

Interference management for multiuser multiantenna OFDMA underlying Device-to-Device communications

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Abstract—Underlying device-to-device (D2D) transmission in cellular wireless systems is one of the promising transmission techniques for fifth generation (5G) and beyond 5G applications. Nevertheless, the interference between the D2D pairs, the interference from cellular users to D2D receivers and the interference that affects the cellular communications should be mitigated to increase the overall system performance. In this paper, we propose interference management techniques for D2D underlying communications in multiuser multiantenna orthogonal frequency division multiple access (OFDMA) systems. Our goal is to increase the data rate of both the cellular users and D2D pairs by performing interference management in frequency, power and spatial dimensions. The performance evaluations illustrate the effectiveness of the proposed algorithm in terms of average data rate and average transmitted power for both cellular users and D2D pairs.

Index Terms—underlying D2D communications, multiuser multiple antenna OFDMA, resource allocation, 5G communications.

I. INTRODUCTION

Direct communication between two or more devices without the intervention of a Base Station (BS), known as device-to-device (D2D) communication, is a promising way to improve performance of cellular networks in terms of spectral and/or energy efficiency for fifth generation (5G) and beyond 5G communications. For the case of in band D2D transmission in cellular networks, efficient interference management techniques are very critical since interference between the D2D pairs, the interference between cellular users and D2D receivers and the interference that affects the cellular communications should be mitigated to increase the overall system performance. In underlay D2D communications, D2D pairs are allowed to transmit as long as the interference that they generate at the BS remains below an interference threshold. In multi-carrier transmissions, Resource Blocks (RB) allocation and power allocation should be optimized in order to coexist both cellular and D2D transmissions as efficiently as possible.

Resource allocation (RA) for D2D underlay communications has been studied in [1], where the optimization objective is to maximize the sum rate of cellular users and to satisfy the rate requirements of all D2D pairs by exploiting the spatial reuse gains of the D2D pairs. In [2], the graph coloring algorithm has been examined for RA underlying D2D system

where the number of D2D users is larger than that of cellular users. In [3], the weighted sum-rate has been maximized under the constraints that each cellular or active D2D link is assigned one subband and the required minimum rates for cellular and active D2D links are guaranteed by considering the multiplexing problem as a graph-coloring algorithm. In [4], energy efficiency of D2D links has been focused by considering jointly channel allocation and power control problem.

Multiple antennas can be added at the BS either to manage interference or to increase the cellular data rate, by efficiently multiplexing cellular users on RB. In this paper, we propose a novel interference management algorithm including RA for cellular users, D2D pairs and power allocation for underlying D2D communication in cellular networks. The proposed algorithm separates RA from power allocation for both cellular and D2D communications, and is used sequentially, first for cellular users and then for D2D pairs, taking into account the interference thresholds. Hence, the interference from D2D in cellular communication, the interference of cellular in D2D communication and mutual interference in D2D communication are managed to maximize the sum data rate of both cellular users and D2D pairs.

The paper is organized as follows: Section II presents the system model and notations. Section III describes the proposed interference management algorithm, composed of RA including multiplexing and power allocation for cellular users, and of resource and power allocation for D2D pairs. Finally, Section IV provides an assessment of the proposed algorithm with numerical simulations, where the sum data rate and transmitted powers of cellular users and D2D pairs are evaluated.

II. SYSTEM MODEL

We consider uplink orthogonal frequency division multiple access (OFDMA) based systems having Q clusters consisting of N_Q subcarriers. There is one cell with a BS having N antennas, K_c cellular users and K D2D pairs, each of which has only one antenna. A clustering structure is considered where adjacent subcarriers are grouped and only one representative value for each cluster is selected. It is noticed that with Pedestrian or Indoor channel models, and since cellular users

are allocated per cluster, channel gains and interference levels do not vary much within a cluster. For the case of multiple antennas, the representative channel coefficient for a cluster is determined by $\mathbf{H}_{a,0}^q = \widehat{\mathbf{H}}_{a,0}^{n_c}$, where $\widehat{\mathbf{H}}_{a,0}^{n_c}$ is the $1 \times N$ channel vector of subcarrier n_c . The value of n_c is determined by $n_c = (q-1)N_Q + \arg \min_{1 \leq i \leq N_Q} \{ \|\widehat{\mathbf{H}}_{a,0}^{(q-1)N_Q+i}\|^2 \}$; $q = 1, \dots, Q$. For the case of single antenna, in order to obtain $G_{a,b}^q$, we use the geometric mean of channel gains of the subcarriers of a given cluster.

