymptotic regime. The angle-of-arrival (AoA)-based method [12] illustrated that different users with non-overlapping AoAs will not interfere each other even if they are assigned with same pilot sequence, but the author of [12] assumes that the AoA spread of each user is small and this is not always true in practical environments. A smart pilot allocation (SPA) algorithm [13] was proposed by optimizing the minimum signal-to-interference-plus-noise ratio (SINR) user for every cells in a ordered way but it cannot be ensured that the convergence will be achieved. Besides, SPA only assumes the number of orthogonal pilot sequences equals to the number of users in a cell. The authors of [14] proposed an adaptive pilot allocation (APA) scheme, in which all users were divided into two different group based to their inter-cell interference. The APA algorithm [14] assumes that the number of orthogonal pilot sequences is more than number of users, and if the pilot sequence resources is limited, APA algorithm becomes conventional scheme, which is random pilot assignment. A blind channel estimation method based on subspace partitioning [15] was proposed to reduce the inter-cell interference when the channel vectors of different users are orthogonal, but the blind method has a very heavy computational complexity. Another research direction is pilot design, as in [16], in which a pilot sequence design criterion was proposed to create the optimal pilot sequences for mitigating the impact of PC. This scheme has high computational complexity because of large matrix inversion and mathematical calculation. Recently, a pilot assignment algorithm is investigated based on user location information such as distance and AoA [17]. The authors of [17] created an interference graph from the metric calculated by user location information and applied a graph coloring-based algorithm to assign pilot sequence to each user. Power allocation is also a promising technique to reduce pilot contamination. The authors of [18] mitigated pilot contamination by optimizing the pilot power of each user while both pilot power and data power are jointly optimized in [19].

In this paper, by taking advantage of the large-scale fading coefficients between the BSs and users, a pilot allocation algorithm based on a cell with the worst channel quality (WCPA) is proposed to improve the uplink achievable sum rate of multi-cell multi-user large scale MIMO systems. Unlike the conventional schemes that the users are assigned available pilot randomly, our proposed WCPA algorithm aims to improve the sum rate of the systems by first choosing some of the highest inter-cell interfering users and assigning each of them an unique pilot sequence if the number of orthogonal pilot sequences is more than number of users in every cell. Next, the cell with the worst channel quality, called the target cell, is chosen and then, we assign the same pilot sequence to the user in the target cell which has the highest channel gain as well as the users in the other cells which have the lowest interference with the target cell in a sequential way. Our proposed WCPA algorithm also makes sure there is at least one user in the target cell with the maximized SINR.

The rest of the paper is organized as follows. The system model is described in Section 2. Section 3 illustrates the pilot contamination problem and the proposed WCPA algorithm in detail. Numerical results are illustrated and discussed in Section 4. Finally, conclusions are given in Section 5.

2. System Model

We regard a multi-cell multi-user large-scale MIMO system which has L hexagonal cells consisting of a BS with M antennas serving $K(K << M)$ users, every user only has a single-antenna [1,5]. In Figure 1, a massive MIMO system with three cells is shown. The channel vector $\mathbf{g}_{ijk} \in \mathcal{C}^{M\times 1}$ from k^{th} user in j^{th} cell to the BS in i^{th} cell is modeled as

$$\mathbf{g}_{ijk} = \mathbf{h}_{ijk}\sqrt{\beta_{ijk}}, \tag{1}$$

where β_{ijk} presents the large-scale fading coefficients that change slowly over time and can readily be tracked [10], and $\mathbf{h}_{ijk}$ is the small-scale fading channel vector which has distribution $\mathcal{CN}(\mathbf{0}, \mathbf{I}_M)$. We consider the typical time-division duplexing (TDD) mode in massive MIMO systems and follow the commonly used block fading model, in which the channel vector $\mathbf{g}_{ijk}$ remains unchanged in one coherence interval [4,5].

