Interference alignment for D2D based on power control and MMSE

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ABSTRACT

In order to reduce the interference of device-to-device (D2D) users to cellular users, in the case of satisfying the preset communications rate, this paper proposes an effective interference alignment algorithm for D2D communications based on power control and Minimum Mean Square Error (MMSE). The proposed algorithm firstly utilizes the MMSE to derive the received precoding matrix based on the initialized transmitted precoding matrix and power allocation matrix, and then in the case of fixed communications rate, using the evaluation iteration or Lagrange duality based power control to derive new power allocation matrix. Finally the updated transmitted precoding matrix can be obtained based on the channel reciprocity. Simulation results show that, compared with the existing algorithm, the proposed algorithm not only can reduce transmitted power, but also satisfies the preset communication rate.

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Key Words

Device-to-device (D2D); communications; power control; minimum mean square error (MMSE); interference alignment

1. INTRODUCTION

As one of key technologies for future 5th generation (5G) mobile communications, Device-to-device (D2D) communications has the characteristics of high rate and low delay. In recent years, As the number of mobile users grows, spectrum shortages become increasingly serious. The shared spectrum between D2D users and cellular users, or within D2D users, have become the main research trend. At the same time, the interference between D2D users and the cellular users, and within D2D users, become one of the factors that restrict the large-scale commercial use[1-5]. Interference alignment, as an effective interference management mechanism, makes the interference from the different transmitters aligned to the same subspace, and the rest of the interference-free space is used to receive the desired signal[6-9]. Because of the flexibility of the D2D user's network, interference alignment is observed as an effective method to solve the problem of interference between D2D users. Therefore, Effectively reduce the D2D user's transmit power and reduce the interference of cellular users become a meaningful research topic.

So far, there are relatively few research about the interference alignment technology in D2D communication [10-12]. Reference [10] only simply analyses the totally freedom degree obtained in system where contains K cells and each cell has

Q antennas. Reference [11] proposes three grouping mechanisms to realize the small scale interference alignment. It is assumed that D2D users use the orthogonal spectrum with cellular users, hence does not consider the interference to cellular users. Reference [12] summarizes the application of interference alignment in D2D communications. The number of research on interference alignment in cellular network and heterogeneous network is numerous, such as the minimizing the interference leakage [12], the maximum Signal Interference Radio (SIR) [14], the Minimum Mean Square Variance Error (MMSE) [15], and a new interference alignment algorithm [16]. In above algorithms, the power of the users is averagely allocated, and the optimization goal is the maximum throughput or the spectrum efficiency, without considering the power control.

In addition, there are few research focus on interference alignment based on the power control in cellular communications. References [17-23] use the water-filling power allocation algorithm to maximize the throughput, and they do not consider to the reduction of the transmitted power of users. Authors in [13], in order to satisfy the data rate, propose an interference alignment algorithm whose goal is to minimize the user's transmitted power. In this algorithm, the transmitted / receiving pre-coding matrices are calculated by minimizing the interference leakage, and the power allocation matrix is updated by the power control based on the assignment iteration, but the transmitted power allocation is not optimal [15, 28]. In conclusion, an interference alignment algorithm that can be efficiently applied in D2D communications is essential.

Aiming at solving challenges above, in order to reduce the interference of D2D users to cellular users, that is, to reduce the transmission power of users in the case of satisfying the communications rate, an interference alignment algorithm based on power control and MMSE is proposed. The simulation results show that the proposed algorithm can effectively reduce the transmission power of D2D users under the premise of the preset data rate.

