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Massive MIMO User Location Based Pilot Allocation in Massive MIMO Systems

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Abstract*: *Aiming at the problem of massive MIMO pilot contamination, a user location information based pilot allocation scheme is proposed. The proposed scheme sorts the users and assigns pilots in accordance to the polar angle of the user's location in the polar coordinate system with the base station of the cell as the pole. The scheme combines the characteristics of the directional large line, and by controlling the reuse distance of the pilots in a relatively long range, the goals of reducing pilot contamination is improving system reachability and speed. Simulation results show that the proposed scheme not only effectively reduce pilot contamination among users, but also improves the performance gap between different users with the improved system fairness.

Keywords: Pilot Contamination Massive MIMO, Pilot allocation， Directional Antenna.

I. INTRODUCTION

With the rapid mobile internet development, data services have gradually replaced voice services as the most important communication service in wireless communication systems. Compared with 4G LTE networks, 5G networks require higher data transmission rates, larger system capacity, and better quality of service [l, 2]. As 5G a key technology, massive MIMO is receiving widespread attention due to its high spectral efficiency [3, 4]. Compared with traditional wireless systems, massive MIMO systems can provide significant improvements in energy efficiency and spectrum efficiency by providing a large number of large lines in cell base stations [5]. In a multi-user MIMO system, the base station needs to obtain accurate channel state information (CSI) to separate the received user signals [6]. In traditional MIMO systems, research hotspots are usually focused on frequency division duplex (FDD) systems. In FDD mode, CSI is usually obtained through limited feedback, and the amount of feedback information is proportional to the number of large lines [7]. Obviously, in a massive MIMO system, as the number of base stations gradually increases, the system overhead for feedback will continue to increase, which will eventually make the system unbearable. In a time division duplex (TDD) system, due to channel reciprocity existence, the corresponding CSI is obtained at base station by estimating the received signal pilot [8], by avoiding a large amount of feedback overhead. Hence, TDD mode is considered to be a more suitable communication mode for massive MIMO systems. As base stations number continues to increase, the impact of non-correlated interference among users in cell can be gradually ignored, and the related interference caused by pilot multiplexing in adjacent cells will become the only non-negligible interference factor [9]. This phenomenon is often referred to as pilot contamination. Pilot contamination will seriously affect the accuracy of channel estimation and the spectral efficiency of the system is reduced significantly. Therefore, effective reduction of pilot contamination is attracting wide attention. Literature [l0] proved that the optimal allocation of pilot sequences can reduce the pilot contamination of the system, and proposed a pilot grouping method based on alliance games. This scheme can find near-optimal pilot multiplexing schemes through certain iterative operations. However, although this scheme can provide near-optimal system performance, it also brings high computational complexity. Aiming at the contradiction between system performance and computational complexity, some improved pilot allocation schemes have gradually emerged, such as graph-based colouring [11], linear programming [12], entropy-based optimization [13], and artificial fish algorithm [14] and other pilot allocation schemes. These solutions can reduce the computational complexity to a certain extent. Where, the pilot allocation method based on the artificial fish algorithm can break through the limitation of the local optimal solution and maximize the user and rate. However, overall, the complexity of these methods is still relatively high. In [15] a pilot allocation scheme is proposed for partial pilot multiplexing, which divided cells into inner and outer two-layer areas. The inner areas of all cells reused the same set of pilots, while the outer layers of adjacent cells, the pilots used by regional users are mutually orthogonal. Although this scheme loses a part of the pilot multiplexing gain, it avoids serious pilot contamination and guarantees the user's lowest signal to interference and noise ratio (SINR). Similarly, in order to improve the minimum SINR of the user, the literature [16] uses the large-scale fading coefficient of the channel to sequentially assign the pilot sequence with the lowest inter-cell interference to the user with the worst channel quality, thereby avoiding the difference in SINR between different users. Literature [17] proposed a pilot allocation method that combined time shift and space division, while suppressing pilot contamination from two perspectives: time domain and space domain. Literature [18] combined with the micro cell method, proposed a new pilot multiplexing method, and used the user's location information to further reduce pilot contamination. In addition, in actual communication systems, since the user's location information is relatively easy to obtain, it can be obtained by measurement and estimation [19] or using global positioning system [20] and other methods.

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The application of user location information in massive MIMO systems is being affected with extensive attention.

Based on the above literature, in this paper a pilot allocation scheme is proposed based on user location information. This solution combines the characteristics of the directional large line, according to the polar angle of the user's location in the polar coordinate system with the base station of the cell in which the user is located, sorts the users and assigns pilots in turn. Compared with the previous pilot allocation scheme, this scheme does not require complicated iterative calculations and cell cooperation. While improving the overall performance of the system, it also takes care of the fairness among users. Simulation results show that the pilot contamination between the cells and the performance gap between different users is effectively reduced.

