Interference-Aware Resource-Sharing Scheme for Multiple D2D Group Communications Underlaying Cellular Networks

Yunpeng Li • Zeeshan Kaleem • KyungHi Chang[1]

Abstract: Device-to-device (D2D) communications underlaying cellular networks have the potential to improve spectrum efficiency and link capacity by allowing nearby devices to communicate directly with each other on the licensed frequency bands. However, co-channel interference between cellular users (CUEs) and D2D pairs and co-channel interference among D2D pairs are major issues to be solved. In this paper, we propose an efficient interference-aware frequency resource-sharing scheme for multiple D2D groups that can efficiently maximize system throughput by considering grouping method, adaptive antenna arrays, and application of interference alignment (IA) for the D2D communications. Using a grouping method, nearby D2D pairs can form D2D groups for the convenience of implementing IA to cancel the interference among the D2D pairs in the group. Interference from the eNB to D2D pairs is reduced by the use of beamforming at the eNB. Furthermore, a greater distance between the D2D pairs and CUEs assists in reducing the interference between them. System-level simulation results confirm that the proposed scheme improves cell throughput compared with conventional distance sharing and random sharing schemes by 8.3% and 23.8%, respectively. The proposed scheme also demonstrates high cell throughput gain in comparison to the scenario of "without IA".

Keywords: *Device-to-device communications, Interference alignment, Grouping, Adaptive antenna arrays, Half power bandwidth*

1 Introduction

With the growth of mobile broadband services such as online gaming, mobile high-definition television, and media sharing services, wireless networks are confronted with an ever-increasing demand for high data rates. As device-to-device (D2D)

Y. Li • Z. Kaleem • K.H. Chang
Department of Electronic Engineering, Inha University, Incheon, Republic of Korea
e-mail: yunpengking0@163.com

Z. Kaleem
e-mail: zeeshankaleem@gmail.com

[1]Corresponding Author: K.H. Chang
e-mail: khchang@inha.ac.kr

This manuscript has also been edited by Editage (http://www.editage.co.kr/corporate/existing.html) regarding English corrections.

communications have the advantage of supporting a higher date rate, lower communications delay, and reducing energy consumption, it has been considered as a key technology for future 5G mobile communication systems [1]. However, co-channel interference between cellular users (CUEs) and D2D pairs and co-channel interference among D2D pairs are the major issues that must be resolved for successful transmission. To reduce the co-channel interference in D2D communications underlaying cellular networks, several techniques have been proposed in the existing literature. In [2-3], a new interference management method was proposed to define a special interference limited area where the D2D pairs can share the same frequency resource with the CUEs. Therefore, the interference between the D2D pairs and CUEs can be canceled. However, these schemes limited the scheduling alternatives for the eNB and reduce the multi-user diversity gain. In [4-6], effective interference cancellation schemes were proposed based on the location of the D2D pairs and CUEs. The D2D pairs or CUEs can measure the signal to interference and noise ratio (SINR) of the channel and then the eNB can decide whether to allocate this channel to the CUEs or D2D pairs based on the measured SINR. Even though these proposed schemes can reduce the interference between D2D pairs and CUEs, the spectrum efficiency becomes low.

Recently, a new interference management scheme called interference alignment (IA) was presented in [7] to align the interference from the different transmitters in a specific signal dimension. Then, the remainder of the dimension becomes interference-free space. Therefore, IA can achieve high multiplexing gain and degrees freedom of the channel. However, the majority of the papers consider the IA technology in a multi-cell scenario with cellular users or in a heterogeneous network (HetNet) scenario where macro cells and femto/small cells coexist in the cell. For instance, in [8-9], the authors proposed the use of IA to mitigate the interference of small-cell users towards the macro-cell eNB.

There are fewer papers that consider IA in D2D communications underlaying cellular networks. In [10], the author proposed a scheme to apply IA in D2D communications; however, the frequency resource is used by the D2D pairs that are orthogonal to the CUEs. Simulation results have indicated that the total sum-rate gain of a cell with D2D can be up to 31.8%. However, the author only considered symbol-extended IA. From [11], we can see that IA with symbol extension in the time domain does not function effectively when the channel is flat or slow fading. This is because coding over multiple time slots with the same channel coefficient does not provide the additional signal dimensions required for alignment. In [12], an effective interference alignment approach for D2D communications underlaying multi-cell interference networks was proposed. However, the authors provided only a brief analysis that IA can achieve $(K+1)Q$ degrees of freedom for a K-cell interference limited system with Q antennas at each eNB. Therefore, it is necessary to apply IA for D2D communications underlaying cellular networks to realize the vast achievable gain using IA.

Furthermore, the implementation of adaptive antenna arrays in future wireless systems is expected to have a significant influence on the spectrum efficiency and optimization of the service quality [13-14]. In adaptive antenna array systems, beam patterns can be orientated in any direction in response to its signal environment. From [13], we can observe that two cellular links can operate simultaneously without interference if the transmitter does not direct its beam to the other receiver. Half power beam width (HPBW) is usually used to describe the effective antenna beam width. In this paper, we assume zero gain outside the HPBW, that is, adaptive antenna arrays are useful for frequency resource sharing under the scenario of D2D communications.

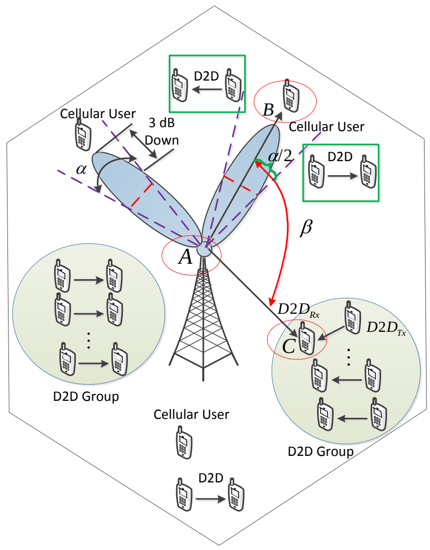

Fig. 1. System model of multiple D2D pairs underlaying cellular network

In our previous work, we implemented IA with multiple antennas for the D2D communications underlaying cellular networks [15]. The simulation results demonstrated that IA with multiple antennas could achieve improved performance compared to symbol-extended IA. However, our previous work assumed that there were three D2D pairs in one D2D group and only one D2D group in the cell. In this paper, we are not only extending the IA to multiple groups but also considering frequency resource-sharing scheme between the CUEs and D2D pairs. System-level simulation results confirm that the proposed sharing scheme performs remarkably well in a D2D communications underlaying cellular networks. The proposed scheme improves the cell throughput (i.e., aggregated throughput of CUEs and D2D pairs) compared to conventional distance sharing [16] and random sharing schemes [17] by 8.3% and 23.8%, respectively. The proposed scheme also demonstrates high cell throughput gain in comparison to the scenario of “without IA”.

The remainder of this paper is organized as follows: In Section 2, we describe the system model that includes the network model, interference scenario, path loss model, and antenna pattern. Section 3 analyzes the detailed procedure of the proposed Grouping, Selection and IA (GSIA) scheme, and Grouping & IA (GIA) scheme. The simulation results are discussed in Section 4. We conclude the paper in Section 5.

Notations: $|\mathbf{A}|$ denotes the modular of $\mathbf{A}$. $E(B)$ denotes the expectation operator over B. $(\cdot)^H$ denotes the Hermitian transpose operator. $null(\mathbf{C})$ denotes the null space of $\mathbf{C}$, i.e., $null(\mathbf{C})\times\mathbf{C}=0$.