Our objective is to maximize the sum data rate of both cellular users and the D2D pairs. Then, the optimization problem is given by,

$$\max_{\mathbf{P}, \mathbf{P}_c} \sum_{\Omega, \Omega_c} \sum_{k_c=1}^{K_c} \sum_{q \in \Omega_{k_c}} \log_2 \left(1 + \frac{P_{k_c}^q |\mathbf{H}_{k_c,0}^q \mathbf{w}_{k_c,0}^q(\mathbb{M}^q)|^2}{\|\mathbf{w}_{k_c,0}^q(\mathbb{M}^q)\|^2 N_0^q + I_0^q + I_{k_c}^q} \right) + \sum_{k=1}^K \sum_{q \in \Omega_k} \log_2 \left(1 + \frac{P_k^q G_{k,k}^q}{N_k^q + I_k^q + \sum_{j \in \mathbb{M}^q} I_{k,j}^q} \right) \quad (1)$$

$$\text{s.t.} \quad \sum_{q \in \Omega_{k_c}} P_{k_c}^q \leq P^{\max}, \quad \forall k_c \in \{1, \dots, K_c\} \quad (2)$$

$$\text{s.t.} \quad \sum_{q \in \Omega_k} P_k^q \leq P^{\max}, \quad \forall k \in \{1, \dots, K\} \quad (3)$$

$$\text{s.t.} \quad I_0^q \leq I_0^{\max}, \quad \forall q \in \{1, \dots, Q\} \quad (4)$$

where s.t. stands for 'subject to', Ω_k is the set of clusters allocated to D2D transmitter k , Ω_{k_c} is the set of clusters allocated to cellular user k_c . N_0^q is the noise power at the BS, N_k^q is the noise power at D2D receiver k , both for cluster q , I_0^{\max} is the maximum allowed interference at the BS per each cluster and P^{\max} is the maximum total transmit power from cellular users or D2D pairs.

$\mathbf{P} = [P_k^q]_{\substack{k \in \{1, \dots, K\} \\ q \in \{1, \dots, Q\}}}$ is the matrix of transmit powers of D2D transmitters in all clusters and $\mathbf{P}_c = [P_{k_c}^q]_{\substack{k_c \in \{1, \dots, K_c\} \\ q \in \{1, \dots, Q\}}}$ is the transmitted power of cellular users in all clusters, where P_k^q and $P_{k_c}^q$ are the transmitted powers per each cluster for k th D2D transmitter and k_c th cellular user, respectively. $G_{j,k}^q$ is the channel gain between D2D transmitter k and D2D receiver j in cluster q including path loss, shadowing and fading. $\mathbf{H}_{k_c,0}^q$ is the channel coefficient of $1 \times N$ between cellular user k_c and the BS including path loss, shadowing and fading.

The inter-user interference (IUI) between the assigned cellular users is determined by

$$I_{k_c}^q = \sum_{j_c \in \mathbb{M}^q; j_c \neq k_c} P_{j_c}^q |\mathbf{H}_{j_c,0}^q \mathbf{w}_{j_c,0}^q(\mathbb{M}^q)|^2 \quad (5)$$

In order to avoid IUI, the postcoding vector at the BS is determined by employing zero forcing (ZF) as,

$$\mathbf{W}_0^q(\mathbb{M}^q) = \beta_0^q(\mathbb{M}^q) (\mathbf{H}_0^q(\mathbb{M}^q))^H [(\mathbf{H}_0^q(\mathbb{M}^q)) (\mathbf{H}_0^q(\mathbb{M}^q))^H]^{-1} \quad (6)$$

where \mathbb{M}^q is the set of assigned cellular users which is more than one and less than the number of antennas at the BS, $\mathbf{w}_{k_c,0}^q(\mathbb{M}^q)$ is the corresponding column vector of post coding matrix for the cellular user k_c and $\mathbf{H}_0^q(\mathbb{M}^q)$ denotes the

matrix consisting of the stacked channel vectors of the pair of assigned cellular users for each cluster. β_0^q is calculated by,

$$\beta_0^q(\mathbb{M}^q) = \frac{1}{\sqrt{\text{tr}[(\mathbf{H}_0^q(\mathbb{M}^q)) (\mathbf{H}_0^q(\mathbb{M}^q))^H]^{-1}}} \quad (7)$$