II. SYSTEM MODEL

In this paper a massive MIMO multi-cell TDD cellular network consisting of L hexagonal cells is considered. The system model is shown in Fig l. Each cell contains K single-line users and a massive MIMO base station. The base station is composed of 6 directional large line arrays each equipped with M large lines, and each large line array respectively covers a sector area with an angle of π/3. According to the directivity of directional large lines, each large line array can only receive signals within its coverage area, and can only send signals to users within that range. In Fig l, the base station in the central cell is taken as an example. The coverage of the six directional large line arrays is indicated by different shades.

It is assumed that the fading channel between the user and the base station is determined by both small-scale fading and large-scale fading. Where, small-scale fading is Rayleigh fading, and large-scale fading follows the general path loss model. Let the channel between user k in cell l and the base station in cell j be $h_{jlk} \in C^M$, then

$$h_{jlk} \sim CN(0, \beta_{jlk} I_M) \quad (1)$$

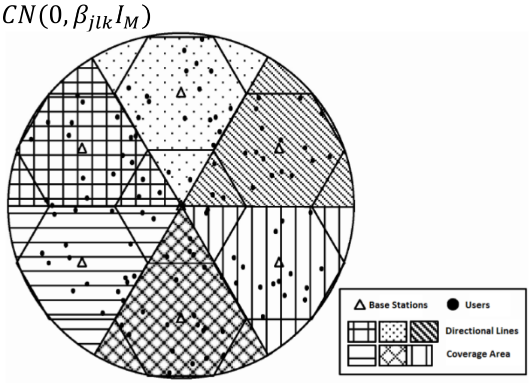

Fig l. System Model

where, β_{jlk} is variance of channel fading, and I_M is the M-th order matrix. Since large-scale fading follows the general path loss model, then

$$\beta_{jlk} = \frac{C}{\|z_{jk} - b_j\|^k} \quad (2)$$

where, z_{jk} represents the coordinates of user k in cell j, b_j represents the coordinates of the base station in cell l, k is the index of path loss, C is a specific parameter.

III. SIGNAL TRANSMISSION SCHEME

A. Pilot Training

In order to eliminate the effect of near and far effects on the system, power control is implemented on user equipment. In cell j, assuming that the power of the user signal received by the base station is ρ, the power of the signal transmitted by user k is $\frac{\rho}{\beta_{jjk}}$. Assuming that the noise power received by the base station is σ^2, the SNR of the system is $\frac{\rho}{\sigma^2}$.

For user k in target cell j and user m in cell l, if both are within the coverage of the same directional large line array of base station j, the signal of user k will be interfered by user m, remember $\xi_{jklm} = l$; Otherwise, note $\xi_{jklm} = 0$. Assume that when $m = k$, user k and user m reuse the same pilot; when $m \neq k$, the pilots used by the two are orthogonal to each other. Then, the base station j receives the pilot signal of user k as

$$y_{jk}^{pilot} = \sqrt{\frac{\rho}{\beta_{jjk}}}\tau h_{jjk} + \sum_{l\neq j} \xi_{jklk} \sqrt{\frac{\rho}{\beta_{llk}}}\tau h_{jlk} + \eta_{jk} \quad (3)$$

Among them, the first term is the effective signal from the target user, the middle term is the interference signal from other cells, and the last term is the additive noise, $\eta_{jk} \sim CN(0, \sigma^2 I_M)$.

B. Channel Estimation and Detection

The MMSE of h_{jjk} in cell j is estimated as [21]

$$\hat{h}_{jjk} = \frac{\sqrt{\rho\beta_{jjk}\tau}}{\rho\tau + \sum_{l\neq j} \xi_{jklk} \frac{\rho\beta_{jlk}}{\beta_{llk}}\tau + \sigma^2} y_{jk}^{pilot}$$

(4)

Then $\hat{h}_{jjk} \sim CN(0, \delta_{jjk} I_M)$, where

$$\delta_{jjk} = \frac{\sqrt{\rho\beta_{jjk}\tau}}{\rho\tau + \sum_{l\neq j} \xi_{jklk} \frac{\rho\beta_{jlk}}{\beta_{llk}}\tau + \sigma^2}$$

(5)

h_{jjk} is channel estimation error

$$\tilde{h}_{jjk} = h_{jjk} - \hat{h}_{jjk}$$

(6)

According to MMSE estimated characteristics, $\tilde{h}_{jjk}$ and $\hat{h}_{jjk}$ are independent from each other, and $\tilde{h}_{jjk} \sim CN(0, (\beta_{jjk} - \delta_{jjk}) I_M)$.