2 System Model

2.1 Network Model

We consider a single-cell scenario for the multiuser cellular network with an eNB equipped with an adaptive antenna array located at the center of the cell. We assume that the number of arrays at the eNB is *S*, each user-equipment (UE) is equipped with *Q* antennas, and *M* CUEs and *N* D2D pairs are uniformly distributed over the cell, as illustrated in Fig. 1.

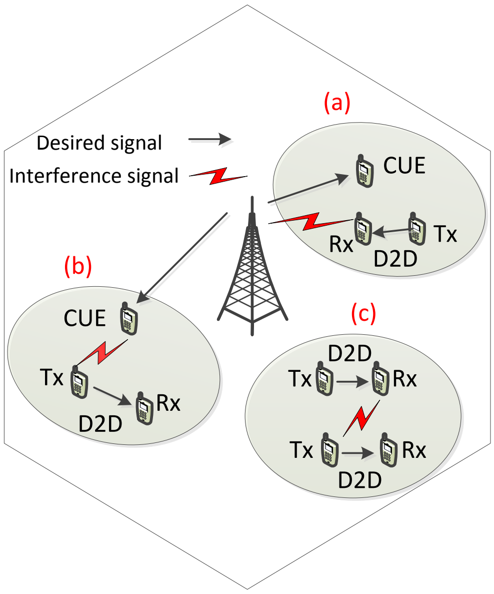

Fig. 2. Possible intra-cell DL interference scenarios: (a) eNB Tx to D2D Rx, (b) D2D Tx to CUE, (c) D2D Tx to other D2D Rx

2.2 Interference Scenario

We assume that all the CUEs and D2D pairs are active at the same time and different D2D pairs in the same group are sharing the same frequency resource. Therefore, it is necessary to consider three kinds of major downlink (DL) intra-cell interference, as indicated in Fig. 2. From the Fig. 2 (a), the first severe case of DL interference is from eNB Tx to the D2D Rx because of sharing the same frequency resources between the eNB and D2D. Similarly, the second major interference occurs between the D2D Tx and CUE Rx because of allocating the same resources between them as shown in Fig. 2 (b). Finally, since multiple D2D pairs in the same group are also sharing the same frequency resources, as a consequence the mutual interference among D2D pairs will also exist as shown in the Fig. 2(c). Thus, in order to reduce these major DL interferences, we propose the interference-aware resource-sharing scheme for multiple D2D group communications in the section 3.

2.3 Channel Model

The channel model represents the propagation loss that occurs when the signal travels from the transmitter to the receiver. The general equation to model the channel gain due to large-scale channel fading is given as: G (dB) = Antenna gain - Path loss - Shadowing.

In this paper, to calculate the path loss (PL) of the UEs residing outside a building and connected to an eNB, the urban area model is considered as:

$$PL(dB) = 15.3 + 37.6\log_{10}(R), \quad (1)$$

where R is the distance between the eNB and UE in meters. For a UE located inside a building and served by an eNB, the PL calculation considers an additional attenuation factor of 20 dB due to the presence of an external wall.

The UE-UE PL model is the WINNER+ B1 case [18], which can be represented as:

Line of sight (LOS):

$$PL(dB) = 35.4 + 22.7\log_{10}(R_1), \tag{2}$$

Non-line of sight (NLOS):

$$PL(dB) = 33.8 + 38.4\log_{10}(R_1), \tag{3}$$

where R_1 is the distance between UE-UE in meters. We utilize the LOS PL model between D2D transmitter ($D2D_{Tx}$) and D2D receiver ($D2D_{Rx}$) in the same group; the PL between D2D UEs and CUEs is modeled as NLOS.

Shadowing is caused by obstacles in the paths between the UEs and the eNB/UEs. This is usually modeled by a log-normal distribution with a mean of 0 dB and standard deviation X dB, i.e., different channel models have different X values [18]. As we only focus on a single cell, there is no requirement to consider the correlated shadowing fading among different eNBs.

Fast fading is a consequence of the constructive and destructive combination of randomly delayed, reflected, scattered, and diffracted signal components [19]. This type of fading is relatively fast and is, therefore, responsible for short-term signal variations that can occur when UEs or reflectors in an environment move short distances. The fast-fading MIMO fading channel gain from the transmitter to the receiver is usually assumed to be $\mathbf{H}$ whose elements are independent and identically distributed complex Gaussian variables with zero mean and unit variance [20].

2.4 Antenna Pattern

The antenna pattern for the adaptive antenna array used by the eNB is illustrated in Fig. 1. From [21], we consider the uniform aperture function:

$$f(x) = \begin{cases} \frac{1}{L}, & -\frac{L}{2} \le x \le \frac{L}{2}, \\ 0, & otherwise. \end{cases} \tag{4}$$

Then, the function of the antenna pattern becomes [21]:

$$F(u) = \int_{-\infty}^{\infty} f(x) e^{j2\pi ux} dx = \sin(\pi Lu) / \pi Lu, \tag{5}$$

where $L = S \times D$, S is the number of antenna arrays, D is the array spacing, u is the electrical angle of the beam, ψ is the physical angle of the beam, i.e., $u = \frac{f \sin\psi}{c} = \frac{\sin\psi}{\lambda}$, and λ is the wave length. $\alpha = \psi_{3dB}$ is the HPBW, i.e., the angular separation where the magnitude of the radiation pattern is decreased by 50% (or 3 dB) from the peak of the main beam, as illustrated in Fig. 1. HPBW is usually denoted as the effective beam width.

The antenna pattern for D2D UEs (pairs) is assumed to be omnidirectional.

2.5 Problem Formulation

A. Problem Formulation of GSIA

We assume that nearby D2D pairs can form D2D groups such as $G=\{g_1, g_2, ..., g_K\}$ where G denotes the collection of all possible D2D groups, and further details will be explained in Section 3. Let g_k be the *k-th* D2D group, g_k^i the *i-th* D2D pair in the *k-th* D2D group, *K* the total number of D2D groups and *N* the number of D2D pairs. The D2D pairs in each group are not overlapped, i.e., $g_k \cap g_t = \varphi,\ k \neq t$. The number of D2D pairs in all groups may not be equal to *N*, i.e., $\bigcup_{k=1}^{K} g_k \neq \{1, 2, ..., N\}$, because some D2D pairs may exist that cannot form D2D groups. The details of the grouping method will be explained in the following section. In this paper, to reduce the computational complexity, we assume that one CUE can be selected to share its frequency resource with one D2D group/pair. Certainly, multiple CUEs also can be selected to share their frequency resource with multiple D2D groups/pairs. Furthermore, if there are no available CUEs to be shared by the D2D groups/pairs, the frequency resource adopted by the D2D groups/pairs are orthogonal to those of the CUEs and thus, no interference is generated between the CUEs and D2D groups/pairs. G_m denotes the set of D2D pairs in the D2D groups or no grouped pairs that can share the same frequency resource with CUE_m.

We address two major interferences in this paper. The first is the interference between CUEs and D2D groups/pairs; the other interference is between different D2D pairs in the same group. Assume that eNB and D2D$_{Tx}$ send data streams $\mathbf{s}_m$ and $\mathbf{s}_n$, respectively, to its intended receiver with a transmitted power of P_m and P_n, respectively. The Tx powers are set to: $E[|\mathrm{s}_m|^2] = P_m$ and $E[|\mathrm{s}_n|^2] = P_n$.