I_k^q is the received interference from all other D2D transmitters by D2D receiver k in cluster q and is determined by,

$$I_k^q = \sum_{\substack{j=1 \\ j \neq k}}^K P_j^q G_{k,j}^q \quad (8)$$

I_0^q is the received interference from all D2D transmitters at the BS in cluster q which must be lower than maximum allowed interference I_0^{\max} and is given by,

$$I_0^q = \sum_{k=1}^K \sum_{j \in \mathbb{M}^q} P_k^q |\mathbf{H}_{k,0}^q \mathbf{w}_{j,0}^q(\mathbb{M}^q)|^2 \quad (9)$$

where $\mathbf{H}_{k,0}^q$ is the channel vector with $1 \times N$ between k th D2D transmitter and the BS.

Finally, I_{k,k_c}^q is the received interference from the cellular user k_c to the k th D2D receiver and determined by,

$$I_{k,k_c}^q = P_{k_c}^q G_{k,k_c}^q \quad (10)$$

where G_{k,k_c}^q is the channel gain between cellular user k_c and D2D receiver k .

III. THE PROPOSED INTERFERENCE MANAGEMENT

In order to manage the interference, we propose to perform RA for cellular users, RA for underlying D2D pairs and power allocation. For cellular RA, we select more than one cellular user by considering the interference caused by cellular users to the D2D receivers for each cluster. For D2D RA, we separate D2D pairs in two sets: \mathbb{S}_C is the cell-center set and \mathbb{S}_E is the cell-edge set. Based on the cell-center set, for each cluster, we select only one semi-orthogonal D2D transmitter that causes lowest interference at the BS. Then, we determine the largest set of D2D pairs that can be multiplexed on the same cluster leading to the highest data rate with a given interference threshold at the BS. At last, the power allocation for D2D pairs is performed to mitigate the interference among D2D pairs as well as at the BS.

The proposed RA algorithm imposes two different interference management techniques for both cellular users and D2D pairs.

While constructing a feasible set of cellular users for which joint transmission is feasible with low interference level, we hold the following two constraints:

- 1) We construct a first set, \mathbb{S}_1 that consists of all of the cellular users. Each cellular user is allocated at least one cluster. The objective is to establish a transmission link for each cellular user for a given target data rate per cluster.
- 2) The second set, \mathbb{S}_2 consists of only the cellular users that causes less interference than a given threshold to all D2D receivers. The users in this set may be

allocated extra clusters, through spatial multiplexing. The objective is to increase the cellular data rate, while mitigating the interference generated by cellular users on D2D receivers.

While constructing a feasible set of D2D pairs for which joint transmission is feasible with low interference level, we hold the following two constraints:

- 1) First, this set must contain the cell-center user k_d^* that is semi-orthogonal to the initially established cellular transmission on cluster q to mitigate interference at the BS.
- 2) Second, this set must not contain any other cell-center user except k_d^* because it may interfere strongly the cellular transmission at the BS.

A. The RA algorithm for cellular users

The optimization problem is re-written to maximize sum rate by assuming no interference coming from D2D transmitters.

$$\max_{\mathbf{P}_c, \Omega_c} \sum_{k_c=1}^{K_c} \sum_{q \in \Omega_{k_c}} \log_2 \left(1 + \frac{P_{k_c}^q |\mathbf{H}_{k_c,0}^q \mathbf{w}_{k_c,0}^q (\mathbb{M}^q)|^2}{\|\mathbf{w}_{k_c,0}^q (\mathbb{M}^q)\|^2 N_0^q + I_{k_c}^q} \right) \quad (11)$$

The RA algorithm is performed in two steps: The first step allocates only one cellular user to each cluster in order to establish a transmission link for each user at a given data rate requirements per cluster. The second step adds more cellular users to each cluster in order to increase the data rate of cellular users, while taking into account the interference caused by the cellular users to the D2D receivers.

