Optimal Interference for Device to Device Communication Underlaying Cellular Network

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Abstract**—**Device to Device (D2D) communication can effectively improve the spectrum eficiency and reduce the load of Base Station in cellular networks. However, when D2D users and cellular users share the wireless channels, it will bring signal interference for the cellular networks. In order to achieve mutual interference between users and base stations, and increase the spectrumutilization efficiency and energy utilization efficiency, this paper proposes a method control algorithm based on bearnforrning and interference alignment in D2D communication underlaying cellular networks. Simulation results show that the proposed algorithm can effectively reduce the interference of the BS transrnitting signal for D2D pais and significantly improve system capacity. Furthermore, D2D communication is more applicable to short-range links.

Index Terms—Device-to-device (D2D) communication, cellular network, interference control, Beamforming

I. INTRODUCTION

Device-to-Device (D2D) communication is a technology component for LTE-A. The existing researches allow D2D as an underlay to the cellular network to increase the spectral efficiency [1]. In D2D communication, user equipments (UEs) transmit data signals to each other over a direct link using the cellular resources instead of through the BS, which differs from femtocell [2] where users communicate with the help of small low-power cellular base stations. D2D users communicate directly while remaining controlled under the BS. Therefore, the potential of improving spectral utilization has promoted much work in recent years [3]-[5], which shows that D2D can improve system performances by reusing cellular resources. As a result, D2D is expected to be a key feature supported by next generation cellular networks.

Although D2D communication brings improvement in spectral efficiency and makes large benefits on system capacity, it also causes interference to the cellular network as a result of spectrum sharing. Thus, an efficient interference coordination must be formulated to guarantee a target performance level of the cellular communication. There exists several work about the power control of D2D UEs for restricting cochannel interference [6]. The authors in [7] utilized MIMO transmission schemes to avoid interference from cellular downlink to D2D receivers sharing the same resources, which aims at guaranteeing D2D performances. Interference management both from cellular to D2D communication and from D2D to cellular networks are considered in [8]. In order to further improve the gain from intra-cell spectrum reuse, properly pairing the cellular and D2D users for sharing the same resources has been studied [9].

In cellular networks, D2D communication refer to direct communication between two proximal cellular equipments (UEs) under the control of the Base Station (BS). No data is transferred through the BS or the core network, which can greatly reduce the traffic load of the BS and facilitate network dep1oyment. In cellu1ar network, D2D communication is classified as non-transparent transmission. Data can be transmitted using the licesed in-band spectrum or the unlicensed out-of-band spectrum [9]. The distance between the transmitter and the receiver of a D2D pair is very short, so the transmission power can be much lower than that needed for the cellular network communications, which reduces the necessary amount of system energy. In addition, D2D and cellular network communications can share the same spectrum resources, which offers great improvement in spectral efficiency. D2D communication a1so offers the advantages of reducing data latency and improving user faimess.

For D2D communication underlaying cellular networks, the cellular UEs and D2D pairs will share the same frequency spectrum, so interference between the cellu1ar networks and the D2D transmissions is a serious problem. Through effective interference management, resource allocation, mode selection, and Multiple-Input Multiple-Output (MIMO) technology, the spectral efficiency can be improved [10], [11]. Interference management algorithms can also be used to improve system capacity and they have attracted much attention. A scheme for reusing cellular uplink resources for D2D communication was proposed. MIMO is an effective technique to reduce interference and to improve the system's spectrum efficiency, and it can also be used in D2D communication scenarios. A heuristic precoding algorithm, in which the channels from the BS to the cellular UEs lie in the null space of the interference channels from the BS to the D2D pairs, was presented. A non-cooperative game strategy with joint channel

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allocation, power control, and the precoding of D2D users was proposed [12]-[15], and the sum rate maximization problem that included cel1ular users and D2D pairs was formulated. Using physical layer network coding and mapping, a joint precoding and decoding scheme was proposed to eliminate interference and improve system performance in MIMO D2D communication. A D2D association algorithm that considered three types of precoding methods was proposed for D2D communication underiaying cellular networks [16], [17l. Among these proposals, precoding is usually applied to prevent interference between cellular UEs or between the D2D pairs where as joint precoding is rarely considered. On the other hand, the interference alignment method is usually not considered for use in conjunction with the precoding method. The present work combines these techniques in a unique way.

