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Interference Mitigation for Device-to-Device based Cellular Communications

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***Abstract*—Device-to-device (D2D) communication underlaying cellular networks can improve the performance of cellular systems and it provides an effective way to meet growing mobile traffic and capacity demand. When user equipments are located in close proximity, they can communicate through direct links. In this case, D2D links can increase both energy and spectrum efficiency by reusing uplink (UL) cellular resources while satisfying the users' quality-of-service requirements. However, integrating D2D links into the cellular infrastructure causes an interference since D2D communication can increase co-channel interference and degrade cellular users' transmission link quality. In this paper, the interference mitigation techniques including power control, multiple antenna and resource allocation based on graph coloring are proposed for D2D communications underlaying cellular systems to increase the data rate of both the cellular users and D2D pairs. Compared to the prior works, in the proposed algorithm, D2D and cellular users have same priority for resource allocation. Finally, the proposed algorithm improves the overall system capacity significantly.**

I. INTRODUCTION

For wireless communications systems, high traffic demands and data rates are a crucial challenge. Beyond fifth generation (5G) networks are considered to maintain the existing and evolving technologies and, at the same time, satisfy the new requirements [1]. There are many new concepts, design criteria, and scenarios that have been examined in beyond 5G. One of them is D2D communication which denotes to direct connections between nearby mobiles without routing data through the base station (BS) or the core network [2]. This direct communication between nearby users (UE)s or mobile devices will improve the spectrum utilization, overall throughput, and energy efficiency. In this way, new types of services such as multimedia downloading, video streaming, online gaming and file sharing between the nearby users can be performed more effectively.

Using direct communication between the UEs can provide higher capacity while causing interference issues. Since D2D pairs are likely to be deployed so densely, interference mitigation will be one of the most important challenges for D2D communication in the wireless networks. Moreover, because of the deployment of dense neighboring of D2D pairs, the usage of same spectrum and their stochastic nature, they require some intelligent techniques to organize themselves and to overcome the interference problem [3]. As a result, interference mitigation techniques have great importance for D2D communication to ensure that users have good quality of service (QoS) without any degradation in the overall system performance.

There has been considerable research in interference mitigation techniques for D2D underlay cellular networks. In [4]- [5], interference-aware resource allocation algorithms have been studied to reduce interference between cellular users and D2D pairs. In [6], a heuristic Graph-Coloring resource allocation (GOAL) algorithm has been formulated to improve the system capacity. In [7], for a single D2D link communication, a dynamic power control technique is used to increase the cellular system performance by managing the interference caused by D2D communication through adjusting D2D transmit power. Additionally, interference suppression technique has been taken into consideration in [8] by employing zero-forcing (ZF) precoding. In [9], an algorithm based on the distance between D2D has been developed to use both the licensed and unlicensed spectrum efficiently while minimizing the interference with the Hungarian bipartite matching algorithm which allows one cellular user to reuse its resources with two D2D pairs. In [10], D2D resource allocation and power control (DRAPC) model has been defined with vertex coloring.

In this paper, we propose a resource allocation algorithm for D2D underlaying uplink cellular communications systems to increase the overall system capacity. The requirements on signal-to-interference-noise ratio (SINR) for both cellular users and D2D pairs are satisfied by adjusting the transmit power at the UE side and implementing the ZF postcoding at the BS side. In the considered scenario, the resources of cellular users can be used by multiple D2D pairs where the number of D2D pairs is greater than the number of cellular users. To mitigate the interference between cellular users and D2D pairs which cause performance degradation, we propose a resource allocation algorithm based on graph coloring technique. In contrast to works in the literature, the proposed algorithm formulate the interference mitigation by assigning the D2D pairs to the available resources independently and without giving any priority between the cellular users and D2D pairs. Therefore, the number of allocated resources to the D2D pairs is increased to provide better performance in terms of total system capacity. However, this method can increase the cumulative system interference. In order to mitigate this cumulative interference, we perform a UL power control and the ZF at the BS. Then, the proposed algorithm find the optimal number of allocated resources that maximize the sum rate of D2D pairs and cellular users while guaranteeing a minimum SINR requirements and mitigating the cumulative interference issue in the network.