2. SYSTEM MODEL

We assume that the cell includes a group of D2D users. A D2D group includes K pairs of D2D users ($D2D_1,\dots,D2D_K$), and the same spectrum is used between those D2D pairs. For the i^{th} D2D pairs, $D2D_i,\ i\in\{1,\dots,\mathrm{K}\}$, the number of antennas in the transmitter and the receiver are respectively M_i and N_i , and The transmitter sends d_i data streams simultaneously, i.e. the user’s degree of freedom is $\left[d_1,\dots,d_K\right]$, $d_i\le\min\left(M_i,N_i\right)/2$. Therefore, the transmitting signal from the D2D transmitter is represented as

$$\boldsymbol{x}_i=\sum_{l=1}^{d_i}v_i^l s_i^l=\boldsymbol{V}_i\boldsymbol{S}_i \tag{1}$$

where, $\boldsymbol{V}_i=\left[\boldsymbol{v}_i^1,\dots,\boldsymbol{v}_i^{d_i}\right]$ is a $N_i\times d_i$ matrix, called D2D transmitted pre-coding matrix, and satisfies $\boldsymbol{V}_i\left(\boldsymbol{V}_i\right)^H=\boldsymbol{I}_{d_i}$. $\boldsymbol{S_i}=\left[s_i^1,\dots,s_i^{d_i}\right]^T$ is the d_i data stream of D2D. Furthermore, the power of the l^{th} $(l\in\{1,\dots,d_i\})$ data stream of $D2D_i$ is $E\left[s_i^l\left(s_i^l\right)^H\right]=p_i^l$ and the transmission power matrix is $\boldsymbol{P}_i=\left[p_i^1,\dots,p_i^l\right]^T$. $\boldsymbol{A}^T$ and $\boldsymbol{A}^H$ are the transpose matrix and associate matrix of $\boldsymbol{A}$.

Therefore, the receiving signal of the D2D receiver is:

$$\boldsymbol{y}_i=\boldsymbol{H}_{ii}\boldsymbol{V}_i\boldsymbol{x}_i+\sum_{\substack{j=1\\ j\ne i}}^{K}\boldsymbol{H}_{ij}\boldsymbol{V}_j\boldsymbol{x}_j+\boldsymbol{n}_i\,. \tag{2}$$

where the $\boldsymbol{H}_{ii}$ of the dimension $N_i\times M_i$ is the channel matrix, which is from the transmitter $D2D_i$ to the receiver $D2D_i$, while the $\boldsymbol{H}_{ij}$ with the dimension $N_i\times M_j$ is the channel matrix between the transmitter $D2D_j$ and receiver $D2D_i$. The elements of $\boldsymbol{H}$ obey the circularly symmetric complex Gaussian distribution with zero mean and unit variance. The noise $\boldsymbol{n}_i$ with the dimension $N_i\times 1$ is the additive white

Gaussian noise with the zero mean and unit variance. In the receiver side, the receiving signal of $D2D_i$ is processed by the $N_i \times d_i$ receiving pre-coding matrix $\boldsymbol{U}_i$. It is represented as:

$$\begin{aligned}&\overline{\boldsymbol{y}_i} = \boldsymbol{U}_i^H \boldsymbol{y}_i = \\ &\boldsymbol{U}_i^H \boldsymbol{H}_{ii}\boldsymbol{V}_i\boldsymbol{x}_i + \sum_{\substack{j=1\\ j\neq i}}^{K} \boldsymbol{U}_i^H \boldsymbol{H}_{ij}\boldsymbol{V}_j\boldsymbol{x}_j + \boldsymbol{U}_i^H \boldsymbol{n}_i\end{aligned} \tag{3}$$

where $\boldsymbol{U}_i = \left[\boldsymbol{u}_i^1,...,\boldsymbol{u}_i^{d_i}\right]$, $\boldsymbol{U}_i\left(\boldsymbol{U}_i\right)^H = \boldsymbol{I}_{d_i}$.