In this paper, a cellular network with multiple cellular UEs and D2D pairs is considered, and the BS is equipped with multiple transmitting antennas. First, by using the channel state information (CSI) from the BS to the cellular UEs and to the receivers of some of the D2D pairs, joint zero-forcing bearnforming is applied at the BS. The channels from the BS to the first portion of the D2D pairs lie in the null space of the precoding matrix of the cellular UEs, so that the transmission signals from the BS have no interference on this portion of the D2D pairs. Next, channel parallelisms between the channels from the BS to the rest of the D2D pairs and the channels from the BS to the above mentioned portion of D2D pairs are calculated, and they are used to align these two portions of the interference channels. The rest of the D2D pairs are checked one by one in a descending order of the channel parallelisms, where higher parallelism means lower BS interference. If the sum rate of all the cellular UEs and D2D pairs increases when a D2D pair is admitted to the system, its admission is confirmed; otherwise, admission is denied, and the algorithm terminates. Simulation results show that the proposed D2D admission control algorithm performs better than the existing algorithms.

II. SYSTEM MODEL

As shown in Fig. 1, a single cell multi-user downlink cellular network with multiple D2D pairs underlaying communications is considered. The BS has Nt antennas, and each of the cellular UEs and D2D users has a single antenna. The sets of the cellular UEs and D2D pairs are defined as RUE={1, 2,…,N} (N≤Nt) and RD=={1, 2,…,M}, respectively. The transmitter and the receiver of the m-th D2D pair D2Dm are DTm and DRm, respectively.

Let the signal vector transmitted by the BS to N cellular UEs be:

$$x = [x_1, x_2, \ldots x_N] \tag{1}$$

where x_n is the signal for the *n-th* cellular UE with $E\{|x_n|^2\}=1$, $n \in R_{UE}$. S_m is the transmission signal of DT_m, with $E\{|s_m|^2\}=1$, $m \in R_D$. The precoding matrix for all Cellular UES $W \in C^{N tx N}$ is defined as:

$$W=[w_1, w_2, \ldots, w_N] \tag{2}$$

where $w_k \in C^{Ntx1}$ is the precoding vector for the k-th cellular UE. Mean while, the channel gain vector from the BS to the *n-th* cellular UE and DR_m are denoted as $h_{BS,n} \in C^{Ntx1}$ and $h_{BS,m} \in C^{Ntx1}$ respectively, and they are all available at the BS. The channel gains from DT_i; to the *n-th* cellular UE and to DR_m are denoted as $p_{i,n}$ and $g_{i,m}$ respectively. All channel gains are modeled as combinations of the Rayleigh fading channel and free-space propagation path loss, so that each element of the channel gain h_{mn} can be expressed as

$$h_{mm} = \sqrt{(d_{mm})^{-a} h_0} \tag{3}$$

where d_{mn} is the distance from transmitter m to receiver n; α is the path-loss exponent; and h_0 is a complex Gaussian random variable with mean σ and variance 1.

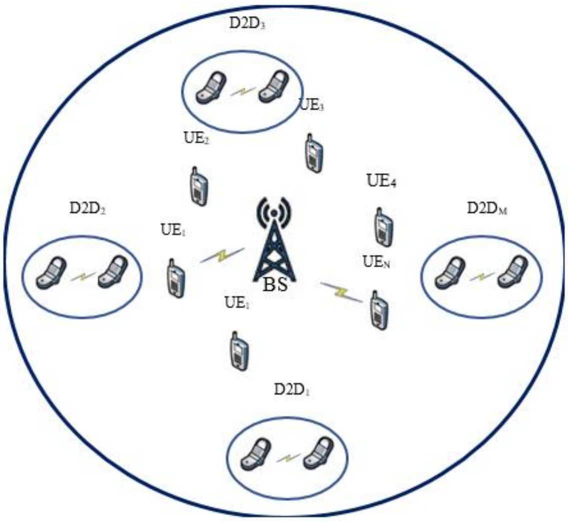

Fig. 1. D2D communication in Cellular network

Furthermore, the transmission power of the BS and DT; are denoted as P_{BS} and P_D, respectively. To simplify the analysis, the BS is assumed to allocate power equally to each transmitting antenna