II. SYSTEM MODEL

Figure 1 shows a single cell system including one BS with multiple antenna settled in the cell center. There are M cellular users and N D2D pairs $(M \leq N)$ which are randomly distributed in the cell coverage area with a radius of *R*. The D2D pairs are allowed to share the same Resource Block (RB) with the cellular users and each D2D pair that has one transmitter and one receiver. The number of RBs and cellular user are equal and one RB can be assigned to only one cellular user. The BS allocates the RBs for both the cellular users and the D2D pairs. In this system, the objective is to mitigate interference caused by the resource sharing between the cellular users and D2D pairs. Eventually, sharing same UL resources by cellular user and D2D pairs is a convenient way to improve signal efficiency, however; it causes three types of interference situation.

- The first one is that D2D receivers can be exposed interference coming from cellular UEs.
- The second one is that D2D transmitters can cause an interference at the BS.
- The third scenario is that D2D transmitters can affect the receiver of other D2D pairs.

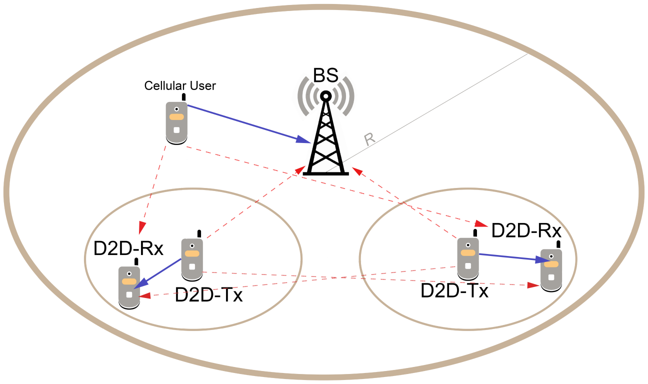

Fig. 1. Uplink System Model including both cellular user and D2D pairs.

In order to represent ith cellular user and jth D2D pair, we use $c_i; i = 1, 2...M$ and $d_j; j = 1, 2...N$, respectively. In the system, d_j^T and d_j^R are denoted for the transmitter and receiver of D2D pair d_j, respectively. The BS is denoted by b. The $\mathbf{C}$ and $\mathbf{D}$ represent a set of cellular users and a set of D2D pairs, respectively. P_{c_i} and P_{d_j} denote the transmit power of the cellular user and the D2D pairs, respectively.

In this system model, path loss and shadowing are all denoted by $PL_{c_i,b}$, from the cellular user c_i to the BS, $PL_{d_j^T,d_j^R}$ from the D2D transmitter d_j^T to the D2D receiver d_j^R, PL_{c_i,d_j^R} from cellular user c_i to the d_j^R, $PL_{d_j^T,b}$ from the d_j^T to BS and $PL_{d_j^T,d_{j'}^R}$ from the D2D transmitter d_j^T to the other D2D receiver $d_{j'}^R$.

The path loss model is defined as [11],

$$PL = A + 10\mu\log_{10}(d) + 20\log_{10}(f_c/5.0) \quad \text{(dB)} \tag{1}$$

where d is the distance between the transmitter and receiver in meter. f_c is the carrier frequency at GHz. A and μ are path loss coefficient and path loss exponent, respectively.

Additionally, $\mathbf{h}_{c_i,b}$ denotes the channel vector of communication link from the cellular user c_i to the BS. $h_{d_j^T,d_j^R}$ denotes the fading channel coefficient of communication link from d_j^T to d_j^R. $\mathbf{h}_{d_j^T,b}$ denotes the channel vector of the interference link from the d_j^T to the BS. $\mathbf{r}_{c_i}$ denotes the received signal vector from cellular user c_i at the BS. $h_{d_j^T,d_{j'}^R}$ denote the fading channel coefficients of the interference link from the c_i to d_j^R and from the d_j^T to $d_{j'}^R$ where $c_i \in \mathbf{C}$, $d_j \in \mathbf{D}$ and $j \neq j^{'}$.