The received signal at CUE_m can be expressed as:

$$\mathbf{y}_{CUE_m} = \sqrt{g_{CUE_m,eNB}}\mathbf{H}_{CUE_m,eNB}\mathbf{W}_{CUE_m} s_{CUE_m} + \underbrace{\sum_{i\in G_m} \sqrt{g_{CUE_m,D2D_{i\_Tx}}}\mathbf{H}_{CUE_m,D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}\mathbf{s}_{D2D_{i\_Tx}}}_{I_{CUE_m,D2D_i}} + \mathbf{n}_{CUE_m},\ i\in\{1, 2, ..., N\}. \tag{6}$$

The throughput of CUE_m can be calculated using Shannon's equation as:

$$T_{CUE_m} = B_{CUE_m}\log_2\Big(1+\frac{P_{CUE_m}\left|\sqrt{g_{CUE_m,eNB}}\mathbf{H}_{CUE_m,eNB}\mathbf{W}_{CUE_m}\right|^2}{I_{CUE_m,D2D_i}+\sigma_{CUE_m}}\Big). \tag{7}$$

Thus, the total throughput of the CUEs is:

$$T_{CUE} = \sum_{m=1}^{M} T_{CUE_m} \tag{8}$$

where $\sqrt{g_{CUE_m,eNB}}$ and $\sqrt{g_{CUE_m,D2D_{i\_Tx}}}$ denote the large-scale channel gain between

CUE_m and eNB, and between CUE_m and $D2D_i$, respectively. The fast-fading channel gains are $\mathbf{H}_{CUE_m,eNB} \in \mathrm{C}^{Q\times 1}$ and $\mathbf{H}_{CUE_m,D2D_{i\_Tx}} \in C^{Q\times Q}$, where Q is the number of antennas on the UE side. Zero-forcing Beamforming (ZFBF) is employed at the eNB that can be modeled as $\mathbf{W} = \mathbf{H}^H(\mathbf{H}\mathbf{H}^H)^{-1}$. For IA to be applied for the D2D groups, we set the IA linear precoder as $\mathbf{V}_{D2D_{i\_Tx}} \in C^{Q\times 1}$. $I_{CUE_m,D2D_i}$ denotes the aggregated interference at CUE_m, where σ_{CUE_m} denotes the received noise and B_{CUE_m} is the bandwidth of CUE_m.

The received signal at $D2D_{i\_Rx}$ is:

$$\begin{aligned}\mathbf{y}_{D2D_{i\_Rx}} &= \sqrt{g_{D2D_{i\_Rx},D2D_{i\_Tx}}}\mathbf{H}_{D2D_{i\_Rx},D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}\mathbf{s}_{D2D_{i\_Tx}} \\ &\quad + \underbrace{\sum_{j\in G_m, j\neq i}\sqrt{g_{D2D_{i\_Rx},D2D_{j\_Tx}}}\mathbf{H}_{D2D_{i\_Rx},D2D_{j\_Tx}}\mathbf{V}_{D2D_{j\_Tx}}\mathbf{s}_{D2D_{j\_Tx}}}_{I_{D2D_i,D2D_j}} \\ &\quad + \underbrace{\sqrt{g_{D2D_{i\_Rx},eNB}}\mathbf{H}_{D2D_{i\_Rx},eNB}\mathbf{W}_{CUE_m}\mathbf{s}_{CUE_m}}_{I_{D2D_i,CUE_m}} + \mathbf{n}_{D2D_{i\_Rx}}, \quad i,j\in\{1,2...N\}, i\neq j.\end{aligned} \tag{9}$$

Similarly, the throughput of $D2D_{i\_Rx}$ can be calculated by Shannon's equation as:

$$T_{D2D_{i\_Rx}} = B_{D2D_i}\log_2\left(1+\frac{P_{D2D_{i\_Tx}}\left|\sqrt{g_{D2D_{i\_Rx},D2D_{i\_Tx}}}\mathbf{H}_{D2D_{i\_Rx},D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}\right|^2}{I_{D2D_i,D2D_j}+I_{D2D_i,CUE_m}+\sigma_{D2D_{i\_Rx}}}\right). \tag{10}$$

Thus, the total throughput of $D2D_{i\_Rx}$ is:

$$T_{D2D} = \sum_{i=1}^{N} T_{D2D_{i\_Rx}}, \tag{11}$$

where $\sqrt{g_{D2D_{i\_Rx},D2D_{i\_Tx}}}$, $\sqrt{g_{D2D_{i\_Rx},D2D_{j\_Tx}}}$, and $\sqrt{g_{D2D_{i\_Rx},eNB}}$ denote the large-scale channel gains between $D2D_{i\_Rx}$ and $D2D_{i\_Tx}$, $D2D_{i\_Rx}$ and $D2D_{j\_Tx}$, and $D2D_{i\_Rx}$ and eNB, respectively. The fast-fading gains are $\mathbf{H}_{D2D_{i\_Rx},D2D_{i\_Tx}} \in C^{Q\times Q}$, $\mathbf{H}_{D2D_{i\_Rx},D2D_{j\_Tx}} \in C^{Q\times Q}$, and $\mathbf{H}_{D2D_{i\_Rx},eNB} \in C^{Q\times 1}$. $I_{D2D_{i\_Rx},D2D_{j\_Tx}}$ and $I_{D2D_{i\_Rx},CUE_m}$ denote the aggregated interferences at $D2D_{i\_Rx}$. $\sigma_{D2D_{i\_Rx}}$ denotes the received noise, and B_{D2D_i} is the bandwidth of $D2D_i$.

From the above analysis and reference [1], we can observe that by utilizing an efficient interference management algorithm, such as IA, system throughput can be improved. Therefore, it is necessary to maximally cancel or decrease these interferences.

B. Problem Formulation of GIA

In the GIA scheme, the D2D groups/pairs use an orthogonal frequency resource independent of the CUEs to avoid the interference among D2D groups/pairs. Thus, the received signal at $D2D_{i\_Rx}$ is:

$$\mathbf{y}_{D2D_{i\_Rx}} = \sqrt{g_{D2D_{i\_Rx},D2D_{i\_Tx}}}\mathbf{H}_{D2D_{i\_Rx},D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}\mathbf{s}_{D2D_{i\_Tx}} + \underbrace{\sum_{j\in G_m{}^{\perp}, j\neq i} \sqrt{g_{D2D_{i\_Rx},D2D_{j\_Tx}}}\mathbf{H}_{D2D_{i\_Rx},D2D_{j\_Tx}}\mathbf{V}_{D2D_{j\_Tx}}\mathbf{s}_{D2D_{j\_Tx}}}_{I_{D2D_i,D2D_j}}, \quad i, j \in \{1, 2 \ldots N^{\perp}\}, i \neq j, \tag{12}$$

where $G_m{}^{\perp}$ denotes the set of D2D pairs in orthogonal groups, and $N^{\perp}$ is the remaining number of D2D pairs after the GSIA scheme.

Then, the throughput of $D2D_{i\_Rx}$ can be calculated by Shannon's equation as:

$$T_{D2D_{i\_Rx}} = B_{D2D_i}\log_2\left(1 + \frac{P_{D2D_{i\_Tx}}\left|\sqrt{g_{D2D_{i\_Rx},D2D_{i\_Tx}}}\mathbf{H}_{D2D_{i\_Rx},D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}\right|^2}{I_{D2D_i,D2D_j} + \sigma_{D2D_{i\_Rx}}}\right). \tag{13}$$

Thus, the total throughput of $D2D_{i\_Rx}$ is:

$$T_{D2D} = \sum_{i=1}^{N^{\perp}} T_{D2D_{i\_Rx}}. \tag{14}$$

3 Proposed Interference-Aware Resource-Sharing Scheme for CUEs and Multiple D2D Groups

3.1 GSIA Scheme

In this scheme, D2D groups/pairs can share the same frequency resource with the CUEs. For the resource scheduling of conventional CUEs, proportional fairness (PF) scheduling is implemented. This scheme can be divided into three parts as follows:

A. Grouping Method

In this function, we require the number of D2D pairs allowed in each group to satisfy the feasibility constraint for IA. Thus, the number of D2D pairs allowed in each group is $l_{\max} = 2Q - 1$ [22], but the actual number of D2D pairs in each group is based on the decision conditions as indicated in Fig. 3 which is due to the limit of total number of D2D pairs.