In this paper, zero-forcing beamforming is applied to precoding of the cellular UEs. Unlike the traditional zero-forcing beamforming method, a joint precoding method is considered. Since the maximum number of streams that can be supported simultaneously is equal to that of transmitting antennas at the BS, the following theorem should hold.

If the BS with N_t, transmitting antennas selects N single-antenna cellular UEs for beamforming, the maximum number of degrees of freedom that can avoid interference from the beamforming signal is $N_t - N$. We select M_1 D2D pairs as set R_{D1} to participate in Joint zero-forcing beamforming, where $M_1 \leq N_t\text{-}N$. so, the precoding vector for the *n-th* cellular UE should satisfy.

$$[h_{BS,1}, h_{BS,2}, \dots, h_{BS,N}, f_{BS,1}, f_{BS,2}, \dots, f_{BS,M1}]^H w_n = 0 \quad (4)$$

where w_n also satisfies the following two conditions:

$$\begin{aligned} h_{BS,i}^H w_n &= 0 \qquad i \neq n;\ i, n \in R_{UE} \\ f_{BS,j}^H w_n &= 0 \qquad n \in R_{UE};\ j \in R_{D1} \end{aligned} \quad (5)$$

If we define:

$$H_{BS,n} \triangleq [h_{bs,1}, h_{BS,2}, \dots\dots, h_{BS,N}, f_{BS,1}, f_{BS,2}, \dots., f_{BS,M1}]^H$$

then each w_n lies in the direction of the projection of its own channel $h_{BS,n}$ on the null space of $H_{BS,n}$, and it can be formulated as:

$$w_k = \frac{(\ker(H^H_{BS,n}))((\ker(H^H_{BS,n}))^H h_{BS,n}}{\|h_{BS,n}\|} \quad (6)$$

The rates of unit bandwidth corresponding to the above SINR are denoted as $r_n^{R_{UE}}$, $r_m^{R_{D1}}$, and $r_l^{R_{D2}}$. The optimization problem is to maximize the system sum rate, by choosing D2D pairs in set R_{D_2} that can be admitted to the cellular network. The problem is formulated as

$$\max_{\lambda_l}\left(\sum_{k=1}^{N} r_n^{UE} + \sum_{m=1}^{M1} r_n^{R_{D1}} + \sum_{l=1}^{M2} r_l^{R_{D2}}\right)$$

where *ker(·)* is the kernel or null space of a matrix. By the joint zero-forcing beamforming, the interference from the BS to the receivers in set R_{D1} can be eliminated completely, so all the D2D pairs in set R_{B1} can be admitted to the cellular network. We denote R_{B2} = [1, 2, ⋯, D_2] as the set of the remaining D2D pairs, where $M_2=M-M_1$. Let the binary variable $\lambda_l \in \{0,1\}$ represent the admission control status of the *l-th* D2D pair in set R_{D2}.

$$\lambda_l = \begin{cases} 1 \text{ The l-th D2D pair in set } R_{D2} \textit{is} \text{ admitted} \\ 0 \text{ Other} \end{cases} \quad (7)$$