3. INTERFERENCE ALIGNMENT ALGORITHM BASED ON POWER CONTROL AND MMSE

In order to solve the optimal transmitted pre-coding matrix $\boldsymbol{V}_i$, receiving pre-coding matrix $\boldsymbol{U}_i$, and power allocation matrix $\boldsymbol{P}_i$. The implementation steps are shown below:

3.1: Solving the Receiving Pre-coding Matrix

Select the transmitted pre-coding matrix $\boldsymbol{V}_i$ and power allocation matrix $\boldsymbol{P}_i$ randomly, with the condition of $\boldsymbol{V}_i\left(\boldsymbol{V}_i\right)^H = \boldsymbol{I}_{d_i}$. In $D2D_i$ receiver side, this paper uses the MMSE criterion to solve receiving pre-coding matrix, therefore, we get the following optimization problems:

$$\begin{aligned}&\min_{\boldsymbol{U}_i} E\left\{\left\|\boldsymbol{U}_i^{\boldsymbol{H}} \boldsymbol{y}_i - \boldsymbol{x}_i\right\|_2^2\right\} = \\ &E\left\{\left\|\boldsymbol{U}_i^{\boldsymbol{H}}\left(\sum_{j=1}^{K} \boldsymbol{H}_{ij}\boldsymbol{V}_j\boldsymbol{x}_j + \boldsymbol{n}_i\right) - \boldsymbol{x}_i\right\|_2^2\right\} \\ &\forall i, j = 1,...,K. \\ &\mathrm{s.}t.\ \boldsymbol{V}_j\left(\boldsymbol{V}_j\right)^H = \boldsymbol{U}_i\left(\boldsymbol{U}_i\right)^H = \boldsymbol{I}_{d_i}, \\ &\qquad E\left[s_i^l\left(s_i^l\right)^H\right] = p_i^l, \\ &\qquad E\left[\boldsymbol{U}_i^{\boldsymbol{H}}\boldsymbol{n}_i\left(\boldsymbol{U}_i^{\boldsymbol{H}}\boldsymbol{n}_i\right)^H\right] = \boldsymbol{I}_{N_i}.\end{aligned} \tag{4}$$

It is assumed that the noise vector $\boldsymbol{n}_i$, the transmission signal vector $\boldsymbol{x}_i$ and the channel matrix $\boldsymbol{H}_{ij}$ are independent to each other. Based on matrix operation, the objective function of equation (4) can be expressed as:

$$\begin{aligned}F_{MMSE}^U &= E\left[Tr\left(\boldsymbol{U}_i^{\boldsymbol{H}}\sum_{j=1}^{K}\boldsymbol{H}_{ij}\boldsymbol{V}_j\boldsymbol{x}_j + \boldsymbol{U}_i^{\boldsymbol{H}}\boldsymbol{n}_i - \boldsymbol{x}_i\right)\right. \\ &\left.\times\left(\boldsymbol{U}_i^{\boldsymbol{H}}\sum_{j=1}^{K}\boldsymbol{H}_{ij}\boldsymbol{V}_j\boldsymbol{x}_j + \boldsymbol{U}_i^{\boldsymbol{H}}\boldsymbol{n}_i - \boldsymbol{x}_i\right)^H\right] \\ &= Tr\left[\boldsymbol{U}_i^{\boldsymbol{H}}\left(\sum_{\boldsymbol{j=1}}^{\boldsymbol{K}}\boldsymbol{P}_j\boldsymbol{H}_{ij}\boldsymbol{V}_j\boldsymbol{V}_j^{\boldsymbol{H}}\boldsymbol{H}_{ij}^{\boldsymbol{H}}\right)\boldsymbol{U}_i\right. \\ &\left.+\boldsymbol{I}_{N_i} + \boldsymbol{P}_i\boldsymbol{I}\text{-}\boldsymbol{P}_i\boldsymbol{U}_i^{\boldsymbol{H}}\boldsymbol{H}_{ii}\boldsymbol{V}_i - \boldsymbol{P}_i\boldsymbol{V}_i^{\boldsymbol{H}}\boldsymbol{H}_{ii}^{\boldsymbol{H}}\boldsymbol{U}_i\right].\end{aligned} \tag{5}$$