Step 1 of RA for cellular users:

- Initialization: $\mathbb{N}_1 = \{1, \dots, K\}$, $P_{k_c}^q = \frac{P_{\max}}{Q}$; $\forall k_c, \forall q$, $R_{k_c} = 0$; $\forall k_c$.
- for $q = 1 : Q$
 - Find the cellular user that has the maximum channel gain:

$$k_c^* = \arg \max |\mathbf{H}_{k_c,0}^q \mathbf{W}_0^q|^2 \quad (12)$$

$$\text{where } \mathbf{W}_0^q = \frac{(\mathbf{H}_{k_c,0}^q)^H}{\|\mathbf{H}_{k_c,0}^q\|}.$$

- Update $\Omega_{k_c^*} = \Omega_{k_c^*} \cup q$, $\mathbb{M}^q = \{k_c^*\}$, $\mathbb{N}_1 = \mathbb{N}_1 \setminus k_c^*$.
- End

Step 2 of RA for cellular users:

- Initialization: $\mathbb{N}_2 = \{1, \dots, K\}$.
- The cellular users cause strong interference on D2D receivers when the distance between the cellular user j_c and any D2D receiver k is smaller than a given threshold distance d^{th} .
 - if $(d_{j_c,j} < d^{th})$, then $\mathbb{N}_2 = \mathbb{N}_2 \setminus j_c$ for $j = 1, \dots, K$ and $j_c = 1, \dots, K_c$.
- for $q = 1 : Q$
 - Find the cellular user that has the maximum multi-user gain:

$$k'^* = \arg \max_{k' \in \mathbb{N}_2} \beta_0^q (\mathbb{M}^{q'}) \quad (13)$$

where $\mathbb{M}^{q'} = \mathbb{M}^q \cup k'$,

– Update $\Omega_{k'^*} = \Omega_{k'^*} \cup q$, $\mathbb{M}^q = \mathbb{M}^q \cup k'^*$.

- End

Then, the transmit power of each cellular user is determined by using open loop power control in order to reduce the interference power on the D2D receivers:

$$P_{k_c}^q = \frac{\gamma_{k_c}^q (\widehat{N}_0^q + I_0^{\max})}{\widehat{G}_{k_c}^q} \quad (14)$$

where \widehat{N}_0^q and $\widehat{G}_{k_c}^q$ are the noise power and the channel gain based on the postcoding matrix/vector respectively and $\gamma_{k_c}^q$ is the target signal-to-noise interference ratio (SINR) for each cellular user in cluster q .

B. The RA algorithm for D2D pairs

The estimated rate per D2D pair in cluster q is given by,

$$\widehat{R}_k^q = \log_2 \left(1 + \frac{P_k^q G_{k,k}^q}{\widehat{N}_k^q + \sum_{\substack{j \in \mathbb{S}^q \\ j \neq k}} P_j^q G_{k,j}^q} \right) \quad (15)$$

where \mathbb{S}^q is the feasible set and initially consists of all D2D pairs, and \widehat{N}_k^q is the sum of the noise and the interference coming from cellular users at receiver k in cluster q .

The target SINR γ_k^q for D2D pairs is chosen large enough to hold the high SINR condition required for the power control step:

$$\widehat{R}_k^q \geq \gamma_k^q \quad \forall k, \forall q \quad (16)$$

Then, the set of equations (16) is equivalent to:

$$(\mathbf{I}_K - \mathbf{\Gamma}^q \mathbf{\Phi}^q) \mathbf{P}^q = \boldsymbol{\nu}^q \quad (17)$$

where $\mathbf{P}^q = [P_1^q, \dots, P_K^q]^T$ is the power vector in cluster q , $\mathbf{\Gamma}^q = \text{diag} \{\gamma_k^q\}$, $\mathbf{\Phi}^q(k, j) = \frac{G_{k,j}^q}{G_{k,k}^q}$ for $k \neq j$, and 0 otherwise and $\boldsymbol{\nu}^q(k) = \frac{\widehat{N}_k^q \gamma_k^q}{G_{k,k}^q}$.