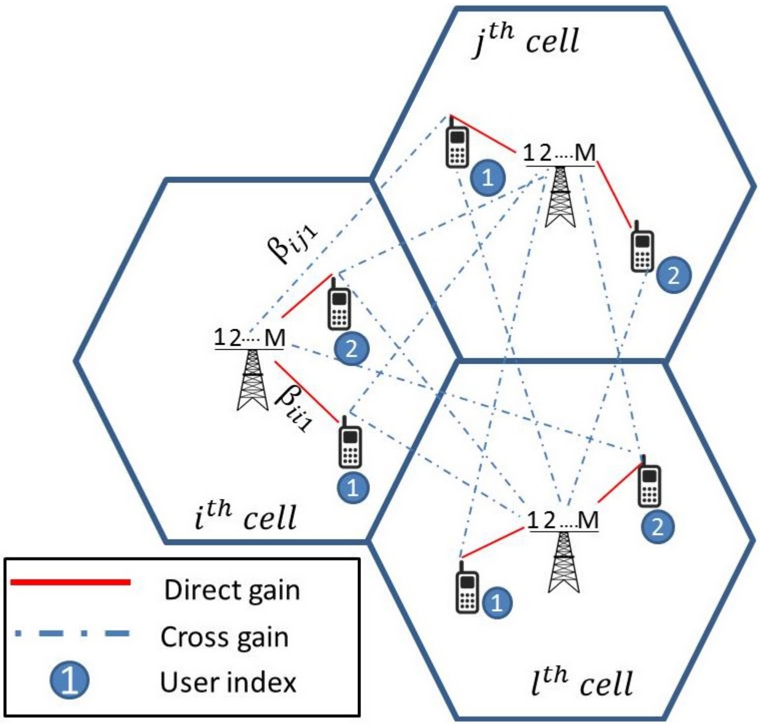

Figure 1. A three multi-cell massive MIMO system.

We assume that the total number of orthogonal pilot sequences is $S(S \geq K)$, and the pilot set $\mathbf{\Phi} = [\mathbf{p}_1, \mathbf{p}_2, ..., \mathbf{p}_S]$ composed of pilot $\mathbf{p}_k$ with length τ are mutually orthogonal, i.e., $\mathbf{\Phi}^H\mathbf{\Phi} = I_S$. The pilot set $\mathbf{\Phi}$ is reused in every cells due to the limitation of pilot resources. In conventional pilot assignment schemes, the k^{th} user is assigned pilot sequence $\mathbf{p}_k$ regardless of the different channel qualities among users.

The operation of massive MIMO systems is commonly divided into two phases: estimating channels phase and transmitting data phase. In the channel estimation phase, users transmit their corresponding pilot sequences to their BSs. We assume the worst-case scenario where all users in the system synchronously send their pilot sequence and the BSs synchronously receive the pilot signal. The BS in i^{th} cell receives pilot sequence $\mathbf{Y}_i$ from its users and also from other cell users as

$$\mathbf{Y}_i = \sqrt{\rho_\mathrm{p}} \sum_{j=1}^{L} \sum_{k=1}^{K} \mathbf{g}_{ijk} \mathbf{p}_k^H + \mathbf{N}_i, \tag{2}$$

where ρ_p presents the power used to transmit the pilot and $\mathbf{N}_i \in \mathcal{C}^{M\times\tau}$ presents the additive Gaussian white noise (AWGN) matrix whose elements are independently and identically distributed (i.i.d) Gaussian random variables with mean is 0 and variance is 1. We estimate the channel of k^{th} user in i^{th} cell by multiplying the received pilot data $\mathbf{Y}_i$ with pilot sequence $\mathbf{p}_k$

$$\hat{\mathbf{g}}_{iik} = \frac{1}{\sqrt{\rho_\mathrm{p}}} \mathbf{Y}_i \mathbf{p}_k = \sum_{j=1}^{L} \mathbf{g}_{ijk} + \mathbf{z}_{ik}, \tag{3}$$

where $\mathbf{z}_{ik} = \frac{1}{\sqrt{\rho_\mathrm{p}}} \mathbf{N}_i \mathbf{p}_k$ denotes the equivalent noise.

In the data transmission phase, we consider uplink data transmission where users transmit their data to their BS. The received user data at the BS in i^{th} cell can be calculated as

$$\mathbf{y}_i = \sqrt{\rho_\mathrm{u}} \sum_{j=1}^{L} \sum_{k=1}^{K} \mathbf{g}_{ijk} s_{jk} + \mathbf{n}_i \tag{4}$$