Let $\partial\left(F_{MMSE}^U\right)/\partial\left(\boldsymbol{U}_i\right) = 0,\ i \in \{1,...,K\}$, according to the derivation property of matrix trace, receiving pre-coding matrix in the receive side can be solved as:

$$\boldsymbol{U}_i = \left(\sum_{j=1}^{K}\boldsymbol{P}_j\boldsymbol{H}_{ij}\boldsymbol{V}_j\boldsymbol{V}_j^{\boldsymbol{H}}\boldsymbol{H}_{ij}^{\boldsymbol{H}} + \boldsymbol{I}_{N_i}\right)^{\boldsymbol{-1}}\boldsymbol{P}_i\boldsymbol{H}_{ii}\boldsymbol{V}_i. \tag{6}$$

3.2: Power Control

Using the solved receiving pre-coding matrix, initialized transmitted pre-coding matrix and power allocation matrix in step one, under the premise of satisfying a certain data rate, by minimizing the transmitted power of D2D users, the optimization problem is obtained as:

$$\begin{aligned}&\min\sum_{i=1}^{K}\boldsymbol{P}_i = \sum_{i=1}^{K}\sum_{l=1}^{d_i}p_i^l, \quad \forall i \in \{1,...,K\}. \\ &s.t.\ C1: \sum_{l=1}^{d_i}\log_2(1+\mathrm{SINR}_i^l) \geq \mathrm{R}_i \\ &\qquad C2: 0 \leq \sum_{l=1}^{d_i}p_i^l \leq \mathrm{P}_i.\end{aligned} \tag{7}$$

where $SINR_i^l = \dfrac{\left\|\left(\boldsymbol{u}_i^l\right)^H\boldsymbol{H}_{ii}\boldsymbol{v}_i^l\right\|_2^2\boldsymbol{p}_i^l}{\sum\limits_{\substack{j=1\\ j\neq i}}^{K}\sum\limits_{m=1}^{d_j}\left\|\left(\boldsymbol{u}_i^l\right)^H\boldsymbol{H}_{ij}\boldsymbol{v}_j^m\right\|_{\boldsymbol{2}}^{\boldsymbol{2}}\boldsymbol{p}_j^m + \boldsymbol{I}}$, R_i is the minimum data rate of the i^{th} user, P_i is the maximum transmitted power of the i^{th} user.

3.2.1: Power Control Based on Assignment Iteration

In order to satisfy the requirements of the user's data rate, the above constraints must be satisfied as:

$$\sum_{l=1}^{d_i} \log_2(1+\mathrm{SINR}_i^l) \geq \mathrm{R}_i. \tag{8}$$

For obtaining the transmitted power limit of a single data stream, we assumed that the data rate of each user is greater than the average data stream rate. Therefore, we obtained:

$$\log_2(1+\mathrm{SINR}_i^l) \geq R_i \,/\, d_i. \tag{9}$$

Substitute the expansion of $SINR_i^l$ into formula (9), we obtained:

$$p_i^l \geq \frac{\left(2^{\frac{R_i}{d_i}}-1\right)\left(\sum_{\substack{j=1\\ j\neq i}}^{K}\sum_{m=1}^{d_j}\left\|\left(\boldsymbol{u}_i^l\right)^H \boldsymbol{H}_{ij}\boldsymbol{v}_j^m\right\|_{\boldsymbol{2}}^{\boldsymbol{2}} p_j^m+\boldsymbol{I}\right)}{\left\|\left(\boldsymbol{u}_i^l\right)^H \boldsymbol{H}_{ii}\boldsymbol{v}_i^l\right\|_2^2} \tag{10}$$

Then, formula (10) can be expressed as a function:

$$p \geq I(p) \tag{11}$$

Finally, iteration is done by $p(\mathrm{n}) = I\left(p(\mathrm{n}-1)\right)$, and using the solved receiving pre-coding matrix, initialized transmit pre-coding matrix and power allocation matrix in step one and minimum data rate, we can get minimum transmitted power. Due to the limitation of space, the proof of convergence is omitted, the specific proof can be seen in reference [13-28].