For example, if $3 \le l_{\max} \le N$, $l_{\max}$ and "3" determine the upper and lower bounds of the number of D2D pairs in each group, respectively. Similarly, if $3 \le N \le l_{\max}$, then N and "3" determine the upper and lower bounds of the number of D2D pairs in each group, respectively. In the case of $0 \le N \le 2$, there is no requirement to consider the grouping method because using this method cannot achieve any gain from IA. We use the location of the $D2D_{Rx}$ as the reference location of the D2D pair because the relative distance between the $D2D_{Tx}$ and $D2D_{Rx}$ of a D2D pair is significantly smaller than the cell radius and also for reducing the computational complexity. Therefore, we can regard the coordinates of $D2D_{Rx}$ as the position of a D2D pair. The detailed procedure of the grouping scheme is as follows:

Step-1: Randomly select one D2D pairs which is chosen as the first pair g_k^1 in the *k-th* group g_k.

Step-2: Find other D2D pairs with minimum d_{ij}, which are chosen as the $g_k^2, g_k^3, ..., g_k^{l_{max}}$ or $g_k^2, g_k^3, ..., g_k^N$ pair in the group g_k based on Grouping method 1 or Grouping method 2, respectively, as indicated in Fig. 3(a) and Fig. 3(b). d_{ij} with $j \in \{1, 2, ..., N\}$, $j \neq i$ denotes the distance between the *i-th* D2D pair and the *j-th* D2D pair.

B. Selection of CUEs for sharing frequency resource with D2D groups

In this step, D2D groups/pairs select CUEs that can share the same frequency resource, as illustrated in Fig. 3(c). The detailed procedure of CUE selection is:

Step-1: Calculate the vector angle between $D2D_i$ and all the CUEs, i.e., $\{\beta_{1i}, ..., \beta_{Mi}\}$.

Step-2: Verify if $\beta_{mi} \geq \alpha_m / 2, \beta_{mi} \in \{\beta_{1i}, \beta_{2i}, ..., \beta_{Mi}\}$. If this condition is satisfied, go to Step 3. Else, move $D2D_i$ to the orthogonal group $g^{\perp}$, i.e., different orthogonal groups use orthogonal frequency resources, which will be described in the GIA scheme.

Step-3: Corresponding CUEs that satisfy the condition, that is, $\beta_{mi} \geq \alpha_m / 2, \beta_{mi} \in \{\beta_{1i}, \beta_{2i}, ..., \beta_{Mi}\}$, are selected as the candidates for frequency resource sharing.

Step-4: Calculate the distance between $D2D_i$ and the selected CUEs. Find a $\tilde{CUE}_m$ with maximum distance from $D2D_i$, that can be chosen for frequency resource sharing with the D2D group/pair.

β_{mi} is defined as the vector angle between CUE_m and $D2D_i$, it can be calculated as follows:

The coordinates of eNB, CUE_m, and $D2D_i$ are denoted as: $A = (x_{eNB}, y_{eNB})$, $B_m = (x_{CUE_m}, y_{CUE_m})$, and $C_i = (x_{D2D_i}, y_{D2D_i})$, respectively. The vector between eNB and CUE_m is $\vec{AB}_m = (x_{CUE_m} - x_{eNB}, y_{CUE_m} - y_{eNB})$ and the vector between eNB and $D2D_i$ is $\vec{AC}_i = (x_{D2D_i} - x_{eNB}, y_{D2D_i} - y_{eNB})$. β_{mi} is the angle between $\vec{AB}_m$ and $\vec{AC}_i$, i.e., $\beta_{mi} = \angle(\vec{AB}_m, \vec{AC}_i)$. Then, the equation to calculate the β_{mi} is represented as:

$$\beta_{mi} = arcos\left[\frac{\vec{AB}_m \cdot \vec{AC}_i}{(\left|\vec{AB}_m\right| \times \left|\vec{AC}_i\right|)}\right]. \tag{15}$$

α_m is the HPBW of CUE_m, and different α_m can influence the performance of Step-2, i.e., the smaller a_m, the more CUEs will be selected as the candidates. From our previous work, we know that the beam width is inversely proportional to the number of array elements and array-element spacing and is directly proportional to the off-boresight angle u_0. Therefore, we set $S = 8, D = \lambda / 2,$ and $u_0 = 0^0$. Then, the optimal α_m can be calculated as [23]:

$$F(u-u_0)=\frac{1}{S}\frac{\sin\left[\pi Sd\left(u-u_0\right)\right]}{\sin\left[\pi d\left(u-u_0\right)\right]}=\frac{1}{\sqrt{2}}. \tag{16}$$

Thus, using (16) we have $\psi_{3dB}=\alpha_m\approx 12^0$. As we know that the gain is zero outside the beam width (HPBW), and since the D2D pairs are out of the HPBW of $\tilde{CUE}_m$, therefore, the interference from eNB to D2D pairs will be canceled based on this fact, i.e., $I_{D2D_{i\_Rx},\tilde{CUE}_m}=0$. Furthermore, as the selection of CUE also considers the distance metric as the decision condition, i.e., the largest distance between D2D pairs and $\tilde{CUE}_m$, therefore, the interference from D2D pairs to CUEs will be decreased noticeably. Thus, (9) and (10) can be rewritten as:

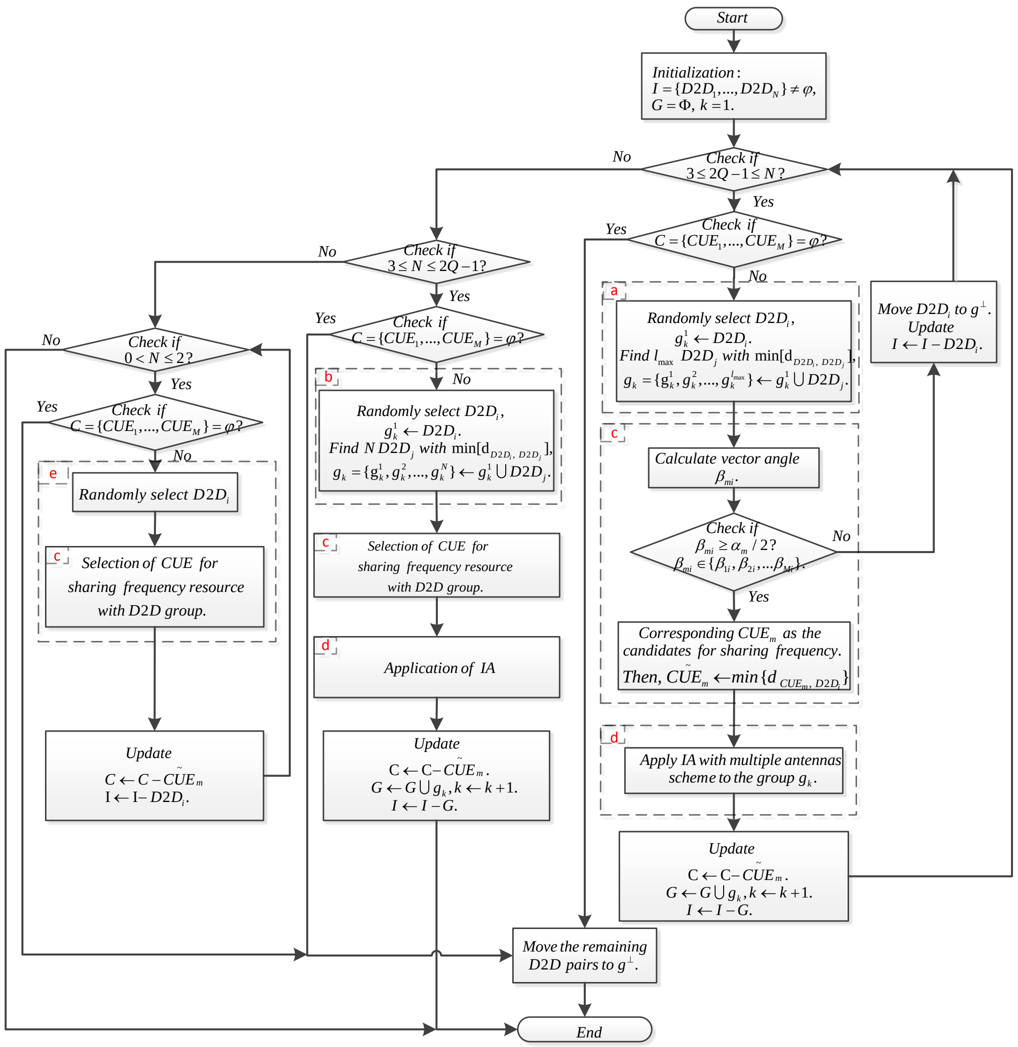

Fig. 3. Flow chart of GSIA scheme: (a) Grouping method 1, (b) Grouping method 2, (c) Selection of CUE for sharing frequency resource with D2D group, (d) Application of interference alignment, (e) Case 1.

$$\mathbf{y}_{D2D_{i\_Rx}} = \sqrt{g_{D2D_{i\_Rx},\,D2D_{i\_Tx}}}\,\mathbf{H}_{D2D_{i\_Rx},\,D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}\mathbf{s}_{D2D_{i\_Tx}} + \underbrace{\sum_{j\in G_m,\, j\neq i}\sqrt{g_{D2D_{i\_Rx},\,D2D_{j\_Tx}}}\,\mathbf{H}_{D2D_{i\_Rx},\,D2D_{j\_Tx}}\mathbf{V}_{D2D_{j\_Tx}}\mathbf{s}_{D2D_{j\_Tx}}}_{I_{D2D_i,\,D2D_j}} + \mathbf{n}_{D2D_{i\_Rx}},$$
$$i, j \in \{1, 2, \ldots, N\},\ i \neq j. \tag{17}$$

$$T_{D2D_{i\_Rx}} = B_{D2D_i}\log_2\left(1 + \frac{P_{D2D_{i\_Tx}}\left|\sqrt{g_{D2D_{i\_Rx},\,D2D_{i\_Tx}}}\,\mathbf{H}_{D2D_{i\_Rx},\,D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}\right|^2}{I_{D2D_i,\,D2D_j} + \sigma_{D2D_{i\_Rx}}}\right) \tag{18}$$

C. Application of interference alignment for D2D group

In this section, we apply IA to the D2D groups to cancel the interference among different D2D pairs in the same group, as indicated in Fig. 3(d). The basic concept of IA in the group is to allow the $D2D_{Tx}$ and $D2D_{Rx}$ pairs in the same group to jointly design the precoders and equalizers to suppress the intra-group interference. At the *i-th* D2D receiver, the interference from the transmitters of other D2D pairs can be completely canceled if perfect IA can be achieved. Using multiple antennas, the linear interference alignment conditions can be described by the following zero-forcing conditions:

$$\mathbf{U}_{D2D_{i\_Rx}} = null[(\mathbf{H}_{D2D_{i\_Rx},\,D2D_{j\_Tx}}\mathbf{V}_{D2D_{j\_Tx}})^H], \tag{19}$$

$$(\mathbf{U}_{D2D_{i\_Rx}})^H\mathbf{H}_{D2D_{i\_Rx},\,D2D_{j\_Tx}}\mathbf{V}_{D2D_{j\_Tx}} = 0,\ i \neq j, \tag{20}$$

$$Rank[(\mathbf{U}_{D2D_{i\_Rx}})^H\mathbf{H}_{D2D_{i\_Rx},\,D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}] = r_i. \tag{21}$$

Equations (19) and (20) guarantee that all the interfering signals at $D2D_{i\_Rx}$ lie in the subspace orthogonal to $\mathbf{U}_{D2D_{i\_Rx}}$, Eq. (21) assures that the signal subspace $[\mathbf{H}_{D2D_{i\_Rx},D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}]$ has the dimension r_i and is linearly independent of the interference subspace. In this ideal case, the intra-group interference $\sum_{j\in G_m,\, j\neq i} I_{D2D_i,\,D2D_j}$ in (17) can be completely eliminated. Therefore, (17) and (18) can be rewritten as:

$$\mathbf{y}_{D2D_{i\_Rx}} = \sqrt{g_{D2D_{i\_Rx},\,D2D_{i\_Tx}}}\,(\mathbf{U}_{D2D_{i\_Rx}})^H\mathbf{H}_{D2D_{i\_Rx},\,D2D_{i\_Tx}}\mathbf{V}_{D2D_{i\_Tx}}\mathbf{s}_{D2D_{i\_Tx}} + (\mathbf{U}_{D2D_{i\_Rx}})^H\mathbf{n}_{D2D_{i\_Rx}},\quad i, j \in \{1, 2, \ldots, N\},\ i \neq j, \tag{22}$$

$$T_{D2D_{i\_Rx}} = B_{D2D_i} \log_2(1 + \frac{P_{D2D_{i\_Tx}} \left| \sqrt{g_{D2D_{i\_Rx},\, D2D_{i\_Tx}}} (\mathbf{U}_{D2D_{i\_Rx}})^H \mathbf{H}_{D2D_{i\_Rx},\, D2D_{i\_Tx}} \mathbf{V}_{D2D_{i\_Tx}} \right|^2}{\sigma_{D2D_{i\_Rx}}}). \quad (23)$$

After the application of the proposed GSIA scheme, the remaining D2D pairs may be one or two in a cell. As mentioned above, the reason for this is that if $0 \le N \le 2$, there is no requirement to perform the grouping because of the limits of the IA application. Thus, we can divide this scenario into the following two cases:

Case 1: The number of D2D pairs is less than three. In this case, the remaining D2D pairs can share the frequency resource with the CUEs without a grouping method as described in Fig. 3(e).

Case 2: Some D2D pairs cannot share the same frequency resource with the CUEs because the angle between the D2D pairs and CUEs is less than half of HPBW. Consequently, interference at the D2D pairs, which comes from the eNB, will be serious. There is also a possibility that there are no CUEs that can share the frequency resource with the D2D pairs, although, additional bandwidth exists in the cell. In this case, it will utilize the GIA scheme.

3.2 GIA Scheme

In this scheme, the remaining D2D pairs can use the additional frequency resource independent of the CUEs. Therefore, there is no interference between the D2D groups/pairs and CUEs. The grouping method and application of IA continue to be required in this scheme. Considering the frequency resource allocation among the D2D groups/pairs, we implement PF scheduling for these D2D groups/pairs. As the GIA scheme is only for the integrity of the proposed sharing scheme, therefore, the optimal frequency resource allocation for this scheme is an open problem that will be addressed in a future work. The flow chart of this scheme is presented in Fig. 4.