In order to allocate the resources to the D2D pairs, a resource sharing distribution matrix $\Psi = [\psi_{ij}]_{M \times N}$ is determined. When a D2D pair d_j shares the same resources with cellular user c_i, ψ_{ij} takes one; $\psi_{ij} = 1$. When a D2D pair d_j does not share same resources with cellular user c_i, ψ_{ij} takes zero; $\psi_{ij} = 0$.

Therefore, the baseband received signal for the d_j^R and c_i are written as [12],

$$\mathrm{r}_{c_i} = \sqrt{P_{c_i}/PL_{c_i,b}}\mathbf{h}_{c_i,B}^H + \textstyle\sum_{d_j \in \mathbf{D}} \psi_{ij} \sqrt{P_{d_j}/PL_{d_j^T,b}}\mathbf{h}_{d_j^T,b}^H + \mathbf{n}_{c_i} \tag{2}$$

Then, we perform ZF postcoding as:

$$y_{c_i} = \mathbf{w}_b^{post}\mathbf{r}_{c_i} \tag{3}$$

The received signal at the D2D pairs are given by,

$$\begin{aligned} y_{d_j} &= \sqrt{P_{d_j}/PL_{d_j^T,d_j^R}}h_{d_j^T,d_j^R} \\ &\quad + \sum_{c_i \in \mathbf{C}} \sum_{d_j \in \mathbf{D}, j \neq j'} \psi_{ij} \cdot \psi_{ij'} \sqrt{P_{d_j}/PL_{d_{j'}^T,d_j^R}}h_{d_{j'}^T,d_j^R} \\ &\quad + \sqrt{P_{c_i}/PL_{c_i,d_j^R}}h_{c_i,d_j^R} + n_{d_j} \end{aligned} \tag{4}$$

where n_{c_i} and n_{d_j} are the Additive White Gaussian Noise (AWGN) with zero mean and σ^2 variance.

The received SINR γ_{c_i} for c_i and γ_{d_j} for d_j, is formulated, respectively, as follows,

$$\gamma_{c_i} = \frac{(P_{c_i}/PL_{c_i,b}) \left|\mathbf{w}_b^{post}\mathbf{h}_{c_i,b}^{H}\right|^2}{\underbrace{\sum_{d_j \in \mathbf{D}} \psi_{ij}(P_{d_j}/PL_{d_j^T,b}) \left|\mathbf{w}_b^{post}\mathbf{h}_{d_j^T,b}^{H}\right|^2}_{interference\ caused\ by\ D2D\ pairs} + \left\|\mathbf{w}_b^{post}\right\|^2 N_0 B} \tag{5}$$

$$\gamma_{d_j} = \frac{(P_{d_j}/PL_{d_j^T,d_j^R})\left|h_{d_j^T,d_j^R}\right|^2}{\underbrace{\sum_{c_i \in \mathbf{C}} \sum_{d_j \in \mathbf{D}, j \neq j'} \psi_{ij} \cdot \psi_{ij'}(P_{d_j}/PL_{d_{j'}^T,d_j^R})\left|h_{d_{j'}^T,d_j^R}\right|^2}_{interference\ caused\ by\ other\ D2D\ pairs} + \underbrace{(P_{c_i}/PL_{c_i,d_j^R})\left|h_{c_i,d_j^R}\right|^2}_{interference\ caused\ by\ cellular\ user} + N_0 B} \tag{6}$$

The sum capacity of system is obtained by,

$$R_{sum} = \sum_{c_i \in \mathbf{C}} \log_2(1+\gamma_{c_i}) + \sum_{c_i \in \mathbf{C}} \sum_{d_j \in \mathbf{D}} \psi_{ij} \log_2(1+\gamma_{d_j}) \tag{7}$$