Using the results of the channel estimation, a corresponding detection vector can be designed. After receiving the data signals from different users, the base station can use the detection vector to process the data, thereby separating the information from the target user. In this paper the maximum Ratio Combining (MRC) algorithm with lower complexity is chosen. Let the merge vector of user k in cell j be $g_{jk} \in \mathbb{C}^M$, then

$$g_{jk} = \frac{l}{M\delta_{jjk}} \hat{h}_{jjk} \quad (7)$$

The MMSE of (2) $\hat{h}_{jlk}$ is estimated as [21]

$$\hat{h}_{jlk} = \frac{\beta_{jlk}}{\sqrt{\beta_{jjk}\beta_{llk}}} \hat{h}_{jjk} \quad (8)$$

That is $\hat{h}_{jlk} \sim CN(0, \delta_{jlk} I_M)$, where

$$\delta_{jlk} = \frac{(\beta_{jlk})^2}{\beta_{jjk}\beta_{llk}} \delta_{jjk} \quad (9)$$

h_{jlk} is the channel estimation error

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$$\tilde{h}_{jlk} = h_{jlk} - \hat{h}_{jlk} \qquad (10)$$

Where, $\tilde{h}_{jlk}$ and $\hat{h}_{jlk}$ are independent of each other, and $\tilde{h}_{jlk} \sim CN(0, (\beta_{jlk} - \delta_{jlk}) I_M)$.

Combining (7) and (2) gives

$$E\{g_{jk}^H h_{jlk}\} = \frac{\beta_{jlk}}{M\delta_{jjk}\sqrt{\beta_{jjk}\beta_{llk}}} E\{\hat{h}_{jjk}^H \hat{h}_{jjk}\} + \frac{l}{M\delta_{jjk}} E\{\hat{h}_{jjk}^H \hat{h}_{jjk}\} \qquad (11)$$

Let $X \cong [x_l, x_2, \dots, x_M]^T$, $Y \cong [y_l, y_2, \dots, y_M]^T$, X and Y are independent of each other and obey the following distributions, $X \sim CN(0, \sigma_l^2 I_M)$, $Y \sim CN(0, \sigma_2^2 I_M)$, then [8]

$$E[|X^H X|^2] = \sigma_l^4 M(M+2) \qquad (12)$$

$$E[|X^H Y|^2] = \sigma_l^2 \sigma_2^2 M \qquad (13)$$

Combining (11) with (12) gives

$$E\{|g_{jk}^H h_{jlk}|\}^2 = \frac{(M+2)\beta_{jlk}^2}{M\beta_{jjk}\beta_{llk}} + \frac{\beta_{jlk} - \delta_{jlk}}{M\delta_{jjk}} \qquad (14)$$

For $m \neq k$, we have

$$E\{|g_{jk}^H h_{jlm}|\}^2 = E\left\{\left|\frac{l}{M\delta_{jjk}} \hat{h}_{jjk}^H h_{jlm}\right|\right\}^2 = \frac{\beta_{jlm}}{M\delta_{jjk}} \qquad (15)$$

C. Uplink Rate

If the user k in cell j is within the coverage of the i^{th} directional large line array of the base station, then in the uplink, the signal received by the i^{th} directional large line array of the base station can be expressed as

$$y_{ji}^{data} = \sum_{l=l}^{L} \sum_{m=l}^{K} \xi_{jklm} \sqrt{\frac{\rho}{\beta_{llm}}} h_{jlm} s_{lm} + n_{ji} \qquad (16)$$

Where, $s_{lm} \in C$ represents the data symbol sent by user m in cell l and satisfies $E\{|s_{lm}|^2\} = l$; the last term represents the additive white Gaussian noise received by large line array i, $n_{ji} \sim CN(0, \sigma^2 I_M)$.

At this point, the detection result of the data sent by user k in cell j can be expressed as

$$x_{jk} = \sum_{l=l}^{L} \sum_{m=l}^{K} \xi_{jklm} \sqrt{\frac{\rho}{\beta_{llm}}} g_{jk}^H h_{jlm} s_{lm} + g_{jk}^H n_{ji} \qquad (17)$$

Assuming that S symbols can be transmitted in a coherent time interval, of which τ symbols are used to transmit pilots, and the rest are used for uplink data transmission, the reachable rate of k^{th} user in j^{th} cell is [22]

$$R_{jk} = \left(l - \frac{\tau}{S}\right) lb(l + SINR_{jk}) \qquad (18)$$

where, $SINR_{jk}$ represents the signal-to-interference noise ratio of k^{th} user in j^{th} cell. Obviously, R_{jk} is positively correlated with $SINR_{jk}$. From equation (l7), the calculation of $SINR_{jk}$ is shown in equation (19).