So, the received signals at the *n-th* cellular UE, the receiver DR_m in set R_{D1}, and the receiver DR_l in set R_{D2} can be expressed as

$$y_n^{UE} = \sqrt{P_{BS}/N_t}\, h_{BS,n}^H w_n x_n + \sum_{i=1}^{M_1} \sqrt{P_{Di}}\, p_{i,n} y_i + \sum_{j=1}^{M_2} \lambda_j \sqrt{P_{Dj}}\, p_{j,k} y_j + n_k \quad (8)$$

$$y_m^{R_{D1}} = \sqrt{P_{Dm}}\, g_{m,m} y_m + \sum_{i=1, i\neq m}^{M_1} \sqrt{P_{Di}}\, g_{i,m} y_i + \sum_{j=1}^{M_2} \lambda_j \sqrt{P_{Dj}}\, g_{j,m} y_j + n_m \quad (9)$$

$$y_l^{R_{D2}} = \lambda_l \sqrt{P_{Dl}}\, g_{l,l} y_l + \sum_{j=1, j\neq l}^{M_2} \lambda_l \sqrt{P_{Dj}}\, g_{j,l} y_j + \sum_{i=1}^{M_1} \sqrt{P_D}\, g_{i,l} y_i + + \sqrt{(P_B/N_t)} \sum_{n=1}^{N} f_{BS,l}^H w_k x_k + n_l \quad (10)$$

where n_n, n_m, and n_l represent additive Gaussian White noise with mean 0, corresponding to variance σ_n^2, σ_m^2, σ_l^2, respectively. The corresponding signal to interference plus noise ratios (SINR) can be calculated as

$$SINR_n^{UE} = \frac{(P_{BS}/N_t)\left|h_{BS,n}^H w_n\right|^2}{\sum_{i=1}^{M_1} P_{Di}\left|p_{i,n}\right|^2 + \sum_{j=1}^{M_2} \lambda_j P_{Dj}\left|p_{j,n}\right|^2 + \sigma_n^2} \quad (11)$$

$$SINR_m^{R_{D1}} = \frac{P_{Dm}\left|g_{m,m}\right|^2}{\sum_{i=1, i\neq m}^{M_1} P_{Di}\left|g_{i,m}\right|^2 + \sum_{j=1}^{M_2} \lambda_j P_{Dj}\left|g_{j,n}\right|^2 + \sigma_m^2} \quad (12)$$

$$SINR_l^{R_{D2}} = \frac{\lambda_l P_{Dl}\left|g_{l,l}\right|^2}{\sum_{j=1, i\neq l}^{M_2} \lambda_j P_{Dj}\left|g_{j,l}\right|^2 + \sum_{i=1}^{M_1} P_{Di}\left|g_{i,l}\right|^2 + (P_{BS}/N_t)\sum_{n=1}^{N}\left|f_{BS,l}^H w_n\right|^2 + \sigma_m^2} \quad (13)$$

$$\text{s.t. } \lambda_l \in \{0,1\},\ l = 1, 2, \dots, M_2$$

This optimazation problem is an NP-hard integer programing problem. It can be solved using an exhaustive search, but the computational complexity is too high for this approach to be practical. In the following section, a novel D2D admission control algorithm based on the combination of beamforming and interference alignment (BIA) is proposed.

III. OPTIMAL INTERFERENCE FOR D2D COMMUNICATONS

For convenience, we first define the notion of channel parallelism: Assume that thechannel vectors from the BS to the i-th user and the j-th user are $h_{BS,n}$ and $h_{bs,j}$, respectively. The channel parallelism between these two users is calculated as

$$\eta_{i,j} = \frac{\left|h_{BS,n}^H h_{BS,j}\right|}{\left\|h_{BS,n}\right\|\left\|h_{BS,j}\right\|} \quad (14)$$

It is clear that $\eta_{i,n}$ is limited to the domain [0,1]. When $\eta_{i,j}$=0, $\left|h_{BS,n}^H h_{BS,j}\right|$=0, the two channels are orthogonal. On the contrary, when $\eta_{i,j}$=1, the two channels are parallel with each other, sharing the sam direction.