The Eq. (17) only has a solution if matrix $(\mathbf{I}_K - \mathbf{\Gamma}^q \mathbf{\Phi}^q)$ can be inverted. This is achieved when the spectral radius of matrix $\mathbf{\Gamma}^q \mathbf{\Phi}^q$ is less than 1. In order to find a solution with lower complexity, we do not compute the spectral radius of $\mathbf{\Gamma}^q \mathbf{\Phi}^q$ but instead use the infinity norm, since any matrix norm is an upper bound to the spectral radius. The infinity norm is defined as the maximum of the sum of all lines of matrix $\mathbf{\Gamma}^q \mathbf{\Phi}^q$ [5]:

$$\|\mathbf{\Gamma}^q \mathbf{\Phi}^q\|_\infty = \max_{1 \leq k \leq K} \sum_{\substack{j=1 \\ j \neq k}}^K \gamma_k^q \frac{G_{k,j}^q}{G_{k,k}^q} \quad (18)$$

This criterion implies that for any D2D pairs that are selected for RA, the following constraint holds:

$$\sum_{\substack{j=1 \\ j \neq k}}^K \gamma_k^q \frac{G_{k,j}^q}{G_{k,k}^q} < 1 \quad (19)$$

RA is performed firstly for cell-center D2D pairs and then for cell-edge D2D pairs, with the objective to find a feasible set of D2D pairs per each cluster. Cell-center D2D pairs have a higher priority other cell-edge D2D pairs. Consequently, RA contains the following two steps:

Step 1 of RA for D2D pairs:

For each cluster q :

- Find the cell-center D2D pair in \mathbb{S}_C that causes the least interference to the cellular transmission:

$$k_d^* = \arg \max_{k \in \mathbb{S}_C} [\mathbf{W}_0^q(\mathbb{M}^q)(\mathbf{H}_{k,0}^q)^H][\mathbf{W}_0^q(\mathbb{M}^q)(\mathbf{H}_{k,0}^q)^H]^H \quad (20)$$

- Update the D2D feasible set of $\mathbb{S}^q = \{k_d^*\}$.

Then the cell-edge D2D pairs are chosen so that they can all jointly, with the cell-center pairs, fulfill the target data rate constraint given by Eq. (16). The set of D2D pairs allocated in cluster q should necessarily include cell-center user k_d^* .

Step 2 of RA for D2D pairs:

First, all the cell-edge D2D pairs that verify the infinity norm criterion (19) are selected for transmission in cluster q and included in \mathbb{S}^q . Then we must check if the cell-center pair k_d^* chosen in Step 1 fulfills the infinity norm criterion (19), considering the set of cell-edge D2D pairs that have just selected, $\{\mathbb{S}^q \setminus k_d^*\}$. The corresponding criterion is:

$$\sum_{j \in \{\mathbb{S}^q \setminus k_d^*\}} \gamma_{k_d^*}^q \frac{G_{k_d^*,j}^q}{G_{k_d^*,k_d^*}^q} < 1 \quad (21)$$

If criterion (21) does not hold, then some cell-edge D2D pairs must be removed from \mathbb{S}^q . In order to remove as few D2D pairs as possible, the cell-edge D2D pairs j are ordered by decreasing value of the interfering channel gain to D2D receiver k_d^* , $G_{k_d^*,j}^q$. The corresponding ordered list is noted \mathbb{A}^q . Then the algorithm is performed as follows, starting from the first j in list \mathbb{A}^q .

- Remove j from set \mathbb{S}^q , $\mathbb{S}^q = \{\mathbb{S}^q \setminus j\}$.
- If criterion (21) holds, stop. Otherwise, go to the next j in \mathbb{A}^q .

This algorithm necessarily has a solution since in the worst case, \mathbb{S}^q finally only contains k_d^* .