$$SINR_{jk} = \frac{\frac{\rho}{\beta_{jjk}} E\{|g_{jk}^H h_{jjk}|\}^2}{\sum_{l=l}^{L}\sum_{m=l}^{K} \xi_{jklm} \frac{\rho}{\beta_{llm}} E\{|g_{jk}^H h_{jlm}|^2\} - \frac{\rho}{\beta_{jjk}} E\{|g_{jk}^H h_{jjk}|\}^2 + \sigma^2 E\{\|g_{jk}\|^2\}} \qquad (19)$$

In formula (19), the numerator represents the effective gain of the target user's signal, and the denominator represents the interference gain caused by other users within the coverage area of the same directional line array to the target user and the additive noise of the system. Combining equations (14) and (15), equation (19) can be rewritten and reduced to

$$SINR_{jk} = \frac{\frac{\delta_{jjk}}{\beta_{jjk}}(M+2) + \frac{\beta_{jjk} - \delta_{jjk}}{\beta_{jjk}}}{\sum_{m\neq k} \xi_{jkjm} + \sum_{l\neq j}\sum_{m\neq k} \xi_{jklk} \left(\frac{(M+2)\delta_{jjk}}{\beta_{jjk}} \left(\frac{\beta_{jlk}}{\beta_{llk}}\right)^2 + \frac{\beta_{jlk} - \delta_{jlk}}{\beta_{llk}}\right) + \frac{\sigma^2}{\rho}} \qquad (20)$$

In the denominator of equation (20), the first term indicates interference caused by other user signals in the cell to the target user signal, the second term indicates user interference caused by other cells using different pilots with the target user, and the third term indicates, pilot contamination caused by users who have reused the same pilot sequence as the target user, the last term represents additive noise.

IV. PILOT DISTRIBUTION SCHEME

A. Specific Steps for Pilot Distribution Scheme

As shown in Fig l, according to the coverage of different directional line arrays in the base station of the target cell, the system can be divided into 6 sectors. For each sector, the part located in the target cell is recorded as the target area; the rest is recorded as the interference area. It can be found that, in each sector, the area occupied by the target area is much lower than the area of the interfering cell, and the number of users in the target area is also much lower than the number of users in the interference area. In other words, in an interfering cell, not all interfering users will cause pilot contamination to users in the target area. Therefore, through effective allocation of pilots, orthogonal pilots are allocated to interfering users close to the target user, and interference users away from the target user can reuse the same pilots as the target user, which can effectively reduce the pilot contamination of the system, thereby Increase the reachability of the system.

Therefore, in this paper pilot allocation scheme is proposed based on the information of user location. The specific operational steps of this scheme are as follows.

Step l Establish a polar coordinate system. With the base station as the pole, a polar coordinate system is established in the range of all the cells, where all cells have the same polar axis direction.

Step 2 Calculate user polar coordinates. According to the location relationship between the base station and the user in the cell, the user's position information is converted into polar coordinates in the polar coordinate system of the cell, where the polar angle coordinates of the user are represented by $\theta, -\pi \leq \theta < \pi$.

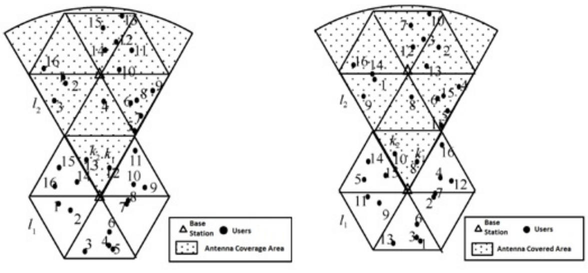
Step 3 Sort. According to the magnitude of the polar angle θ, all users in the cell are sorted in ascending order.

Step 4 Pilot allocation. The consecutive users are numbered with consecutive natural numbers $l, 2, \dots, N (N \leq \tau)$, and each number corresponds to an orthogonal pilot.

For a single cell, the base station needs to collect the location information of all users in the cell and complete the pilot allocation work described above. For different cells, the base station of each cell only needs to complete the pilot assignment in the cell in which it is located, and does not need to participate in the pilot assignment tasks of other cells.

Taking two of the cells in Fig. l as an example, Fig. 2 (a) and Fig. 2 (b) show the pilot allocation results after using the pilot allocation scheme and the conventional random pilot allocation scheme, respectively. In Fig 2, 11th cell is the target cell, and 12th cell is the interfering cell; the target users in the shadow area of the target cell are recorded as users k_l and k_2 in turn; each pilot number corresponds to an orthogonal pilot. In an interfering cell, an interfering user with the same number as the target user will cause pilot contamination to the target user.

In the case of known user distribution, the pilot allocation result is different from that determined by the proposed scheme. Due to the randomness of pilot allocation, there are many different pilot allocation results in the traditional scheme. Fig 2 (b) only shows the situation.