where s_{jk} denotes the data symbol from k^{th} user in j^{th} cell with $E\{|s_{jk}|^2\} = 1$, ρ_u denotes the power used to transmit data in uplink, and $\mathbf{n}_i \in \mathcal{C}^{M\times 1}$ denotes the AWGN noise vector with $E\{\mathbf{n}_i \mathbf{n}_i^H\} = \mathbf{I}_\mathrm{M}$. In this paper, we adopt matched-filter (MF) detector which is created from the channel estimation result $\hat{\mathbf{g}}_{iik}$ to detect data symbols. The detected data symbol of the k^{th} user in i^{th} cell is represented as

$$\begin{aligned} \hat{s}_{ik} &= \hat{\mathbf{g}}_{iik}^H \mathbf{y}_i \\ &= \left(\sum_{j=1}^{L} \mathbf{g}_{ijk} + \mathbf{z}_{ik} \right)^H \left(\frac{1}{\sqrt{\rho_\mathrm{u}}} \sum_{j=1}^{L} \sum_{k=1}^{K} \mathbf{g}_{ijk} s_{jk} + \mathbf{n}_i \right) \\ &= \sqrt{\rho_\mathrm{u}} \left(\mathbf{g}_{iik}^H \mathbf{g}_{iik} s_{ik} + \sum_{j\neq i}^{L} \mathbf{g}_{ijk}^H \mathbf{g}_{ijk} s_{jk} \right) + \varepsilon_{ik}, \end{aligned} \tag{5}$$

where ε_{ik} presents the uncorrelated interference and noise which decrease substantially by adding more BS antennas and goes to zero when the number of BS antennas is infinite [4,5].

3. Propsed WCPA Algorithm

3.1. Problem Formulation

From the system model in the previous part, the uplink SINR of k^{th} user in i^{th} cell can be presented as

$$\mathrm{SINR}_{ik} = \frac{|\mathbf{g}_{iik}^H \mathbf{g}_{iik}|^2}{\sum_{j\neq i}^{L} |\mathbf{g}_{ijk}^H \mathbf{g}_{ijk}|^2 + \frac{|\varepsilon_{ik}|^2}{\rho_\mathrm{u}}} \xrightarrow{M\to\infty} \frac{\beta_{iik}^2}{\sum_{j\neq i}^{L} \beta_{ijk}^2}, \tag{6}$$

Therefore, the corresponding average uplink achievable rate of k^{th} user in i^{th} cell can be presented as

$$\mathrm{C}_{ik} = (1-\mu_0) E\{\log_2(1+\mathrm{SINR}_{ik})\}, \tag{7}$$

where μ_0 represents the loss of spectral efficiency caused by transmitting uplink pilot to estimate the channel, which actually is the proportion of the pilot length τ and the channel coherence time T [3], i.e., $\mu_0 = \frac{\tau}{T}$.

It is known that the channel estimation of k^{th} user in i^{th} cell $\hat{\mathbf{g}}_{iik}$ is a linear combination of the channels $\mathbf{g}_{ijk}$ of users in all cells of the system which have the same pilot sequence, which is the cause of PC problem. It is also clear that the AWGN noise and the small-scale fading coefficients approach zero as the number of BS antennas M goes to infinity. However, the average uplink capacity is still limited by PC and cannot increase even if we increase the transmit power ρ_{u} or ρ_{p}.

Fortunately, as the asymptotic SINR of an user is proportional to its large-scale fading coefficients, which varies slowly over time and is easily tracked [20]. Based on this behavior, we propose our WCPA algorithm based on a target cell to improve the sum rate of the system.

3.2. Proposed WCPA Algorithm

From cell aspect, for the i^{th} cell, we have define a parameter d_i as the summation of the channel gains from its users to its BS as

$$d_i = \sum_{k=1}^{K} \beta_{iik}^2. \tag{8}$$

We define another parameter c_i as the summation of interference from other cell users with their BS as

$$c_i = \sum_{j \neq i}^{L} \sum_{k=1}^{K} \beta_{ijk}^2. \tag{9}$$

To evaluate the channel quality of i^{th} cell, we calculate the ratio q_i of its total channel gains to its total interference as

$$q_i = \frac{d_i}{c_i}. \tag{10}$$

Finally, we define the parameter λ_{ik} to be the sum of interference that k^{th} user in i^{th} cell interfere all BS in other cells, which will be used to find $(S-K)$ highest interfering users, as below

$$\lambda_{ik} = \sum_{j \neq i}^{L} \beta_{jik}^2, i = 1, 2, ..., L; k = 1, 2, ..., K. \tag{11}$$