3.2.2: Dual Optimal Power Control Based on Lagrange

Using the method of Lagrange duality to solve the original optimization problem, we construct the Lagrange function:

$$\begin{aligned} L\left(p_i^l,\lambda_i^l,u_i^l\right) &= \sum_{i=1}^{K}\sum_{l=1}^{d} p_i^l \\ &+\sum_{i=1}^{K}\lambda_i\left(R_i-\sum_{l=1}^{d}\log_2\left(1+SINR_i^l\right)\right) \\ &+\sum_{i=1}^{K}\zeta_i\left(\sum_{l=1}^{d}p_i^l-P_i\right) \end{aligned} \tag{12}$$

where λ_i and ξ_i are the Lagrange multiplier in the constraint C1-C2, $\lambda_i \geq 0$, $\xi_i \geq 0$, $i \in \{1,2,...,K\}$.

The dual optimization problem of the original optimization problem is:

$$\max_{\boldsymbol{\lambda}\geq 0,\boldsymbol{u}\geq 0}\ \min_{p_i^l}\ L\left(p_i^l,\boldsymbol{\lambda},\xi\right) \tag{13}$$

The dual problem (13) consists of two sub-problems: internal maximization sub-problem and external maximization sub-problem.

3.2.2.1: Internal Maximization Sub-problem

With the given Lagrange multiplier $\boldsymbol{\lambda}$ and ξ, by using the standard convex optimization theory, the data flow power allocation of each user is solved from the optimization of formula (13). Therefore, calculate the partial derivative of p_i^l in (12), and let it equal to zero. i.e. $\frac{L\left(p_i^l,\lambda_i^l,\xi_i^l\right)}{\partial\left(p_i^l\right)}=0$. The optimal power allocation $\left(p_i^l\right)'$ is

$$\left(p_i^l\right)' = \frac{\lambda_i}{\ln 2\left(\xi_i+1\right)} - \frac{I+\sigma^2}{\left\|\left(u_i^l\right)^H H_{ii}v_i^l\right\|_2^2} \tag{14}$$

where $I=\sum_{\substack{j=1\\ j\neq i}}^{K}\sum_{l=1}^{d}\left\|\left(u_i^l\right)^H H_{ij}v_j^l\right\|_2^2 p_j^l$.

3.2.2.2: External Maximization Sub-problem

The external optimization sub-problem of (13) is based on the transmitted power of the user data stream determined by formula (14). Update Lagrange multipliers by using a gradient algorithm:

$$\lambda_i(\mathrm{t}+1)=\Big[\lambda_i(\mathrm{t}) + \varepsilon_1(\mathrm{t})\Big(\Big(R_i-\sum_{l=1}^{d}\log_2\left(1+SINR_i^l\right)\Big)\Big)\Big]^{+} \tag{15}$$

$$\xi_i(t+1)=\Big[\xi_i(t)+\varepsilon_2(t)\Big(\Big(\sum_{l=1}^{d}\left(p_i^l\right)-P_i\Big)\Big)\Big]^{+} \tag{16}$$

where $[A]^{+}=\max(0,\mathrm{A})$, $t\ (t=0,1,...,t_{\max})$ is the number of iterations, ε_a is the step size. $\varepsilon_a\geq 0,\ a=\{1,2\}$.

3.3: Solve The Transmitted Pre-coding Matrix

Using channel reciprocity, combining the updated receiving pre-coding matrix U_i and power allocation matrix $\boldsymbol{P}_i$ obtained in steps 1 and 2 with the MMSE criterion. Let $\overleftarrow{\boldsymbol{V}}_i=\boldsymbol{U}_i$. The following optimization problems are obtained:

$$\begin{aligned}
&\min_{\boldsymbol{V}_i} E\left\{\left\|V_i^{\boldsymbol{H}}\overleftarrow{\boldsymbol{y}}_i-\boldsymbol{x}_i\right\|_2^2\right\}=\\
&E\left\{\left\|\boldsymbol{V}_i^{\boldsymbol{H}}\left(\sum_{j=1}^{K}\overleftarrow{\boldsymbol{H}}_{ij}\boldsymbol{U}_j\boldsymbol{x}_j+\overleftarrow{\boldsymbol{n}}_i\right)-\boldsymbol{x}_i\right\|_2^2\right\}\\
&\forall i,j=1,...,K.\\
&\mathrm{s.}t.\ \ \boldsymbol{U}_j\left(\boldsymbol{U}_j\right)^H=\boldsymbol{V}_i\left(\boldsymbol{V}_i\right)^H=\boldsymbol{I}_{d_i}\\
&\qquad E\left[s_i^l\left(s_i^l\right)^H\right]=p_i^l\\
&\qquad E\left[\boldsymbol{V}_i^{\boldsymbol{H}}\overleftarrow{\boldsymbol{n}}_i\left(\boldsymbol{V}_i^{\boldsymbol{H}}\overleftarrow{\boldsymbol{n}}_i\right)^H\right]=\boldsymbol{I}_{M_i}.
\end{aligned} \tag{17}$$

Similar to the method of solving the receiving pre-coding matrix with the forward channel, the updated transmitted pre-coding matrix can be solved:

$$\boldsymbol{V}_i=\left(\sum_{j=1}^{K}\boldsymbol{P}_j\overleftarrow{\boldsymbol{H}}_{ij}\boldsymbol{U}_j\boldsymbol{U}_j^H\overleftarrow{\boldsymbol{H}}_{ij}^{\boldsymbol{H}}+\boldsymbol{I}_{M_i}\right)^{\boldsymbol{-1}}\boldsymbol{P}_i\overleftarrow{\boldsymbol{H}}_{ii}\boldsymbol{U}_i \tag{18}$$

Algorithm 1 is a power control flow chart based on assignment iteration.

Algorithm 1 Power Control Based on Assignment Iteration

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1： Initialize the transmitted pre-coding matrix $V_i$、$P_i$, and the maximum number of iterations $T_{\max}$, $\forall i\in\{1,...,K\}$, s.t. $V_iV_i^H=I_{d_i}$.
2： Using the MMSE criterion and formula (6), the receiving pre-coding matrix is calculated, then unitizing $U_i$.
3： a)： Using $p_i^l=\frac{\left(2^{\frac{R_i}{d_i}}-1\right)\left(\sum_{j=1,j\neq i}^{K}\sum_{m=1}^{d_j}\left\|\left(u_i^l\right)^H H_{ij}v_j^m\right\|_2^2 p_j^m+I\right)}{\left\|\left(u_i^l\right)^H H_{ii}v_i^l\right\|_2^2}$ and limited data rate $R_i$, update the transmitted power of the D2D user.
4： By using channel reciprocity, reverse channel matrix, let $\overleftarrow{V}_i=U_i$. By combining the MMSE criteria and formula (18), the transmitted pre-coding matrix is solved, then unitizing $V_i$.
5： Repeat steps 2-4, until the algorithm converges or $T=T_{\max}$
6： Output $V_i$、$U_i$ and $P_i$, $\forall i\in\{1,...,K\}$.
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Algorithm 2 is a power control flow chart based on Lagrange duality