The aim of post-coding is to maximize the $\left|\mathbf{w}_b^{post}\mathbf{h}_{c_i,b}^{H}\right|^2$ and minimize the $\left|\mathbf{w}_b^{post}\mathbf{h}_{d_j^T,b}^{H}\right|^2$ for the selected D2D pairs. We perform ZF post-coding for the selected V number of D2D pairs and one cellular user which share the same resource. Thus, we select the nearest D2D pairs based on their distance to the BS. Besides, we restrict the number of D2D pairs as number of BS transmit antenna N_t. Assuming that U is the number of transmitter which share the same resources in a single cell and v represents the elements of a set $\mathbf{V}$ refers to selected D2D pairs for interference cancellation, where $\mathbf{V} \subset \mathbf{D}$ and $d_v; v = 1, 2 ... V$. Hence, U equals to the summation of V and one cellular user.

For each RB, the inference cancellation can be performed by having $N_t \geq U$ and satisfying orthogonality criterion for the selected D2D pairs d_v^T:

$$\mathbf{w}_b^{post}\mathbf{h}_{d_v^T,b}^{H} = 0 \tag{8}$$

This corresponds to the selection of $\mathbf{w}_b^{post}$ in the direction of the projection of the channel vector, which is $\mathbf{h}_{c_i,b}$, on the null-space of $\mathbf{H}_b^{post} = \left[\mathbf{h}_{d_1^T,b}, \mathbf{h}_{d_2^T,b}, ..., \mathbf{h}_{d_v^T,b}\right]$ with the size of $V \times N_t$.

Then, for each RB, the post-coding vector is determined as follows [13],

$$\mathbf{w}_b^{post'} = (\mathbf{I} - \mathbf{P})\,\mathbf{h}_{c_i,b} \tag{9}$$

where $\mathbf{P}$ is the projection matrix on $\mathbf{H}_b^{post}$, $\mathbf{I}$ is identity matrix and $(.)^H$ is Hermitian matrix (transpose conjugate).

The projection matrix $\mathbf{P}$ is formulated as,

$$\mathbf{P} = \mathbf{H}_b^{post}\left((\mathbf{H}_b^{post})^H \mathbf{H}_b^{post}\right)^{-1}(\mathbf{H}_b^{post})^H \tag{10}$$

Finally, the zero-forcing post-coding vector is,

$$\mathbf{w}_b^{post} = \frac{\mathbf{w}_b^{post'}}{\left\|\mathbf{w}_b^{post'}\right\|} \tag{11}$$

In the practice, the channel vector is not known at the receiver side and $\tilde{\mathbf{h}}_{c_i,b}$ and $\tilde{\mathbf{h}}_{d_v^T,b}$ are estimated. The estimation errors can be modelled by using a Gaussian distribution, as follows [14];

$$\tilde{\mathbf{h}}_{c_i,b} = \mathbf{h}_{c_i,b} + \mathbf{e}_c \tag{12}$$

$$\tilde{\mathbf{h}}_{d_v^T,b} = \mathbf{h}_{d_v^T,b} + \mathbf{e}_d \tag{13}$$

where $\tilde{\mathbf{h}}_{c_i,b}$ and $\tilde{\mathbf{h}}_{d_v^T,b}$ denote the estimated channel, $\mathbf{e}_c$ and $\mathbf{e}_d$ denote a complex Gaussian distribution vector with independent components with zero mean and independent real and imaginary parts each with a noise variance $\frac{\sigma_e^2}{2}$ for cellular users and D2D pairs. Then, we can calculate the SINR values belonging to the cellular users and D2D pairs based on the estimated channel vectors.