As mentioned above, in the D2D communication underlaying cellular network, when the CSI of *N* cellular UEs and M_1 D2D pairs are used for joint zero-forcing beamforming, the transmission signals at the BS will have no interference on the receivers of D2D pairs in set R_{D1}. This arrangement avoids interference because the channels from the BS to the D2D pairs in set R_{D1} all lie in the null space of the precoding matrix of the cellular UEs. If we can completely align the interference channels from the BS to the receivers of D2D pairs in set R_{D2} with the interference channels from the BS to the receivers of the D2D pairs in set R_{D1} the precoding transmission signals will exert no interference on the receivers of the D2D pairs in set R_{D2}. Unfortunately, the probability of all interference channels being perfectly parallel is almost zero in a practical system. If the channels from the BS to the receivers of D2D pairs in set R_{D2} are more parallel to the channels from the BS to the receivers of D2D pairs in set R_{D1}, i.e., the value of $\eta_{i,j}$ approaches 1, less interference will arise. The concept of channel parallelism allows the formulation of a D2D admission control algorithm that combines beamforming and interference alignment.

The D2D pairs in set R_{D2} will participate in joint precoding, which causes the BS to exert no interference on them. Selecting the D2D pairs that have less interference with the cellular UEs to constitute set R_{D1} is, therefore, a reasonable way to proceed. For simplicity, we select the M_1 D2D pairs that are the farthest away from the BS,i.e. , the D2D pairs which have the largest channel gain norm. Other methods can be used to select D2D pairs to constitute set R_{D1}, but they may require additional information, such as the channel gains from the transmitters of D2D pairs to the cellular UEs, which will increase the network overhead.

The proposed D2D admission control algorithm based on BIA consists of the following steps:

1) Initialize: The number of transmitting antennas Ni , number of cellular UEs N, number of D2D pairs M.

2) Select M_1 ($M_1 \le N_t$ -N) D2D pairs that are the farthest away from the BS to constitute set R_{D1} and perform joint zero-forcing beamforming with N cellular UEs.

3) Compute the sum rate RL for N cellular UEs and M_1 admitted D2D pairs.

4) Compute the channel parallelism $\eta_{i,\,j}$ between the D2D pairs in set R_{D1} and set R_{D2} (constituting set $M_2 = M - M_1$).

5) Sort $\eta_{i,\,j}$ in a descending order.

6) Assume that the D2D pair with the maximum parallelism (assumed to be the *l-th* D2D pair) in set R_{D2} is associated with the cellular network, and compute the temporary sum rate R*.

7) If R*> RL, the *l-th* D2D pair is admitted to the cellular network, the admission control status of this D2D pair is set to be λ_l=1, and RL= R*.(go to step 8). Else, set λ_l=0, and stop.

8) Pick the next most parallel D2D pair in set R_{D2}, and go to step 6.

IV. SIMULATION AND PERFORMANCE

In this section, the performance of the proposed D2D control algorithm based on BIA is discussed with simulation results. In the simulations parameters as Table I.

TABLE I: SIMULATION PARAMETTERS

PARAMETER	VALUE
The number of the transmitting antennas at the BS (N_t)	N_t=6
The path-loss factor	α =2
The cell radius	R=100m
Number of UEs	4
UEs are uniformly and independently distributed in a central area with a radius	80m
D2D pairs randomly distributed in a ring area with a radius from 80 to 100m	30

The number of D2D pairs in set R_{D1} is set to be M_1 = 2 to allow more channels for interference alignment. The transmission powers of all D2D transmitters are the same and they are much lower than those of the BS, which is set to be P_D=P_{BS}/20. The distance between the transmitter and the receiver in each D2D pair is 5m. The results of 10000 Monte Carlo simulations are shown in the following figures.