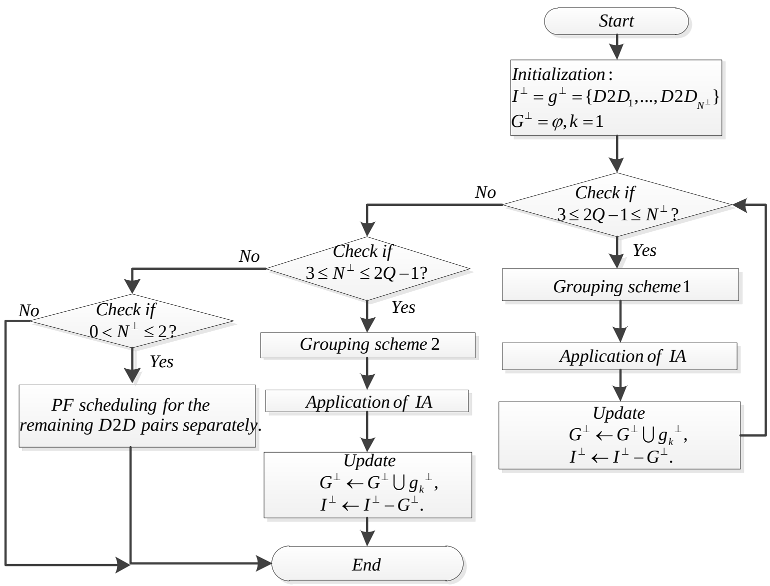

Fig. 4. Flow chart of GIA scheme

Table 1 Simulation Parameters

Parameter	Value
Carrier Frequency	2.62 GHz
Bandwidth	10 MHZ
Total Number of RBs	50
RB Bandwidth	180 KHZ
Number of eNB Antennas	1 with 8 antenna arrays
Number of D2D Tx Antennas	2
Number of D2D Rx antennas	2
Number of CUE antennas	2
Cell Radius	500 m
Number of CUEs	20
Path Loss	See path loss model in Section 2 (C)
Shadowing Standard Deviation (eNB-UE)	8 dB
Shadowing Standard Deviation (UE-UE)	4 dB
Noise Figure	5 dB
Noise Spectrum Density	-175 dBm/Hz
Antenna Pattern	See antenna pattern in Section 2 (D)
Maximum eNB Tx Power	46 dBm
Maximum D2D Tx Power	23 dBm
Traffic Model	Full buffer

4 Performance Evaluation

In this section, we describe the simulation environment and results of the performance of the proposed scheme. Without loss of generality, we assume that the entire bandwidth is allocated to the CUEs and there is no additional bandwidths for the orthogonal groups, i.e., we only estimate the performance of the GSIA scheme. The main simulation parameters are listed in Table 1. As indicated in Fig. 1, simulations are performed in a single cell. Path loss model, shadow fading, and antenna gains are considered for the cellular and D2D links. The average distance between the transmitter and receiver of a D2D pair is 50 meters [24]. Based on the number of antennas in each UE, the number of D2D pairs in each group is set to three. Furthermore, we assume that the transmit power of the eNB and $D2D_{Tx}$ are fixed with 46 dBm and 23 dBm, respectively.

Fig. 5 shows the topology of the CUEs and D2D pairs under the proposed sharing scheme. The number of D2D pairs is assumed to be 60 and the HPBW is 12 degrees in Fig. 5, where "+" denotes the eNB, the black dot with numeral denotes the D2D pair, and the pink dot with numeral denotes the CUE. In this figure, we can see that D2D pairs form multiple D2D groups based on the grouping method. For example, the D2D group is formed by the D2D pairs of the same number, such as (1 1 1), (2 2 2), …, and (20 20 20). Because the D2D pairs in the same group are located within a short range, we apply IA to mitigate the interferences. The same numeral with a different color denotes that the CUEs and D2D pairs are sharing the same frequency resource, e.g., black (1 1 1) and pink "1". We can also observe that they are far apart, hence, resource sharing is allowed. Fig. 5 illustrates how the D2D pairs form multiple D2D groups and select the CUEs for frequency resource sharing in the proposed sharing scheme.

Fig. 6 demonstrates the number of D2D pair in communication with increase in the number of deployed D2D pairs for varying HPBW. The simulation result verifies that larger HPBW results in reduction of the number of D2D pairs in communication. This is because in order to avoid the interference between the CUEs and D2D pairs, the concept of HPBW is being utilized. The D2D pairs lying in the HPBW of the CUEs will not be able to share the same frequency band to avoid the interference. When HPBW increases, more number of D2D pairs will lie under the HPBW of CUE. Hence, smaller the HPBW less number of D2D pairs will lie in the HPBW of CUE, which results in more chances of frequency sharing between the CUEs and D2D pairs. For example, in Fig.1 the *B* CUE represented by red circle lie under the HPBW of angle α/2, and the two D2D pairs represented by green boxes are out of that HPBW, and hence that D2D pairs can share the frequency band of CUEs. In case, if the HPBW increases then these two D2D pairs will lie inside the area of the HPBW, and hence will not be able to share the frequency band with CUEs to avoid the interference. This case especially happens when the number of deployed D2D pairs and CUEs are large, and D2D pairs are trying to find the CUE to share the same frequency band. Therefore, the number of D2D pair in communication varies (increase or decrease) with the increase in the number of deployed D2D pairs for varying HPBW.

In Fig. 7, we observe that a large HPBW leads to a total throughput loss because of the reduction of D2D pairs in communication, therefore, HPBW=12 achieves the highest throughout compared with the cases of HPBW=40 and HPBW=70 in the D2D links.

Fig. 8 demonstrates the negative influence of enabling D2D communications in a cellular network. Decreasing the HPBW increases the number of D2D pairs in communication, hence, increases the number of the interfering transmitters to the CUEs.

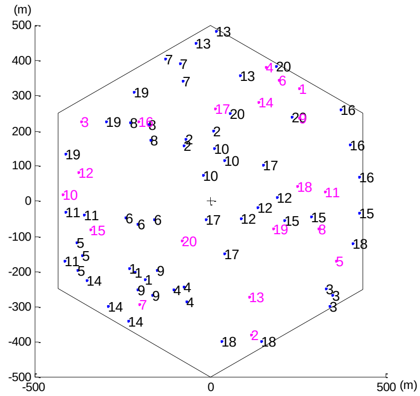

Fig. 5. Topology of the proposed sharing scheme for CUEs and D2D pairs.

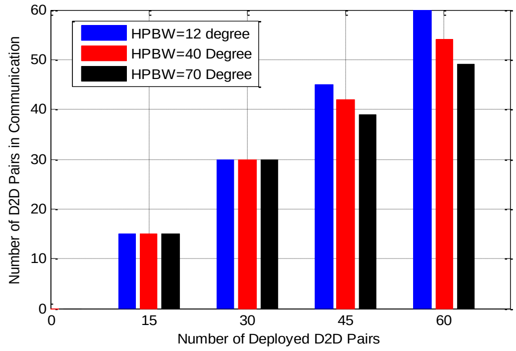

Fig. 6. Number of D2D pairs in communication with HPBW=12, 40, and 70 degrees.