III. PROPOSED RESOURCE ALLOCATION ALGORITHM

To solve the interference problem, we propose a resource allocation algorithm so as to maximize the summation of the resource sharing distribution matrix Ψ. The proposed algorithm is based on Graph Coloring method. The interference between a couple of D2D pair and resources are represented as an edge and as a set of colors in a graph, respectively. When D2D pairs share same resources, they are grouped within colors where no D2D transmitter highly interferes with the other D2D receivers considering the interference negligible distance concept. In the algorithm, the each color corresponds to the different spectrum resources and two D2D pairs cannot be grouped to the same color when there is an edge between them. The cellular users and D2D pairs have same priority to access the resources. Each D2D pair has a set of candidate colors and each color can include only one cellular user. In Figure 2, an example of D2D system with 6 D2D pairs and 2 cellular users is illustrated.

For addressing the proposed algorithm, two graph $\boldsymbol{G}_i = (\boldsymbol{C}, \boldsymbol{E}_i)$ and $\boldsymbol{G}_j = (\boldsymbol{D}, \boldsymbol{E}_j, \boldsymbol{K})$ are constructed for the single cell system models shown in Figure 2. In the graph $\boldsymbol{G}_i$, a set of cellular users is denoted by a $1 \times M$ matrix $\boldsymbol{C} = \left\{c_i, i = 1, 2, ..., M\right\}$. A set of edges for cellular users is denoted by a $M \times N$ matrix $\boldsymbol{E}_i = \left\{e_{i,j}\right\}$, where $e_{i,j} = 1$ if $e_{i,j} \in \boldsymbol{E}_i$ connects c_i and d_j, this means that cellular user c_i and D2D pair d_j cannot share the same spectrum resources simultaneously. In the graph $\boldsymbol{G}_j$, a set of D2D pairs is denoted by a $1 \times N$ matrix $\boldsymbol{D} = \left\{d_j, j = 1, 2, ..., N\right\}$. A set of edges for D2D pairs is denoted by a $N \times N$ matrix $\boldsymbol{E}_j = \left\{e_{j,j'}\right\}$, where $e_{j,j'} = 1$ if $e_{j,j'} \in \boldsymbol{E}_j$ connects D2D pair d_j and $d_{j'}$, this means that D2D pair d_j and D2D pair $d_{j'}$ cannot share the same spectrum resources simultaneously. The $M \times N$ coloring matrix is denoted by $\boldsymbol{K} = \left\{k_{i,j}\right\}$, where $k_{i,j} = 1$ indicates the availability of D2D pair d_j to share the resources with cellular user c_i, and $k_{i,j} = 0$ otherwise [6].

In the proposed algorithm, each D2D pair can share more than one cellular user resource and the resource of one cellular user can be allocated by more than one D2D pairs. The definition of the adjacency degree of cellular users and D2D

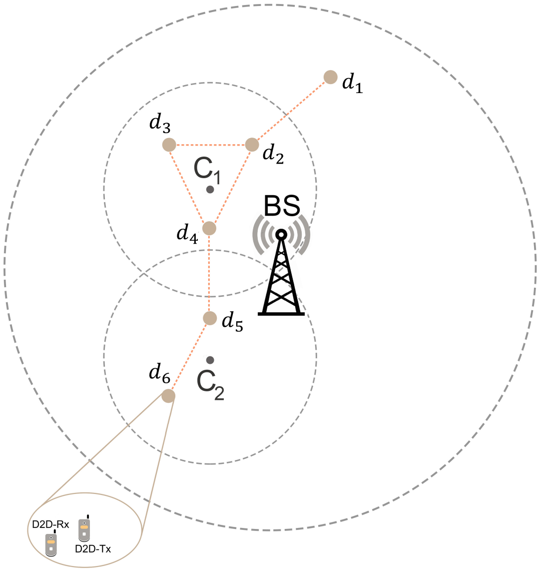

Fig. 2. Illustration of proposed resource algorithm.

pairs is important for the system capacity denoted by α_{c_i} for c_i and α_{d_j} for d_j. In the graph $\boldsymbol{G}_i = (\boldsymbol{C}, \boldsymbol{E}_i)$, the adjacency degree α_{c_i} of c_i is calculated as the number of c_i's neighbor D2D pairs. In graph $\boldsymbol{G}_j = (\boldsymbol{D}, \boldsymbol{E}_j, \boldsymbol{K})$, the adjacency degree α_{d_j} of d_j is calculated as the number of d_j's neighbor D2D pairs which are not assigned any resources yet. If c_i or d_j are not available for resource sharing , then $\alpha_{c_i} = -\infty$ and $\alpha_{d_j} = -\infty$.