C. Power Allocation

The power allocation algorithm proposed in details in [6] is performed to further mitigate the interference among D2D pairs and at the BS. Due to lack of space, a summary is provided in this section. The main difference with the work in [6] is that in this paper, we do not assume that interfering signals are received asynchronously and we consequently do not take into account inter-channel-interference. This corresponds to a special case of [6], when inter-channel-interference vector \mathbf{V} is equal to $\{1\}$. To summarize, we assume that the high SINR assumption holds thanks to the RA allocation explained in the previous section. Then with approximation $\log_2(1 + \text{SINR}) \approx \log_2(\text{SINR})$, the optimization problem of D2D power allocation is the following:

$$\max_{\mathbf{P}} \sum_{k=1}^K \sum_{q \in \Omega_k} \log_2 \left(\frac{P_k^q G_{k,k}^q}{\widehat{N}_k^q + I_k^q} \right) \quad (22)$$

$$\text{s.t.} \quad \sum_{q \in \Omega_k} P_k^q \leq P_{\max}, \quad \forall k \in \{1, \dots, K\} \quad (23)$$

$$\text{s.t.} \quad I_0^q \leq I_0^{\max}, \quad \forall q \in \{1, \dots, Q\} \quad (24)$$

In [6], we proved that the optimal transmit power values can be obtained using an iterative algorithm and are equal, at each step, to:

$$(P_k^q)^* = \frac{1}{f_k^q(\mathbf{P}^*, \boldsymbol{\mu}^*, \boldsymbol{\lambda}^*)} \quad (25)$$

where $\boldsymbol{\mu}^* = [\mu_1^*, \dots, \mu_K^*]$ and $\boldsymbol{\lambda}^* = [\lambda_1^*, \dots, \lambda_Q^*]$ are the Lagrange multipliers at their optimal values, and function f_k^q is defined as follows:

$$f_k^q(\mathbf{P}^*, \boldsymbol{\mu}^*, \boldsymbol{\lambda}^*) = \sum_{\substack{j=1 \\ j \neq k}}^K G_{j,k}^q \Pi_j^q(\mathbf{P}^*) + \mu_k^* + \frac{1}{I_0^q} \lambda_q^* \quad (26)$$

and $\Pi_j^q(\mathbf{P}^*)$ is the interference information of receiver j in cluster q , that indicates the interference plus noise level at receiver j from all other D2D transmitters and defined as:

$$\Pi_j^q(\mathbf{P}^*) = \frac{1}{\widehat{N}_j^q + I_j^q(\mathbf{P}^*)} \quad (27)$$

The algorithm uses an outer loop and an inner loop. In the inner loop, the values of P_k^q and Π_j^q are iteratively computed, for fixed Lagrange multipliers μ_k and λ . Then in the outer loop, the Lagrange multipliers values are updated. The first Lagrange multiplier $\boldsymbol{\mu}^* = [\mu_1^*, \dots, \mu_K^*]$ corresponds to the sum power constraint per D2D, whereas the second Lagrange multiplier $\boldsymbol{\lambda}^* = [\lambda_1^*, \dots, \lambda_Q^*]$ corresponds to the interference constraint at the BS.

IV. PERFORMANCE RESULTS

We consider a BS with $N = 4$ antennas in the cell with radius $R = 0.5\text{km}$. The noise is modelled as additive white Gaussian noise (AWGN) with power spectrum density -174dBm/Hz . The number of clusters is equal to $Q = 25$ and the number of cellular users are also selected as $K_c = 25$. Therefore, each cellular user is allocated at least 1 cluster to establish a transmission with target SINR of $\gamma_{k_c}^q = 20\text{dB}; \forall k_c$ for each cluster. D2D transmitters are either cell edge or cell center region with target SINR of $\gamma_k^q = 10\text{dB}; \forall k$ for each cluster. The maximum transmit power is 21dBm for both D2D transmitters and cellular users. The channel is modelled by using Rayleigh fading and shadowing follows log-normal distribution. The path loss and shadowing standard deviation both depend on whether the receiver is BS or a device. The threshold distance is set to $d^{th} = 125\text{m}$.

- If the receiver is the BS, the path loss model is urban model. $L = 128.1 + 37.6 \log_{10}(d)$ where d (in km) is the distance between the transmitter and receiver. The standard deviation is equal to 9dB .

- If the receiver is a device, the path loss model is small cell's model. $L = 140 + 36.8 \log_{10}(d)$ where d (in km) is the distance between the transmitter and receiver. The standard deviation is then equal to 4dB.