Algorithm 2 Power Control Based on Lagrange

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1： Initialize the transmitted pre-coding matrix $V_i$、$P_i$, and the maximum number of iterations $T_{\max}$, $\forall i\in\{1,...,K\}$, s.t. $V_iV_i^H=I_{d_i}$.
2： Using the MMSE criterion and formula (6), the receiving pre-coding matrix is calculated, then unitizing $U_i$.
3： b)： The maximum number of iterations is assumed to be $t_{\max}$, the convergence threshold is $\varepsilon$, initialize the Lagrange multiplier $\lambda_i$ and $u_i$.
    b1： $for\ t=0$
    b2: The power allocation $(p_i^l)'$ is determined by using formula (14).
    b3: By using formula (15-16), the Lagrange multiplier $\lambda_i$ and $\xi_i$ are updated.
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b4:
    if $\sum_{i=1}^{K}\left(\left|\lambda_i(\mathrm{t}+1)-\lambda_i(\mathrm{t})\right|\right)+\sum_{i=1}^{K}\left(\left|\xi_i(\mathrm{t}+1)-\xi_i(\mathrm{t})\right|\right)$
        $\le \varepsilon$
      then convergence, $\left[p_i^l\right]^{opt}=\left[p_i^l\right]'$
    else
      $t=t+1$
    end if
b5: Repeat until the algorithm converges or $t=t_{\max}$.
4: By using channel reciprocity, reverse channel matrix, let
   $\overleftarrow{\boldsymbol{V}_i}=\boldsymbol{U}_i$. By combining the MMSE criteria and formula
   (18), the transmitted pre-coding matrix is solved, then
   unitizing $\boldsymbol{V}_i$.
5: Repeat steps 2-4, until the algorithm converges
   or $T=T_{\max}$
6: Output $\boldsymbol{V}_i$、$\boldsymbol{U}_i$ and $\boldsymbol{P}_i$, $\forall i\in\{1,\dots,K\}$.
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4. SIMULATION RESULTS AND PERFORMANCE ANALYSIS:

In MATLAB simulation, suppose there is only one group of D2D in one cell, the number of D2D pairs in the group is three. The number of the transmitted antennas M_i and the receiving antennas N_i of each D2D user are equal to 2 and freedom degree of each user is equal to 1, i.e. $d_1=d_2=d_3=1$. Assuming that the channels between all transmitted and receiving antennas are flat Rayleigh fading channels, the channel matrix elements are independent and identically distributed, and they obey the complex Gaussian symmetric random distribution with 0 mean and unit variance. Compared with the reference [13], assuming that the user data rate is limited to R=[1064] (bps/Hz), initializing $p_i^l/n_i=60(dB)$, and the maximum user transmitted power is $\boldsymbol{P}_i=60$.

Figure 1 is a graph of the average transmission power of the user as the number of iterations increases. It can be seen from Fig. 1 that compared with the algorithm in [13], the transmitted power of the user in the algorithms 1 and 2 proposed in this paper are lower. In [13], even though the user's power control is considered, the transmitted / receiving pre-coding matrix are calculated by minimized interference leakage criterion and the transmitted power is updated by the assignment iteration. Algorithm 1 in this paper uses the MMSE criterion, because of the full consideration of direct channels, interference channels and the impact of noise, compared with the literature [13] based on minimizing interference leakage, the average transmitted power of the user can be reduced. Algorithm 2 in this paper combines MMSE criterion with the optimal power control based on Lagrange duality, compared with the reference [13] and algorithm 1 in this paper, because of the fact that the global optimal solution of Lagrange duality is better than the power control based on assignment iteration, the average transmitted power of the user is further reduced. Although the maximized SINR algorithm adequately considers the effects of direct channels, interfering channels and noise, the performance and convergence rate is worse than MMSE algorithm in [15] under the imperfect channel. Therefore, the MMSE is used to solve the pre-coding matrix criterion.