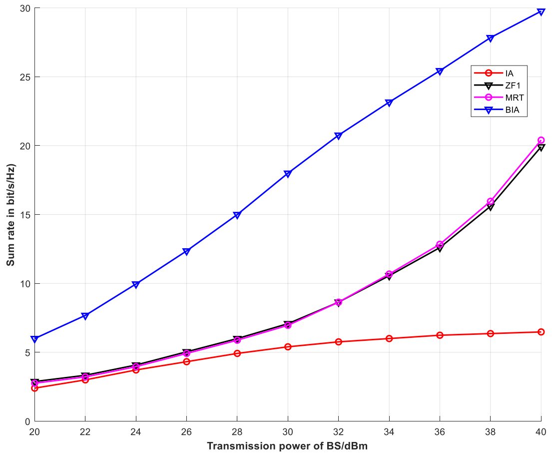

Fig. 2. Sum rate of cellular UEs and D2D pairs

In Fig. 2 we surveyed sum rate of the cellular UEs and the D20 pairs varies with the transmission power when using four different control algorithms. For comparison, the performances of the association vector search algorithm with the Maximum Ratio Transmission (MRT) method, zero-forcing method 1 (ZF1) and the Interference Alignment (IA) method [18] are also simulated. The MRT algorithm serves each cellular UE and does not perform interference cancelation for other UEs and D2D pairs. The ZF1 algorithm serves each cellular UE and considers interference cancelation among the cellular UEs. The IA algorithm is like the ZFl algorithm, but the D2D pairs selected for admission are those whose interference channels almost lie within the null space of the precoding matrix of the cellular UEs. In these results, when the transmission power increases, the sum rates of the four algorithms all inc rease. The proposed algorithm eliminates interference among the cellular UEs, and additionally reduces the interference between the BS and the admitted D2D pairs. This feature explains how the performance of the proposed BIA algorithm is much better than that of the other three algorithms.

Fig. 3 illustrates the relationship between the sum rate of all the cellular UEs and the transmission power. Our proposed BIA algorithm admits more D2D pairs to the cellular network. But more admitted D2D pairs causes more interference with the cellular UEs. Therefore, the sum rate of all cellular UEs for the proposed algorithm is smaller than that of the the other three algorithms. The ZFl and IA algorithms cancel the interference among the cellular UEs, and the number of the admitted D2D pairs is relatively small, so the sum rates increase rapidly.

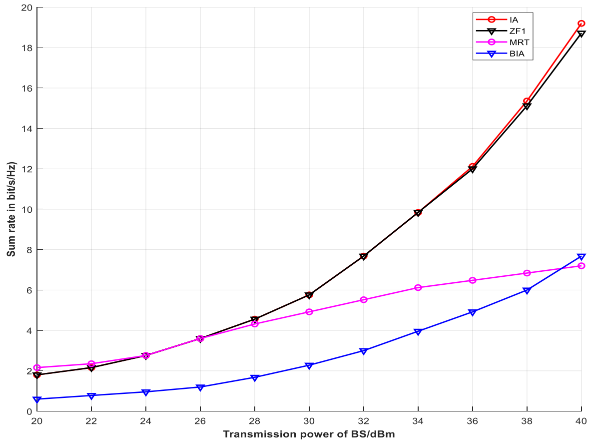

Fig. 3. Sum rate of all cellular UEs

Fig. 4 plots the number of admitted D2D pairs of different algorithms. The MRT and ZFl algorithms admit no more than 7 D2D pairs. The IA algorithm admits more D2D pairs than the MRT and ZFl algorithms when the transmission power of the BS is low, but fewer pairs are admitted as the BS transmission power increases. Although the number of admitted D2D pairs for the proposed BIA algorithm gradually decreases as the transmission power increases, it is still much greater than that of the other three algorithms, which explains the superior sum rate performance shown in Fig. 2.

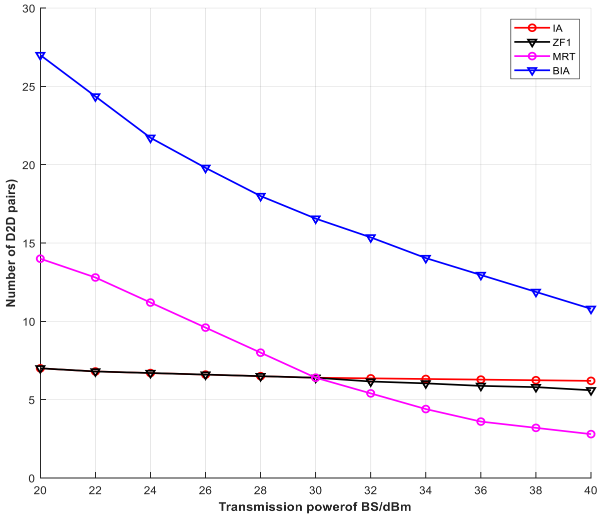

Fig. 4. Number of admitted D2D pairs

Fig. 5 plots the sum rate of all D2D pairs against the transmission power. Since the interference between the BS and the D2D pairs is serious, as the transmission power increases, the sum rates of the other three algorithms stay roughly constant. For our proposed BIA algorithm, the interference between the BS and the D2D pairs in set R_{D1} is completely eliminated by joint zero-forcing beamforming, and the interference between the BS and the D2D pairs in set R_{D2} is alleviated by interference alignment. Therefore, as the transmission power increases, the sum rate of all admitted D2D pairs for the proposed algorithm increases.