We compare the average data rate and transmit power for both cellular users and D2D pairs for the proposed multiuser multi-antenna OFDMA and graph coloring algorithm (GBA) for single antenna OFDMA systems. In GBA algorithm, D2D pairs are allocated to the clusters as follows: the same clusters cannot be reassigned to D2D pairs k and j if the distance between the transmitter of D2D pair k and the receiver of D2D pair j is lower than a given threshold, set to 125 m. This graph coloring problem is solved with DSATUR algorithm [7]. Then the bandwidth is equally shared by all colors. The power allocation algorithm described in [6] is also used for GBA, as in the proposed algorithm.

In Figure 1, we illustrate the average data rate of cellular users and D2D pairs for the proposed algorithm and GBA. According to the performance results, the average data rate per cellular user is doubled by employing the proposed multiuser multi-antenna OFDMA systems compared to GBA by allocating more than one cellular users by reducing the interference at the BS thanks to the semi-orthogonal selection. In addition to that, the supportable average data rate of the D2D pairs is provided between 1.15Mbps to 0.75Mbps in the proposed algorithm while the supportable average data rate of the D2D pairs by GBA is varying between 0.9Mbps to 0.45Mbps depending on the number of D2D pairs. The reason is that the proposed algorithm increases the number of multiplexing D2D pairs on the same cluster and managing the interference at the D2D receiver.

In Figure 2, we show the average power per cellular user and D2D pair. The cellular user power is increased about 1dB, even though we allocate more than one cellular users per cluster. The average D2D transmitted power is almost the same for both single and multiple antenna case since we perform power allocation for both the proposed algorithm and GBA.

V. CONCLUSION

We have presented the interference management for underlying D2D communication in the cellular networks with multiple antennas at the BS. We have multiplexed several cellular users and managed the D2D interference which interrupts the cellular transmission by employing on semi-orthogonality criterion at the BS. We have shown that the proposed algorithm increases the average data rate of both cellular users and D2D pairs while requiring almost the same transmitted power for both cellular users and D2D pairs.

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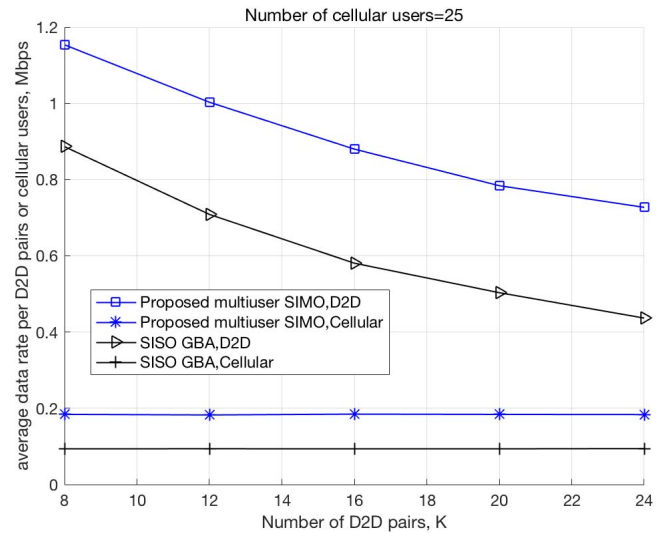


Figure 1: Average data rate per cellular user and D2D pair.

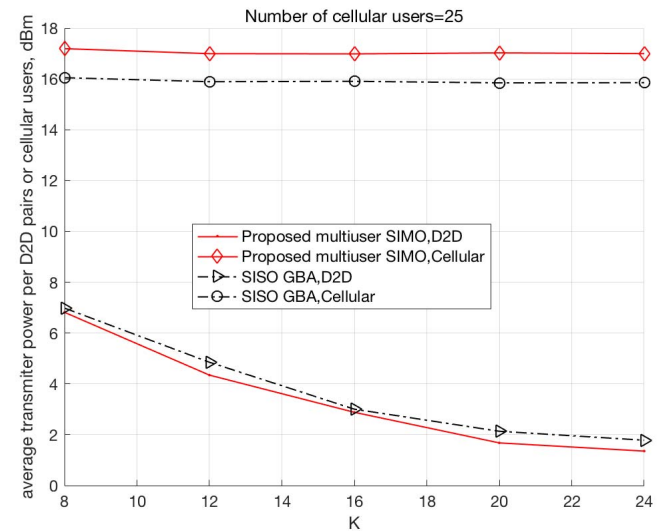


Figure 2: Average transmitted power per cellular user and D2D pair.

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