(a) Proposed Frequency allocation Scheme

(b) Pilot Distribution Scheme

Fig 2. Pilot Distribution

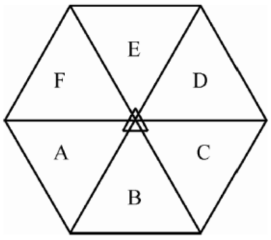


Fig 3. Cell Division

B. Performance Analysis

As shown in Fig 3, according to the coverage of different directional large line arrays in the base station, the cell can be evenly divided into 6 areas, which are marked with the letters A to F, respectively. In the proposed pilot allocation scheme, pilots are allocated to users in turn according to the size of polar angle coordinates. Therefore, especially in the case of uniform user allocation, users with the same pilot number in different cells are more likely to combine in the same numbered area. As shown in Fig. 2 (a), the users in the interfering 12th cell multiplexing the same pilots with the target users k_l, k_2 are all distributed in the area *E*, thereby ensuring the pilot reuse distance. In the traditional random pilot allocation scheme, as shown in Fig 2 (b), any user in the interference cell range may reuse the same pilot as the target user.

i. Channel Estimation Error

Here

$$\mu_{jlm} = \sum_{l\neq j}\xi_{jmlm}\frac{\beta_{jlm}}{\beta_{llm}} = \sum_{l\neq j}\xi_{jmlm}\left(\frac{\|z_{lm}-b_l\|}{\|z_{lm}-b_j\|}\right)^k \quad (21)$$

The normalized mean square error (NMSE) of the user channel estimation results in the target cell can be obtained by (2).

$$NMSE = E\left\{\frac{\|h_{ijm}-\hat{h}_{jjm}\|^2}{\|h_{jjm}\|^2}\right\} = E\left\{\frac{\mu_{jlm}+\frac{\sigma^2}{\rho\tau}}{l+\mu_{jlm}+\frac{\sigma^2}{\rho\tau}}\right\} \quad (22)$$

In general, since $\mu_{jlm} \ll l+\frac{\sigma^2}{\rho\tau}$, the NMSE can be approximated as

$$NMSE = \frac{E\{\mu_{jlm}\}+\frac{\sigma^2}{\rho\tau}}{l+\frac{\sigma^2}{\rho\tau}} \quad (23)$$

According to equation (23), the NMSE of channel estimation is mainly affected by pilot contamination, SNR, and pilot length. where, $E\{\mu_{jlm}\}$ represents the impact of pilot contamination on the NMSE. The result is only related to the location distribution of the interference users, which can be obtained based on the distribution of the interference users that cause the pilot contamination. It's calculation formula is

$$E\{\mu_{jlm}\} = \sum_{l\neq j}\xi_{jmlm}\frac{\iint\left(\frac{\|z_{lm}-b_l\|}{\|z_{lm}-b_j\|}\right)^k d\sigma}{\iint d\sigma} \quad (24)$$

where, Ω represents the distribution area of the interfering users who reuse the same pilot as the target user. In the random pilot allocation scheme, the area is the entire range of the interfering cell; in the proposed pilot allocation scheme, especially in the case of uniform user distribution, the area is usually a triangle in the interfering cell with the same number as the target area region.

From (24), it can be known that the farther away the interfering user who uses the same pilot from the target user is away from the target base station, the less pilot contamination is caused, and the lower the NMSE is. Obviously, the proposed scheme guarantees the pilot reuse distance. Compared with the traditional random pilot allocation scheme, this scheme has certain performance advantages in channel estimation.

ii. Signal to Interference Noise Ratio

On simplifying (20), when the number of large lines $M \to \infty$ is given as

$$\lim_{M\to\infty} SINR_{jk} = \sum_{l\neq j}\xi_{jklk}\left(\frac{\beta_{llk}}{\beta_{jlk}}\right)^2 = \sum_{l\neq j}\frac{l}{\mu_{jlk}^2} \quad (25)$$

Obviously, when M → ∞, the SINR of the target signal will be limited by the pilot contamination and the pilot contamination becomes the main factor affecting the SINR. Under the proposed pilot allocation scheme, because pilot contamination is controlled in a lower range, SINR can often achieve a higher value.