Consequently, the total throughout of the CUEs indicates the worst performance in the case of HPBW=12. Moreover, an eNB with a different HPBW can allow the same number of D2D pairs in communications for frequency resource sharing when the number of deployed D2D pairs is less than 30, i.e., the aggregated interferences at the CUEs is virtually the same. However, from Fig. 8, we can see that the total throughput of the CUEs in the case of HPBW=12 is slightly greater than the other two cases owing to the greater antenna gain of the smaller HPBW [21].

In Fig. 9, we can observe that HPBW = 12 achieves the best performance in terms of cell throughput combining the CUEs and D2D pairs. Though HPBW=12 can allow more D2D pairs resulting in a reduction of the CUEs' throughput, the throughput gain of the D2D pairs is greater than the throughput loss of the CUEs, which can compensate this loss.

In Fig. 6, we found that HPBW = 12 is the best choice to reduce the interference for D2D pairs in communication. Thus, Figs. 10 to 13 are based on the case of HPBW = 12, i.e., the number of D2D pairs in communications equal the number of deployed D2D

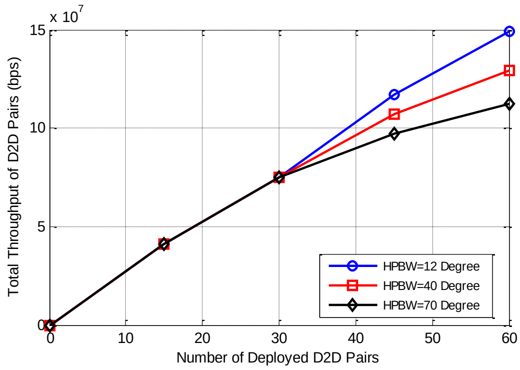

Fig. 7. Total throughput of D2D pairs with HPBW = 12, 40, and 70 degrees.

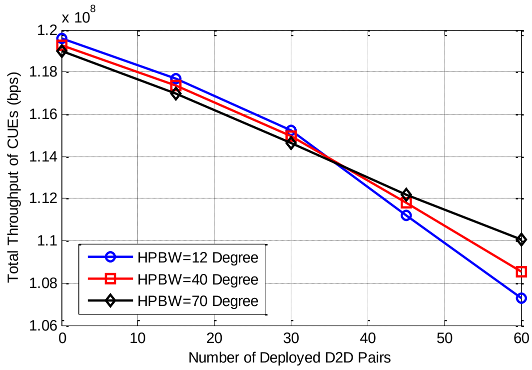

Fig. 8. Total throughput of CUEs with HPBW=12, 40, and 70 degrees.

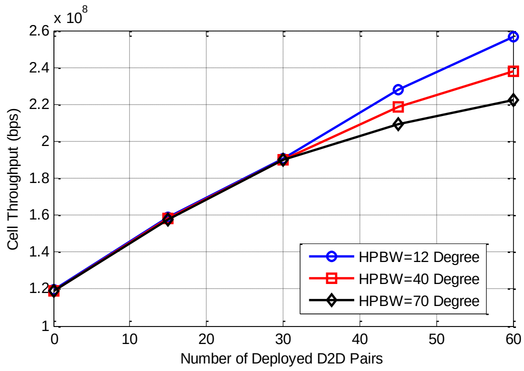

Fig. 9. Cell throughput with HPBW=12, 40, and 70 degrees.

pairs. In the references [16-17], authors consider a frequency resource-sharing scheme between the D2D groups/pairs and CUEs based on the distance, i.e., the farthest CUEs are usually selected to share the same frequency resource with the D2D groups/pairs, and random sharing scheme, i.e., the D2D groups/pairs randomly select the CUEs for frequency resource sharing. However, this is not sufficient to cancel or reduce the interference from the eNB to the D2D groups/pairs, especially when there are many D2D pairs. Therefore, in Figs. 10 to 11, we evaluate the total throughput of the D2D pairs and cell throughput for the case of the proposed, distance, and random sharing schemes.

From Fig. 10, we can observe that the total throughout of the D2D pairs of the proposed sharing scheme outperforms the conventional distance and random sharing schemes. This is because some of the D2D pairs are located in the HPBW of the sharing CUEs, which are influenced by interference from the eNB in the case of the distance and random sharing schemes. The proposed sharing scheme not only considers the angle factor (i.e., the D2D groups/pairs are only located outside the HPBW of the sharing CUEs) but also the distance factor as decision conditions to select the CUEs for frequency resource sharing. Consequently, the proposed scheme can efficiently avoid interference from the eNB to the D2D pairs, which results in improved performance in terms of the total throughput of the D2D pairs.

In Fig. 11, we can observe that the proposed sharing scheme improves the cell throughput compared with the conventional distance sharing and random sharing schemes by 8.3% and 23.8%, respectively, owing to the throughput gain of the D2D pairs.

In Fig. 12, we assess the performance of IA in terms of cell throughput, where it indicates that the proposed sharing scheme with IA can provide a high cell throughput gain compared to the case of "without IA". This is because the intra-group interferences

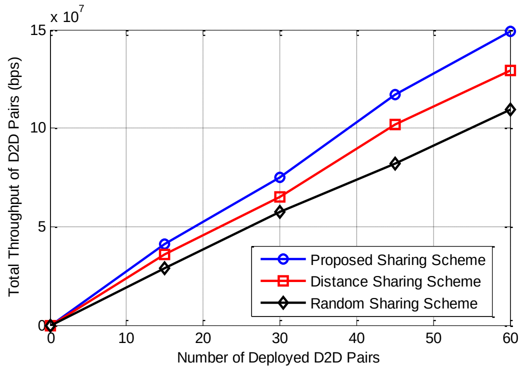

Fig. 10. Total throughput of D2D pairs with the proposed sharing scheme, distance and random sharing schemes.

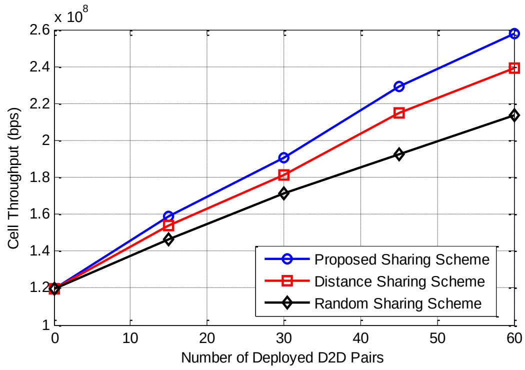

Fig. 11. Cell throughput with the proposed sharing scheme, distance and random sharing schemes.

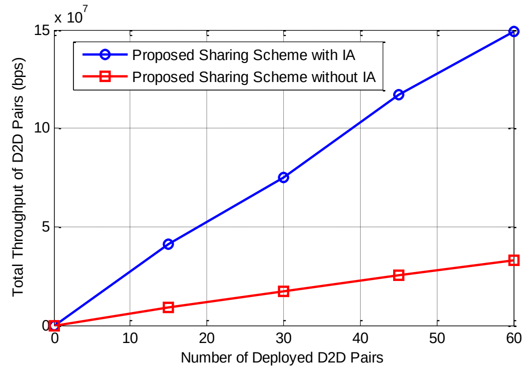

Fig. 12. Total throughput of D2D pairs of the proposed sharing scheme with and without IA.