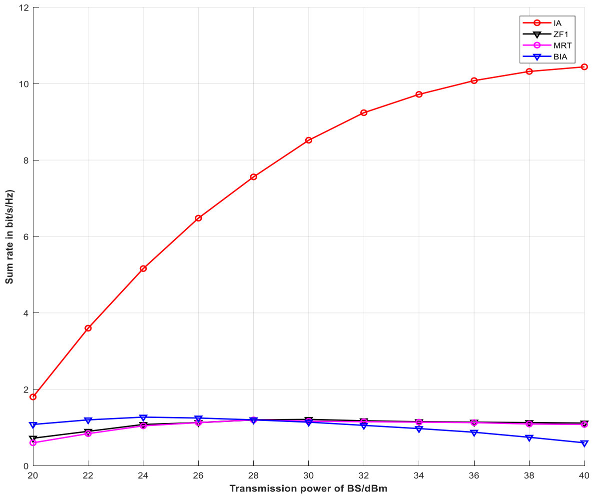

Fig. 5. Sum rate of all D2D pairs

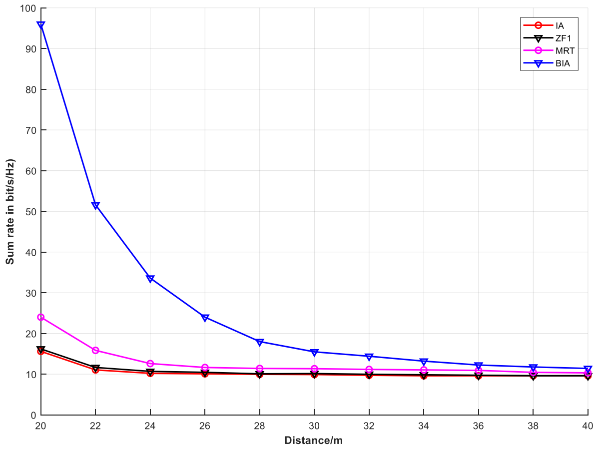

Fig. 6. Sum rate of all cellular UEs and D2D pairs with difference distance

Fig. 6 plots how the system sum rate varies with the distance between the transmitter and the receiver of each D2D pair. The distance varies from 1 to 10 m. The transmission power of the BS is set to be 30 dBm for these simulations, and the transmission power of D2D transmit ter is still $P_D=P_{BS}/20$. The system sum rate decreases as the distance between the transmitter and the receiver of D2D pair increases with any of the control algorithms. When the distance between the D2D transmitter and the receiver increases, the path loss of the D2D receiver increases, so the sum rate decreases. Therefore, D2D communication performs best at a short range. Furthermore, the proposed algorithm offers significantly better performance than the other three algorithms, even if the D2D devices are somewhat far apart.

V. CONCLUSION

A D2D admission control algorithm based on BIA that maximizes the system sum rate is proposed. By using the CSI of the cellular UEs and the selection of D2D pairs, we first perform joint zero-forcing beamforming on the cellular UEs, so that the transmitted signals of the BS exert no interference on the selected D2D pairs. For the rest of the D2D pairs, the channel parallelism is computed for the channels from the BS to each pair. Then, in the descending order of channel parallelism, each of the remaining D2D pairs is checked for admission to the network. The algorithm stops when the sum rate of the cellular UEs and admitted D2D pairs decreases. Simulation results show that the proposed BIA algorithm admits more D2D pairs than comparable algorithms and improves system performance significantly.

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