When the number of large lines is limited, it can be found from equation (20) that in addition to pilot contamination caused by pilot multiplexing, other users in the coverage area of the same large line array will also cause interference to target users. When pilot contamination is reduced to a certain extent, the impact of pilot contamination on SINR can be almost ignored. Because the proposed scheme guarantees the distance of pilot multiplexing, pilot contamination can be controlled in a lower range, and when the interference other than pilot contamination is relatively serious, it can achieve performance close to that without pilot pollution.

iii. System Fairness

In the traditional pilot allocation scheme, pilot sequences are randomly assigned to different users. In Fig. 2 (b), any user in the interfering cell 12th may reuse the same pilots as the target users k_l and k_2, and there is a huge difference in the pilot contamination caused by the target users in different multiplexing situations. As shown in Fig 2 (b), the pilot reuse distance of user k_l is much lower than that of user k_2, and user k_l will be polluted by pilots far below k_2, thereby achieving a higher reachable rate. Therefore, in the traditional random pilot allocation scheme, there is serious unfairness. The proposed scheme utilizes the user's location information, and assigns pilots to users in turn according to the size of the polar angle, so that the signal strength of user signals with adjacent pilot numbers in the interfering cell will be closer when they reach the target base station. Within the coverage of a directional large line array, since users in the target area have adjacent pilot numbers, the intensity of pilot contamination to different users is also relatively close. Therefore, the fairness of the system is improved with proposed scheme to a certain extent, so that all users can obtain a higher reachable rate.

Table 1: Simulation Parameters

Parameters	Values
Number of cells	L=14
Pilot length	$\tau = 32$
Number of users	K=32
Cell radius/m	R=600
Path loss index	*K=3.9*
Large lines	M=256
SNR/dB	$\frac{\rho}{\sigma^2} = 10$

Table 2: Ratio of the user pilot interference and the cell radius to the target cell base station

Method	Average Minimum	Average Value	Variance
Random Assignment	1.14	1.7	0.11
Proposed Method	1.78	2.09	0.07
SPA Method	1.47	1.83	0.20

Table 3: Ratio of the user pilot interference and the cell radius to the target cell base station

Method	Average Minimum	Average Value	Variance
Random Assignment	0.35	0.72	0.052
Proposed Method	0.35	0.52	0.042
SPA Method	0.09	0.56	0.033

V. SIMULATION RESULTS

The Monte Carlo simulations are used for the proposed method to improve the performance efficiency. In this simulation, a cellular network consisting of hexagonal L cells is considered. Each cell contains K single-line users and a large-scale large-line base station. Each base station consists of 6 M-line lines, it consists of directional large line arrays. Each large line array covers a sector with an angle of $\pi/3$. The simulation model is shown in Fig l. Assume that the communication process adopts TDD mode, and the channel is subject to fast fading, i.e., the channel parameters remain unchanged during the coherence time. The detection algorithm uses the MRC algorithm. The default simulation parameters of the system are shown in Table l.

In order to be able to analyze the performance of the proposed scheme more objectively, the traditional random pilot allocation scheme, smart pilot assignment (SPA) scheme [16] and pilotless pilot scheme are also added to the simulation experiments in this section. The contamination situation is for comparison. Among them, the SPA solution first uses the large-scale fading coefficient of the channel to calculate the multi-user interference intensity of all users in the target cell, and ranks the users in descending order according to the magnitude of the interference intensity, and then uses the exhaustive method to preferentially prioritize the interference. Serious users choose the best pilot. The SPA solution needs to use an exhaustive method to sequentially select the optimal pilot for different users. The calculation complexity of this solution is $O\ (K\ lg\ K)$, while the random pilot allocation scheme and the scheme proposed in this paper do not require the computational complexity of lifting or iterating operations is only $O(l)$.