In Figure 2, for instance, D2D pair d_2 has four neighbors which are d_1, d_3, d_4 and c_1. Hence, α_{d_2} is 4 and α_{c_1} is 3. If c_2, d_3 and d_1 create a color group (i.e. the second spectrum resources), next time d_2 will have two neighbors. Thus, α_{d_2} will be 2.

The Weight factor W is considered as the main parameter to determine resource sharing matrix. The Weight W_{c_i} of a cellular user c_i is defined as,

$$\mathrm{W}_{c_i} = \frac{\log_2(1+\gamma_{c_i})}{\alpha_{c_i}+1} \tag{14}$$

The Weight W_j of a D2D pair d_j is defined as,

$$\mathrm{W}_{d_j} = \frac{\log_2(1+\gamma_{d_j})}{\alpha_{d_j}+1} \tag{15}$$

In order to perform the most efficient resource allocation scheme, the proposed algorithm chooses the largest weight value from weight cluster, W= (W_{c_i},W_{d_j}).

IV. Power Control for Uplink Communication

In open loop power control (OLPC), the transmitting power [15] is adjusted at the cellular users and D2D pairs using signal parameters and measures obtained from the BS. In this case, there is no feedback link at the cellular users and D2D pairs regarding the power to be used for transmission. In closed loop power control (CLPC), the BS sends feedback to the UE, which is then made corrections to the transmission power [16]. In this paper, we only consider OLPC system. The uplink problem for interference mitigation is formulated by,