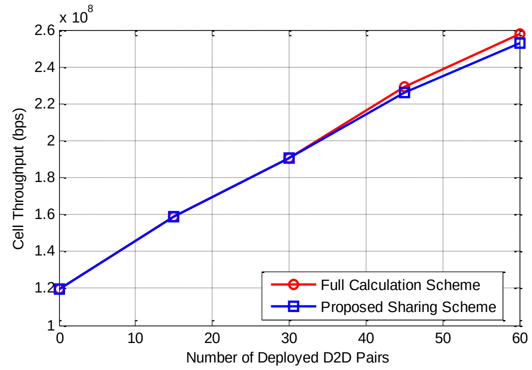

Fig. 13. Cell throughput of the proposed sharing scheme and full calculation scheme.

among the D2D pairs are significantly reduced because of the application of IA into the group. The scenario without both grouping and IA schemes is analyzed in our previous work [18].

Fig. 13 presents the cell throughput of the proposed sharing and full calculation schemes. To select the CUEs for frequency resource sharing in the proposed scheme, we select a random D2D pair as the reference location of its belonging group to calculate the angle and distance between the D2D group and CUE. The full calculation scheme is defined to calculate the angle and distance for each D2D pair in the group separately. Slight throughput degradation due to the use of the full calculation scheme comes from the additional interference of the D2D pairs in the HPBW by the eNB.

5 Conclusions

In this paper, we propose an interference-aware resource-sharing scheme for multiple D2D groups and CUEs. The GSIA scheme proposed in this paper considers the angle and distance factor simultaneously for the grouping of D2D pairs and the application of IA. Thus, it can cancel the interference not only from the eNB to the D2D pairs but also among the different D2D pairs in the same group. Moreover, it can also reduce the interference from the D2D pairs to the CUEs based on the distance requirement. The simulation results confirm that, compared with conventional distance sharing and random sharing schemes, the proposed scheme improves the cell throughput by 8.3% and 23.8%, respectively. The proposed scheme also provided a high cell throughput gain in comparison to the scenario of “without IA”.

Acknowledgements
This research was supported by the MSIP (Ministry of Science, ICT and Future Planning), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2015-H8501-15-1019) supervised by the IITP (Institute for Information & communications Technology Promotion).

References

1. M. Tehrani, M. Uysal and H. Yanikomeroglu, “Device-to-device communications in 5G cellular network: challenges, solutions, and future directions,” *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 86-92, May 2014.
2. H. Min, J. Lee, S. Park and D. Hong, “Capacity enhancement using an interference limited area for device-to-device uplink underlaying cellular network,” *IEEE Trans. on Wireless Commun.*, vol. 10, no. 12, pp. 3995–4000, Dec. 2011.
3. X. Chen, L. Chen, M. Zeng, X. Zhang and D. Yang, “Downlink resource allocation for device-to-device communications underlaying cellular network,” in *Proc. IEEE PIMRC*, Jun. 2012, pp. 232–237.
4. B. Kaufman and B. Aazhang, “Cellular network with an overlaid device-to-device network,” in *Proc. ACSSC*, July 2008, pp. 1537–1541.
5. S. Xu, H. Wang, T. Chen, Q. Huang and T. Peng, “Effective interference cancellation scheme for device-to-device communications underlaying cellular network,” in *Proc. IEEE VTC-Fall*, Sept. 2010, pp. 1–5.
6. P. Janis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler and K. Hugl, “Interference-aware resource allocation for device-to-device radio underlaying cellular network,” in *Proc. IEEE VTC Spring*, April 2009, pp. 1–5.
7. Viveck R. Cadambe and A. Jafar, "Interference alignment and degree of freedom of the k-user interference channel," *IEEE Trans. Inf. Theory*, vol. 54, no. 8, pp. 3425-3441, Aug. 2008.
8. M. Maso, M. Debbah and L. Vangelista, “A distributed approach to interference alignment in OFDM-based two-tiered network,” *IEEE Trans. Veh. Technol.*, vol. 62, no. 5, pp. 1935–1949, Jun. 2013.
9. S.Sharma, S. Chatzinotas and B. Ottersten, “Interference alignment for spectral coexistence of heterogeneous network,” *EURASIP J. Wirel. Commun. Netw.*, 2013, 6:125.
10. Hussain E. Elkotby, Khaled M. F. Elsayed and Mahmoud H. Ismail, "Exploiting interference alignment for sum rate enhancement in D2D-enabled cellular network," in *Proc. WCNC*, April 2012, pp. 1624-1629.
11. S. Chen and Roger S. Cheng, “Clustering for interference alignment in multiuser interference network,” *IEEE Trans. Veh. Technol.*, vol. 63, no. 6, pp. 2613-2324, July 2014.
12. X. Qu and Chung G. Kang, “An effective interference alignment approach for device-to-device communications underlaying multi-cell interference network,” in *Proc. ICTC*, Oct. 2012, pp. 219-220.
13. J. Qiao, X. Shen, J. Mark, Shen, Y. He and L. Lei, “Enabling device-to-device communications in millimeter-wave 5G cellular network,” *IEEE Commun. Mag.*, vol. 53, no. 1, pp. 209-215, Jan. 2015.
14. Alexiou. A and Haardt. M, “Smart antenna technologies for future wireless systems: trends and challenges,” *IEEE Commun. Mag.*, vol. 42, no. 9, pp. 90-97, Sept. 2004.
15. Y. Li and K.H. Chang, “Interference alignment with multiple antennas for single group D2D communications,” in *Proc. KICS Winter Confer.*, Jan. 2015, pp.136-138.
16. José Mairton B. da Silva Jr, Tarcisio F. Maciel, Rodrigo L. Batista,Carlos F. M. e Silva and Francisco R. P. Cavalcanti, “UE grouping and mode selection for D2D communications underlaying a multi cellular wireless system, ” in *Proc. WCNC*, April 2014, pp. 230-235.
17. S. Dinh-Van, Q. Duong and Oh. Shin, “User grouping for device-to-device communications underlaying Cellular Networks,” in *Proc. CCNC*, Jan. 2014, pp. 563-568.

18. 3GPP, "3rd Generation Partnership Project; Technical Specification Group RAN; Study on LTE Device to Device Proximity Services (ProSe) - Radio Aspects (Release12)," TR 36.843 V1.0.0, Nov. 2013.
19. Z. Kaleem, B. Hui, and K.H. Chang, "Qos priority-based dynamic frequency band allocation algorithm for load balancing and interference avoidance in 3GPP LTE HetNet," *EURASIP J. Wirel. Commun. Netw.*, 2014, 1:185.
20. C. Xu, L. Song, B. Jiao and X. Cheng, "Efficiency resource allocation for device-to-device underlay communications systems: a reverse iterative combinatorial auction based approach," *IEEE Selected Areas in Commun.*, vol. 31, no. 9, pp. 348-358, Sept. 2013.
21. S. Chandran, "Adaptive antenna arrays trends and applications," Springer Science & Business Media, Jun. 2004.
22. C. M. Yetis, T. Gou, S. A. Jafar and A. H. Kayran, "On feasibility of interference alignment in MIMO interference network," *IEEE Trans. Signal Process.*, vol. 58, no. 9, pp. 4771–4782, Sep. 2010.
23. M. Razaviyayn, G. Lyubeznik and Z. Luo, "On the degrees of dreedom achievable through interference alignment in a MIMO interference channel," *IEEE Trans. Signal Process.,* vol. 60, no. 2, pp. 812–821, Feb. 2012.
24. X. Su and K.H. Chang, "Polarized uniform linear array system: beam radiation pattern, beamforming diversity order, and channel capacity," *Int. J. Antenn. Propag.* , vol. 2015, Article ID 371236, 9 pages, 2015..
25. N. Lee, Jeffrey G. Andreas and Robert W. Heath, "Power control for D2D underlaid cellular network: modeling, algorithms and analysis," *IEEE Selected Areas in Commun.*, vol. 33, no. 1, pp. 1-13, Jan. 2015.