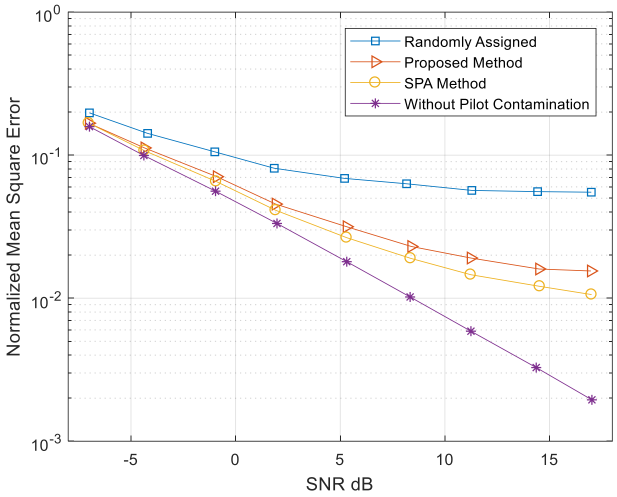


Fig 4: Normalized mean square error at different signal-to-noise ratios

From Equation (24), it can be seen that when the distance from the interfering user to the interfering cell base station is constant, the longer the distance from the interfering user to the target cell base station, the lighter the interference to the target user. The proposed scheme controls the pilot contamination to target users by controlling the distance between the pilot interference users and the target base station in a relatively long range. Tables 2 and 3 show the ratio of the distance between the pilot interference user to the target cell and the cell base station to the cell radius, respectively. Comparing the data of the random pilot allocation scheme and the proposed scheme, it can be found that in the two schemes, the average distance between the pilot interference user and the base station of the cell is almost the same, and the average distance between the user and the target cell base station in the proposed scheme is significantly more Random allocation scheme. In particular, in the random allocation scheme, the distance between some pilot interference users and the target base station is very close, and these users may cause serious pilot contamination to the target user. In addition, the variance of the distance between different interfering users and the target cell base station in the proposed solution is lower, which indicates that the difference in pilot contamination intensity caused by different interfering users to the target user is smaller, thereby improving the fairness of the system to a certain extent. Comparing the data of the proposed scheme with the SPA scheme, it can be found that although the average distance between the pilot interference user and the target base station is longer in the proposed scheme, the distance between the interference user and the base station of the cell in the SPA scheme is relatively closer. It can be found from equation (24) that the intensity of pilot interference is also closely related to the distance between the interference user and the base station in the cell. This is because the simulation system in this paper performs power control on the user's transmit power. The closer the user is to the base station in the cell, the lower the user's transmit power, and the interference to neighbouring cells is reduced accordingly.

Therefore, the performance of the proposed scheme and the SPA scheme need to be further compared.

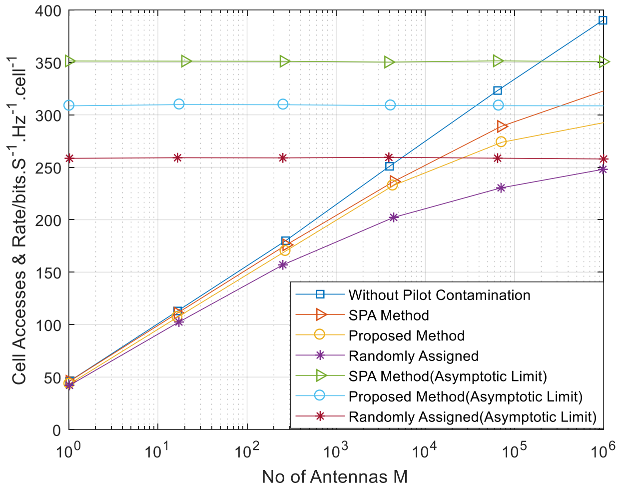


Fig 5: Cell Reachability and rate under different large line numbers

As shown in Fig 4, under different SNRs, the normalized mean square error of the proposed scheme is significantly lower than the traditional random pilot allocation scheme, and the proposed scheme can effectively improve the accuracy of channel estimation. Compared with the SPA scheme, the normalized mean square error of the proposed scheme is slightly higher, but it is also relatively close. In addition, when the SNR is low, the normalized mean square error of the proposed scheme, the SPA scheme, and the absence of pilot contamination is very close, indicating that under the condition of low SNR, the proposed scheme and the SPA scheme can provide close to non-leading Frequency contamination performance. With the improvement of SNR, the normalized mean square error curves of the random allocation scheme, the proposed scheme and the SPA scheme have all stabilized. At this time, as the noise interference has decreased to a certain extent, pilot contamination has affected the channel estimation results.

Fig 5 shows the reachability and rate of all users in the cell for different large line numbers. It can be seen from Fig. 5 that under the condition of pilot pollution, the reachable rate of the SPA scheme is the highest, and the proposed scheme is the second, and the performance of the random pilot allocation scheme is the worst. In particular, when the number of large lines of the base station is less than 10^4, the performance of the proposed scheme is very close to that of the SPA scheme, and both are close to the situation without pilot pollution. From Equation (20), it can be known that when the number of large base stations is small, interference factors other than pilot contamination (including multi-user interference and noise interference, hereinafter referred to as non-pilot interference) are still in the total interference signal. Occupy a larger proportion. At this time, when the pilot contamination drops to a certain level (much lower than non-pilot interference), the impact of pilot contamination on reachability and rate can be almost ignored. Since the proposed scheme and the SPA scheme can control pilot contamination in a lower range, when the number of large lines is small, it can provide performance close to that without pilot pollution. With the increase of the number of base stations, the proportion of pilot contamination in the interference source is increasing, and the impact of non-pilot interference on system performance can be gradually ignored. From equation (25), we can know that when the number of large lines approaches infinity, SINR is inversely proportional to the square of the pilot pollution. The dashed lines in Fig 5 indicate the random access, the proposed scheme, and the SPA scheme. As the number of large lines approaches infinity, the user's reachability and the asymptotic limit of the rate.