Algorithm 1 Proposed Algorithm

```
Initialization
  * Generate $M$ cellular users and $N$ D2D pairs uniformly.
  * Initialize the $\boldsymbol{E}_i$ and $\boldsymbol{E}_j$ as a $M \times N$ and $N \times N$ matrix.
  * Initialize the $\boldsymbol{K}$ as a $1 \times N$ matrix that represents the availability of the D2D pairs for assigning.
Repeat
  * Calculate $\gamma_i$ of cellular user $c_i$ and $\gamma_j$ of D2D pair $d_j$.
  * Determine adjacency degrees $\alpha_i$ and $\alpha_j$ for $c_i$ and $d_j$, respectively.
  * Calculate Weight factor W for $c_i$ and $d_j$, create Weight cluster W= (W$_i$,W$_j$).
      • repeat
      - Pick the largest Weight factor from W, according to $\boldsymbol{E}_i$, $\boldsymbol{E}_j$ and $\boldsymbol{K}$ matrices.
      • until there is no possibility to pick any UE from graphs.
  * Remove the selected D2D pair or cellular user from graphs and assign the next available color.
Until all D2D pairs and cellular users are assigned any color.
  * Find the created sets which only consist of a cellular user and share its resource with a set which has the largest number of D2D pairs.
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Objective:

$$\min \left(\sum_{i=1}^{M} P_{c_i} + \sum_{j=1}^{N} P_{d_j} \right) \tag{16}$$

subject to:

$$\gamma_{c_i} \geq \gamma_{c_i\_tar} \qquad \forall i = 1, 2, ..., M \tag{17}$$

$$\gamma_{d_j} \geq \gamma_{d_j\_tar} \qquad \forall j = 1, 2, ..., N \tag{18}$$

where $\gamma_{c_i\_tar}$ and $\gamma_{d_i\_tar}$ are the target SINR for the c_i and d_j^R, respectively.

The setting of the c_i and d_j^T transmits power values P_{c_i} and P_{d_j} for the UL transmission are defined in dBm scale for the single cell scenario [16] and $P^{\max}$ refers both $P_{c_i}^{\max}$ and $P_{d_j}^{\max}$. P refers both P_{c_i} and P_{d_j}.

$$\text{P=min } \{P^{\max}, P_0 + 10log_{10}(q) + aPL + \delta_{msc} + \Delta\} \, (dBm) \tag{19}$$

where the parameters are given in the following:

- P_0: The power to be contained in one RB. It is cell specific parameter and measured in dBm/RB.
- a: Path loss compensation factor. It is a cell specific parameter in the range [0 1].
- q: Number of resource blocks (RB).
- δ_{msc}: Modulation and Coding Scheme (MCS) dependent offset.
- Δ: Closed loop correction value.

The parameter P_0 is calculated for D2D transmitter as [17],

$$P_0 = a(\gamma_{tar} + P_n) + (1-a)(P_{\max} - 10log_{10}q) \quad (dBm) \tag{20}$$

P_n is calculated in dB scale as the summation of interference and thermal noise in linear domain [18].

In this architecture, the path loss is measured at the UE side based on the reference symbol received power. This information is used to adjust the transmission power of UE initially. In this paper, the closed loop correction value (Δ) and UE-specific parameter (δ_{msc}) depending on chosen modulation and coding scheme are not considered.

The compensation factor a is the key value of the UL power control mechanism and the power control scheme can be categorized based on the value of a as [15]:

- $a = 1$: The scheme totally compensates the path-loss in order to reach the target received power P_0.
- $a = 0$: The transmission power is fixed and does not depend on the path-loss. There is no compensation and in fact no power control at all.
- $0 < a < 1$: In the case of a fractional power control, where path-loss is partially compensated by the power control scheme. In practice, the values from 0.7 to 0.9 have been widely used for power control studies. Hence a is taken average of these values.

In the proposed UL power control procedure, the P_n value is calculated for each case. Therefore, during the UL power control mechanism, the P_0 is not constant for all users and the term $a \cdot PL$ varies for each cellular user and D2D pair according to its experienced path loss.

V. PERFORMANCE EVALUATIONS