The physical meaning of Algorithm 1 is explicated as follows:

1. If $S > K$, find $(S-K)$ highest inter-cell interfering users, based on (11), and assign to each of them a unique pilot. Make sure to cancel out all large-scale coefficients related to these $(S-K)$ users.
2. Calculate the ratio between the total channel gain and the total interference of every cell and choose the cell with the lowest ratio as the target cell.
3. Sort the direct gain of users in the target cell in descending order and assign pilots from 1 to K to them sequentially. If some users are already assigned a pilot, do not assign another pilot to them.
4. In the other cells, sort the cross gain of the users in the other cells to the target cell in ascending order. If some users are already assigned a pilot, put them at the end of the ascending order. Assign pilots pilot 1 to K sequentially. If the users are already assigned a pilot, do not assign another pilot to them.

Algorithm 1 Proposed WCPA Algorithm

Input: System parameters: S, K, L, Large-scale fading coefficients: β_{ijk}, λ_{ik}, $\Psi = \varnothing$
If $(S > K)$
For $idx = 1 : 1 : (S - K)$.

- $(i, k) = \arg\max \{\lambda_{ik}, i = 1, 2, ..., L; k = 1, 2, ..., K\}$.
- $\lambda_{ik} = 0$.
- Assign pilot $\mathbf{p}_{K+idx}$ to k^{th} user in i^{th} cell.
- Set $\beta_{iik} = 0, \beta_{jik} = 0, j \neq i$ and $j = 1, 2, ..., L$; $\Psi = \Psi \cup (j, i, k)$.

EndFor
EndIf

- Calculate c_i, d_i, q_i.
- Find target cell: $t = \arg\min_{i=1,2,...,L} \{q_i\}$.
- Sort $\{\beta^2_{ttk}\}, k = 1, 2, ..., K$ in descending order ($\beta^2_{ttf_t^1} \geq \beta^2_{ttf_t^2} \geq ... \geq \beta^2_{ttf_t^K}$) with $F_t = [f_t^1, f_t^2, ..., f_t^K]$ is index set of K users in i_{th} cell.

For $k = 1 : 1 : K$
If $((f_t^k)^{th}$ user in t^{th} cell is not assigned any pilot)
Assign pilot $\mathbf{p}_k$ to user corresponding to $\beta^2_{ttf_t^k}$.
EndIf
EndFor
Set $\beta_{jik} = 10^{10}, (j, i, k) \in \Psi$.
For $l = 1 : 1 : L, l \neq t$
Sort $\{\beta^2_{tlk}\}, k = 1, 2, ..., K$ in ascending order ($\beta^2_{tlf_l^1} \leq \beta^2_{tlf_l^2} \leq ... \leq \beta^2_{tlf_l^K}$) with $F_l = [f_l^1, f_l^2, ..., f_l^K]$ is index set of K users in l^{th} cell
For $k = 1 : 1 : K$
If $((f_l^k)^{th}$ user in l^{th} cell is not assigned any pilot)
Assign pilot $\mathbf{p}_k$ to user corresponding to $\beta^2_{tlf_l^k}$.
EndIf
EndFor
EndFor
Output: Pilot allocation for all users in the system.

3.3. Performance Analysis and Discussion

In this subsection, we analyze the advantages of our proposed algorithm as well as the scenario that the proposed algorithm can be well applied.

When $S > K$, distinct pilots are assigned to the $(S - K)$ highest interfering users to avoid $(S - K)$ potential high interference between users and this reduces significantly the influence of pilot contamination. When $S = K$, the algorithm aims to improve the sum rate of a target cell which is a cell which has the worst channel quality. By improving it's sum rate, the system performance is significantly improved. By using Algorithm 1, within the target cell, the highest direct gain user is grouped with the lowest cross gain users in the other cells, the second highest direct gain user is with the second lowest cross gain users and so on. Consequently, the low SINR users will have lower SINR, but the high SINR users end up having much higher SINR. This is reasonable since users in massive MIMO systems are frequently moving and changing their locations, one specified user can not be low or high user forever and eventually, in an average of time, the proposed algorithm is fairness for every user in the system.