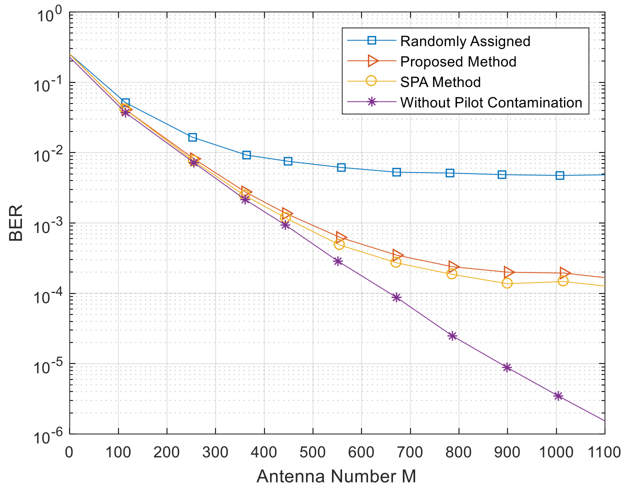


Fig 6. BER of signal transmission under different large line numbers

In the presence of pilot pollution, the reachability and rate of the cell increase with the increase of the number of lines, and gradually approach its performance limit. In the absence of pilot pollution, the reachability and rate of the cell can always maintain an approximately proportional relationship with the logarithm of the large number of lines.

Fig 6 shows the uplink data transmission bit error rate (BER, bit error rate) under 8 phase shift keying (8PSK) modulation. As shown in Fig 6, when the number of large lines is relatively limited, the bit error rate of the proposed scheme is very close to that of the SPA scheme, and both are significantly lower than the random pilot allocation scheme. At this stage, massive MIMO base stations are usually only equipped with one or two hundred large lines. Although the performance of the proposed scheme is still slightly lower than the SPA scheme at this time, considering that the computational complexity of the proposed scheme is much lower than that of the SPA scheme, the application of the proposed scheme in actual systems still has great advantages.

Fig 7 shows the cumulative distribution function (CDF) of the user's SINR in uplink transmission. In Fig 7, the steeper the CDF curve, the smaller the SINR difference between different users, the higher the fairness of the system. Obviously, the CDF curves of the proposed scheme, the SPA scheme, and the case without pilot contamination are significantly steeper than the CDF curves of the random pilot allocation scheme, indicating that the proposed scheme, the SPA scheme, and the case without pilot contamination all have higher levels. System fairness. In particular, in the traditional random pilot allocation scheme, about 10% of the users have SINRs lower than 10 dB, and the reachable rate of these users is much lower than other users, which results in serious system unfairness.

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In the proposed scheme and the SPA scheme, the SINR of almost all users exceeds 10 dB, and the communication quality of all users is guaranteed. In addition, according to the partial enlargement of the CDF curve in Fig 7, it can be seen that the CDF curve of the SPA scheme is slightly steeper than the proposed scheme, indicating that the system of the SPA scheme is more fair, but in general, the difference is not large.

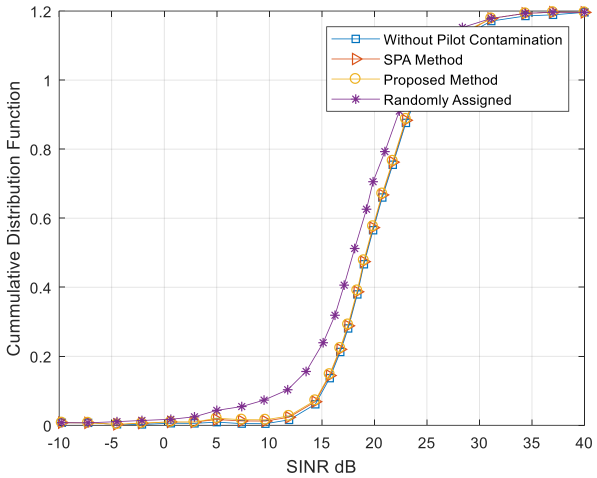

Fig 7. Cumulative Distribution Function of Signal-to-Noise Ratio for User Signals

VI. CONCLUSION

This paper proposes a pilot allocation scheme based on user location information. This scheme sorts users and assigns pilots in sequence according to the polar angle of the user's location in the polar coordinate system with the cell base station as the pole. This solution combines the characteristics of directional lines, which can control pilot contamination among users at a low level. Theoretical and simulation results show that the proposed scheme can effectively reduce pilot contamination among users, thereby improving the accuracy of channel estimation, increasing the reachable rate of user transmission, and reducing the bit error rate of data transmission. In addition, the proposed scheme makes the SINR of different users closer by reducing the randomness of pilot allocation, which improves the fairness of the system. In simulation experiments, the performance of the proposed scheme is very close to that of the SPA scheme, and the computational complexity of the proposed scheme is much lower than the latter.

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