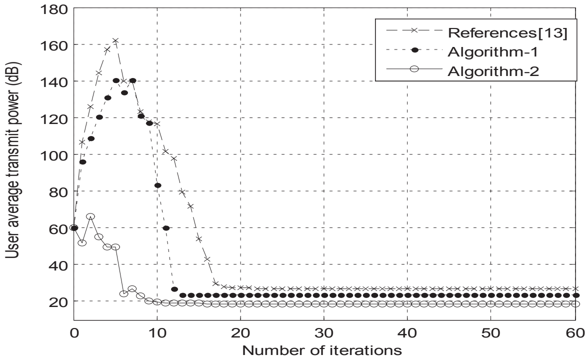
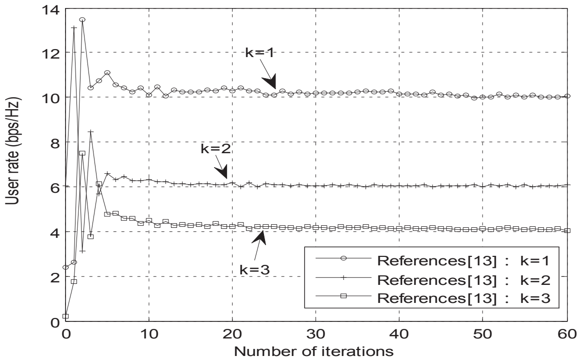
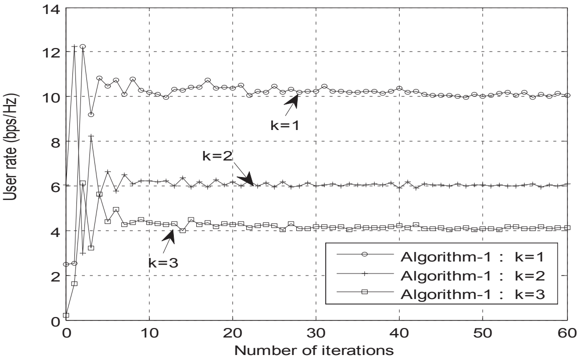


Figure 1 User average transmit power vs. Number of iterations.

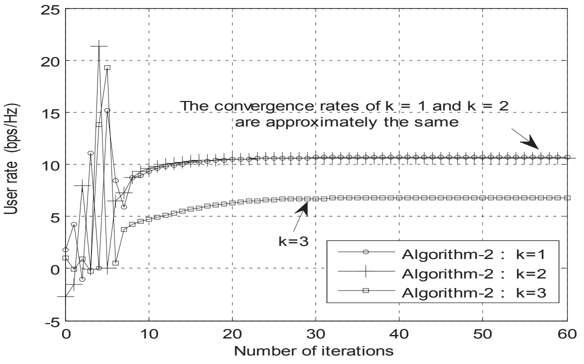
Figure 2 (a-c) show the user's data rate under various number of iterations. It can be seen from the figure, as the number of iterations increasing, the algorithms 1 in this paper and the algorithms in [13] converge to the desired data rate. Using the MMSE criterion and the optimal power control based on Lagrange duality, the final convergence rate of algorithm 2 in this paper is faster than that of algorithm 1 and [13].



(a) Reference [13]—User rate vs. Number of iterations.



(b) Algorithm 1—User rate vs. Number of iterations.



(c) Algorithm 2—User rate vs. Number of iterations.

Figure 2 User rate for different algorithms vs. Number of iterations.

In terms of algorithm complexity, according to the flowcharts of algorithm 1 and 2, in Step 3 of algorithm 2, using Lagrange pairs for power to optimize, compared with algorithm 1 and [13], the increase of the iteration leads to higher algorithm complexity.

In conclusion, algorithm 1 and algorithm 2 proposed in this paper satisfy the preset data rate, although the algorithm 2 increases the complexity of the algorithm, the user's transmission power is reduced effectively.

5. CONCLUSIONS

The existing interference alignment techniques are mostly based on the average power distribution. Even if the power control is considered,

and the optimization goal is the maximum throughput , without the research on reducing the transmitted power. Aimed at the above problem, this paper proposes an efficient interference alignment algorithm, which considers the features of the direct channel of the received signal, the interference channel of interfering signal and noise. Simultaneously, it uses MMSE technology to solve the pre-coding matrix which is aimed at minimizing the mean square error of the received signal and the transmitted signal. Furthermore, to meet the preset D2D user data rate, the minimum D2D user transmission power is calculated by using the optimal power control which is based on Lagrange duality. Simulation results show, compared with the representative algorithms, algorithms 1 and 2 proposed in this paper significantly reduce the average transmission power of users under the premise of user's preset minimum data rate requirements. Therefore, the algorithms proposed in this paper is meaningful for spectrum sharing and interference control between D2D users and cellular users and within D2D users in future 5G wireless communications.

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