The proposed algorithm ensures that there is at least one user with maximized SINR in the target cell. For the target cell i, maximum user SINR is expressed as

$$\begin{aligned}\max_{1\le k\le K} \text{SINR}_{ik} &= \max_{1\le k\le K, j\ne i, 1\le m\le K} \frac{\beta_{iik}^2}{\sum_{j\ne i, m\in 1,2,\ldots,K}^{L} \beta_{ijm}^2} \\ &= \frac{\max\limits_{1\le k\le K}(\beta_{iik}^2)}{\sum_{j\ne i, m\in 1,2,\ldots,K}^{L} \min\limits_{1\le k\le K}(\beta_{ijm}^2)}.\end{aligned} \quad (12)$$

The last equation in (12) follows directly our algorithm that in target cell, the user with the highest direct gain is grouped with the users in other cells with lowest interference to target cell.

However, since increasing sum rate of the target cell can only affect remarkably to the sum rate of the system with a few of cells so the proposed algorithm should be applied in remote areas where there are a few macro cells. If a system has many cells, we divide it into clusters with 3–5 cells in each cluster and apply independently WCPA to each of them without considering interference from other clusters.

4. Numerical Results

In this section, we evaluate the performance of the proposed WCPA algorithm based on the simulations in two cases: $S = K$ and $S > K$. We consider a conventional hexagonal cellular network with L cells, each cell has a central BS equipped with M antennas and simultaneously serving K users which are randomly and uniformly distributed inside the cell. Table 1 lists up the system parameters used in the simulation.

As pointed out in [1], the large-scale fading coefficient β_{ijk} can be calculated as

$$\beta_{ijk} = \frac{z_{ijk}}{(r_{ijk}/R)^{\alpha}}, \quad (13)$$

where z_{ijk} is the shadow fading coefficient and follows a log-normal distribution with standard deviation σ_{shadow} (i.e., $10\log(z_{ijk})$ obeys Gaussian distribution with mean is 0 and standard deviation is σ_{shadow}), r_{ijk} is the distance between the k^{th} user in j^{th} cell and the BS in i^{th} cell, and R is the cell radius.

Table 1. System parameters.

Network Parameter	Value
Number of cells L	3
Number of BS antennas M	$100 \le M \le 300$
Number of users in each cell K	8
Cell radius R	500 m
Transmit power at use $\rho_u(\rho_p = \tau\rho_u)$	10 dB
Path loss exponent α	3
Shadow fading standard deviation σ_{shadow}	8 dB
Number of pilot sequences S	$K, K+4, K+8$

Four referenced systems in Figures 2–7 are considered, which are WCPA with randomly choosing target cell, SPA [13], APA [14], and the conventional system. The WCPA with randomly choosing target cell is made by choosing the target cell randomly to show that choosing target cell in the proposed algorithm is very important. SPA [13] and APA [14] are recently results about pilot assignment for pilot contamination, which are the algorithms of referenced paper [13,14], respectively. Finally, the conventional system shows that pilot sequence are assigned randomly [4,5,13,14].

We first evaluate the performance of the proposed algorithm in the case with $S = K = 8$. Figure 2 shows the average uplink achievable sum rate of the system when the number of BS antennas M

increases from 100 to 300. Clearly our proposed WCPA outperforms all other algorithms: Smart Pilot Assignment SPA [13], Adaptive Pilot Allocation (APA) [14] and conventional schemes.

Figure 3 illustrates the cumulative distribution function (CDF) curve of the uplink achievable sum rate of the system with a conventional number of BS antennas $M = 300$. It can be seen clearly that WCPA outperforms the conventional schemes as well as APA and SPA algorithms by nearly 3 bit/s/Hz. The reason why SPA performance is worse than our WCPA algorithm (SPA performance is nearly the same with conventional schemes) is that SPA only focuses on improving the minimum SINR in a target cell while our proposed algorithm focuses on improving the achievable sum rate of the target cell (worst channel quality cell) by sacrificing some low SINR users in the target cell. In case of $S = K$, APA will perform as same as conventional schemes. From Figure 3, we also see the importance of choosing the target cell in our proposed algorithm, which is, the proposed WCPA algorithm performs better when choosing target cell (worst channel quality cell) than randomly choosing a target cell by about 1.5 bit/s/Hz.