In this section, we provide uplink average data rate and average transmit power for the proposed resource allocation algorithm and Graph Coloring algorithm via different number of D2D pairs in the UL transmission. The values of A and μ are given in Table I for non-line-of-sight (NLoS) path-loss parameters [19]. The simulation parameters are given in Table II. The bandwidth of 10RB is set to 1.8MHz.

TABLE I
PATHLOSS PARAMETERS

Device	μ	A
Between BS and UE	3.67	30.55
Between UE and UE	4	28.03

TABLE II
SIMULATION PARAMETERS

Explanation	Parameters	Value
Max. transmit power of UE for per RB	$P_{d_j}^{\max}$	16.4 dBm
Number of BS Antenna	N_t	4
Shadowing	σ	4 dB
Target SINR	γ_{target}	10 dB
Number of Cellular User	M	10
Number of D2D Pair	N	20 - 50
Number of Available RB	RB	10
OLPC Compensation Factor	α	0.8
BS Coverage Radius	R	500 m
Maximum Distance, D2D Tx and Rx	dt	50 m
Minimum Distance, D2D Tx and Rx	dt	2 m
Noise power spectral density	N_0	-174 dBm/Hz
Number of simulation times	-	1000
Carrier frequency	f_c	5.0 GHz

In order to evaluate the impact of the number of D2D pairs on the system capacity, we compare the average data rate of cellular users and D2D pairs in Figure 3. It is observed that as the number of D2D pairs grows, the average data rate of D2D pairs decrease. When the number of D2D pairs increases, more D2D pairs can share the same spectrum resources and it causes large cumulative interference on the system. This indicates that the data rate is degraded by this cumulative system interference. The proposed algorithm has the highest data rate when the number of number of D2D pairs is low since it aims to allocate more resource to the D2D pairs by considering amount of cumulative interference. The achievable percentage of data rate that can reach up to 65% in the proposed algorithm compared to Graph Coloring when 20 D2D pairs are allocated. Additionally, we can observe that the affect of allocating more resources to the D2D pairs is not degraded the data rate of cellular user since ZF postcoding is performed at the BS. In order to reduce the interference at the receiver side, the power control mechanism is also an useful method. Power control mitigates the interference and provides battery saving. Considering the amount of time required to execution is taken, the proposed algorithm requires 14% less time compared to Graph Coloring based resource allocation.

in Figure 4, we provide the performance results of the proposed algorithm under both perfect and estimated channel state information when the variance of channel estimation error σ_e^2 is equal to 10^{-2}. Under the estimated channel for uplink communication, the cellular users are not experienced any loss while it is observed that D2D pairs have around 19% average data rate loss when the number of D2D pairs are 40.

VI. CONCLUSION

In this paper, we have investigated the interference mitigation including power control and resource allocation when D2D pairs and cellular users share the same UL resources under perfect and estimated channel state information. In the considered scenario, each D2D pair can use the resources of several

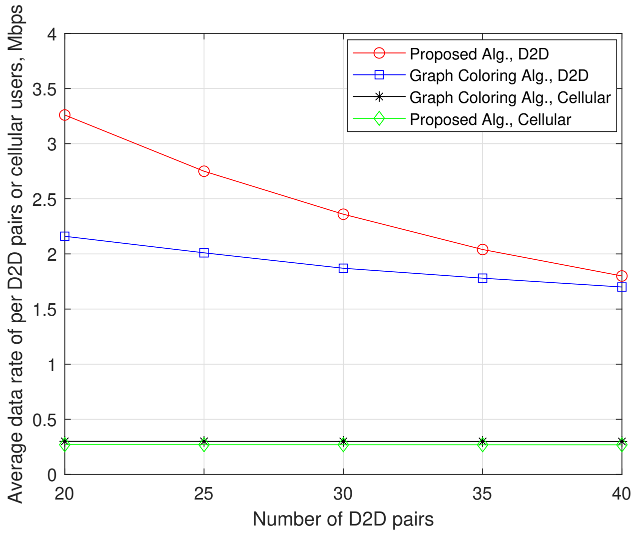

Fig. 3. Comparison results based on Average data rate per cellular user and D2D pair in UL communication under perfect channel state information

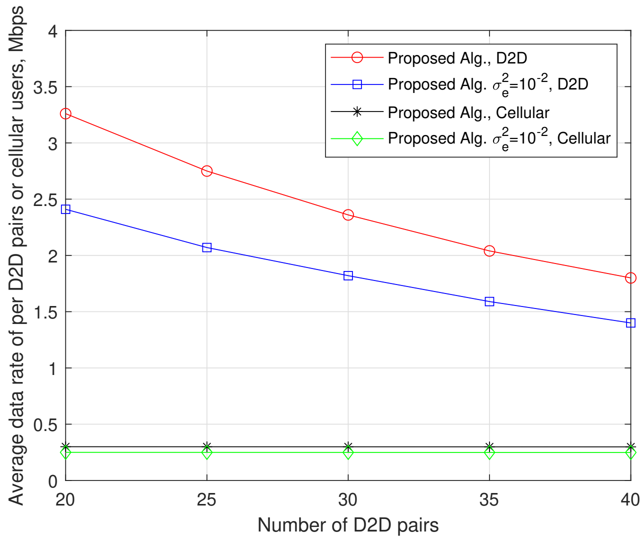

Fig. 4. Average data rate per cellular user and D2D pair in UL communication for the proposed resource allocation under perfect and estimated channel state information

cellular users and one cellular user can share its resource with multiple D2D pairs. In addition to, a power control scheme is performed to further manage the interference. The proposed algorithm is increased the number of allocated RBs to the D2D pairs while the power control technique and multiple antenna system can manage interference by performing interference mitigation techniques. The performance results show that the proposed algorithm can significantly improve the average data rates under the cumulative system interference.

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