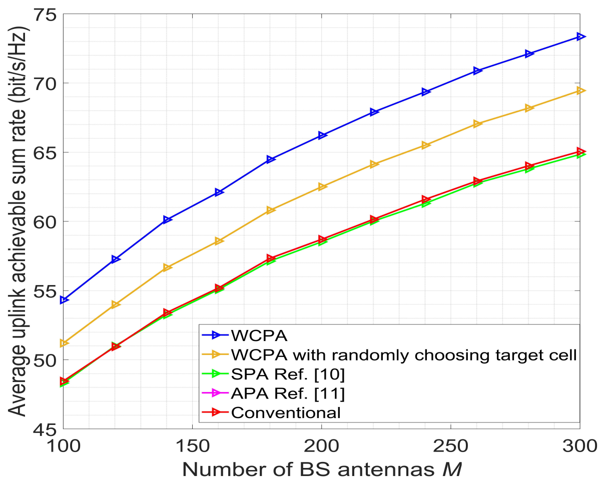

Figure 2. Average uplink achievable sum rate in case $K = 8$, $S = 8$.

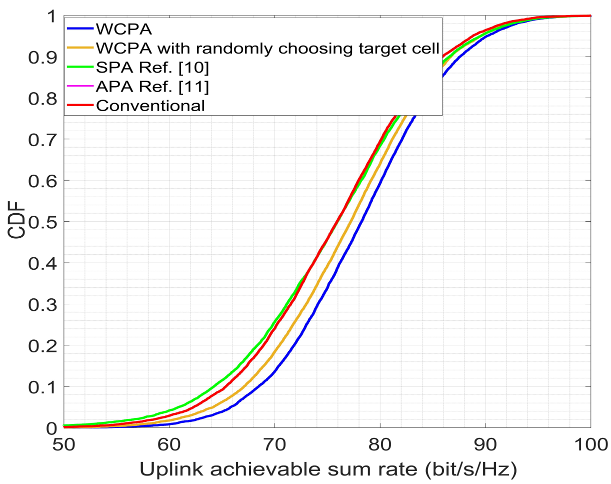

Figure 3. CDF of uplink achievable sum rate in case $K = 8$, $S = 8$.

Next, we verify the outperformance of our proposed WCPA algorithm in the case with $S > K$. Figures 4 and 5 are the simulation results when $K = 8$ and $S = 12$, Figures 6 and 7 are the simulation results when $K = 8$ and $S = 16$. First, we see that both APA and our proposed algorithm perform much better than SPA and conventional schemes, this is because both WCPA and APA assign unique pilots to some high inter-cell interfering users so that they will not interfere with other users in the system. We can also see the outperformance of our proposed system in compare to APA algorithm. It is noteworthy from Figures 4 and 6 that the outperformance of our proposed WCPA algorithm can be gradually improved when the number of BS antennas M is increased.

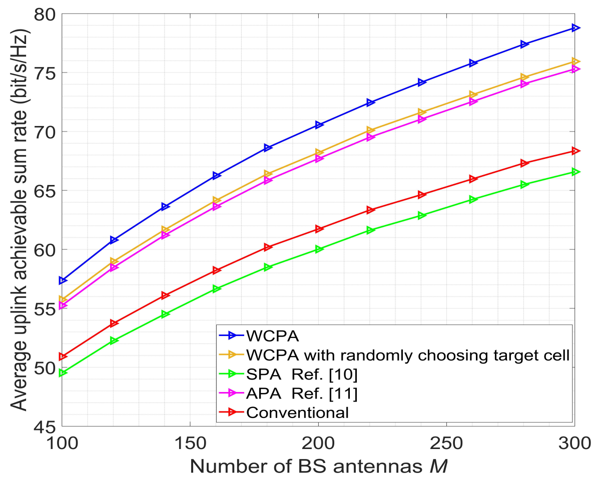

Figure 4. Average uplink achievable sum rate in case $K = 8$, $S = 12$.

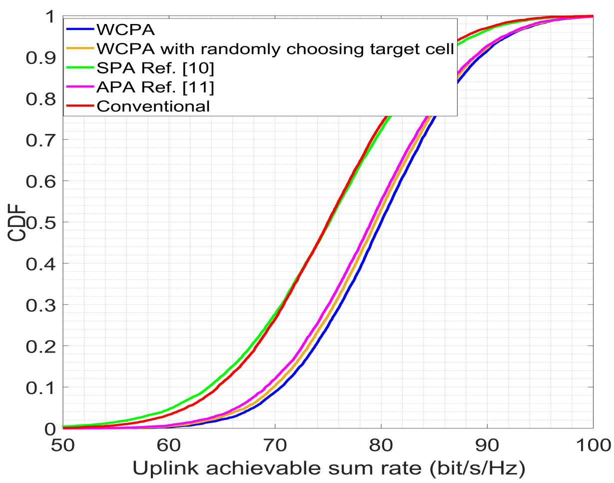

Figure 5. CDF of uplink achievable sum rate in case $K = 8$, $S = 12$.

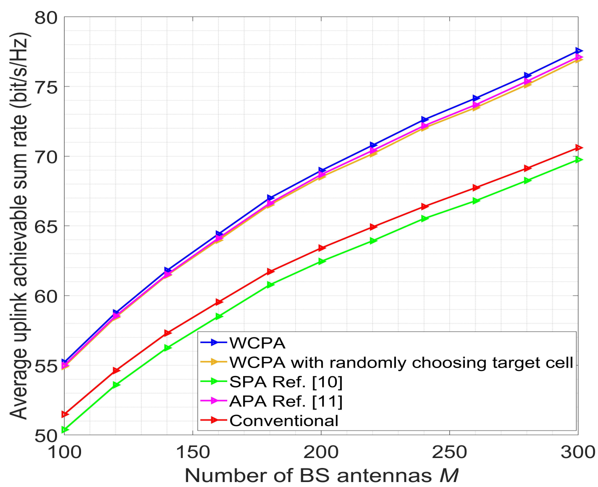

Figure 6. Average uplink achievable sum rate in case $K = 8$, $S = 16$.

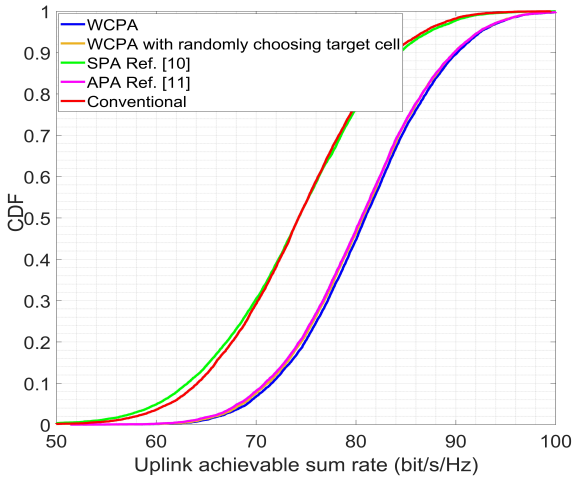

Figure 7. CDF of uplink achievable sum rate in case $K = 8$, $S = 16$.

Figures 5 and 7 plot the cumulative distribution function (CDF) curve of the uplink achievable sum rate of the system with number of BS antennas $M = 300$, Figure 5 illustrates that our WCPA performs better than both APA and conventional schemes by nearly 1.5 bit/s/Hz compared with APA and 5 bit/s/Hz compared with conventional schemes. From Figure 7, we can see that our proposed algorithm still outperforms APA but by a smaller gain of around 0.5 bit/s/Hz. This is because of the fact that if the number of pilot sequences are more larger than the number of users in each cells, there are more unique pilot sequences which will be assigned to the high inter-cell interfering users, which means there is less interference between the other users and thus the sum-rate of the target cell in our proposed algorithm will be less improved.

5. Conclusions

In this paper, a pilot assignment algorithm based on a target cell is proposed to improve the uplink achievable sum rate in multi-cell multi-user massive MIMO systems. By using the large-scale coefficients of the channels, the proposed WCPA algorithm first chooses the highest inter-cell interfering users and assigns each of them a unique pilot sequence if the number of orthogonal pilot sequences is more than number of users in each cell. Next, the target cell, which is the cell with the worst channel quality, is chosen. Finally, the user with the highest direct gain in the target cell is grouped with the lowest cross gain of other cell users by assigning the same pilot sequence to these users. By theoretical analysis and simulation results, our proposed WCPA can improve the uplink achievable sum rate in massive MIMO systems and outperforms the conventional schemes, the SPA algorithm and the proposed APA algorithm.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

MIMO	Multiple-input multiple-output
BS	Base station
PC	Pilot contamination

ICI	Inter-cell interference
MMSE	Minimum mean squared error
SINR	Signal-to-interference-plus-noise
TDD	Time division duplex
AWGN	Additive white Gaussian noise

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