Device-to-Device Channel Allocation based on Neighborhood Information

Gökhan Kılıç*, Tolga Girici*,
*TOBB University of Economics and Technology
Department of Electrical and Electronics Engineering
06561, Ankara, Turkey
Email: {gkilic,tgirici}@etu.edu.tr

***Abstract*—Device-to-Device transmission is one of the enabling technologies of 5G, with a potential of significantly improving the spectral efficiency. Spectral reuse in D2D underlay necessitates interference management. A challenge in D2D underlay systems is the increased number of D2D and interfering links and CSI feedback requirement. In this work we propose a solution for D2D channel allocation, which requires only the neighbor information of D2D communicating nodes. We aim to maximize the supported D2D pairs with a constraint on the interference caused at the base station, at each subchannel. We formulate the problem as a Mixed Integer Programming (MIP). We also propose suboptimal allocation algorithms and evaluate and compare their performances by simulations. Numerical results reveal that the proposed algorithms perform quite close to the MIP-based solution.**

***Index Terms*—Device-to-device (D2D), Cellular network, Underlay, Resource Allocation, Partial CSI, Interference, Mixed Integer Programming.**

I. Introduction

Device-to-device (D2D) communications is listed among the 10 enabling technologies of 5G [1]. D2D facilitates the direct communication of two nearby devices, without the base station (BS) being involved in routing. D2D transmission can also be used for terminal relaying [2], in order to extend coverage. D2D technique has the potential of significantly improving the spectral efficiency and reduce the delay. However, the proposed methods should take into account the interference created at the cellular network [3].

Three main problems in D2D resource allocation are 1) mode selection 2) channel allocation 3) power allocation. Mode selection is the problem of deciding whether two nodes will communicate via the BS or directly by D2D transmission [4]. Channel allocation is the problem of deciding which channels will be used by the D2D pairs. In some scenarios D2D users use an unlicensed (ISM) band. In many other works D2D transmissions are assumed to use the regular licensed cellular bandwidth. In terms of resource sharing there are two main choices 1) Overlay (Orthogonal) 2) Underlay (Non-orthogonal). In overlay, D2D and regular cellular transmissions use orthogonal channels [5]. This provides a much predictable and interference-free environment. However, this may not be spectrally efficient especially if the number of D2D pairs reach to a significant level. This necessitates D2D pairs reusing the cellular users(CU) bandwidth. This is called D2D underlay [6]. Resulting interference makes resource allocation problems challenging and interesting. In this study, we will concentrate on D2D underlay and channel allocation problem. We don't address power allocation and assume fixed power for each terminal.

There are several work that study D2D resource allocation for the underlay case. For example in [7], [8], [9], [10], [11], [12], [13], [14], the authors propose interference-aware schemes for power and subchannel allocation algorithm for D2D users for maximum total throughput. Again, there are a number of possibilities for bandwidth sharing. The most restricting case is allowing only one D2D pair for each subchannel and cellular user. Secondly, as we assume in this work, multiple D2D pairs can share a single CU's channel. Also, a D2D pair can reuse multiple CUs' resources and can use a part of each of them. In a great majority of the works, first the resources are allocated (or assumed given) to the CUs and then channel allocation and reuse of the D2D pairs are performed. In order to manage and control the interference, some channels are prohibited to some D2D pairs (based on channel conditions) [7]. Some works maximize total D2D rate subject to SINR constraints of CUs [15]. The work in [16] does not consider the problem of grouping, but only considers power optimization for the grouped users subject to outage probability constraints. Some works disregard fading and shadowing and only consider distance-based path loss in grouping D2D users and pairing them with a cellular resource.

Another classification for D2D resource allocation is the choice of subframe for resource sharing. D2D pairs can be chosen to communicate in the cellular downlink and/or uplink subframe. In this work we will assume sharing of the uplink subframe. The works in [7], [15], [16] assume sharing in the downlink subframe. The works like [4], [8], [9], [11], [12], [13], [17], [21], [22] utilize the uplink subframe for resource reuse. Some works assume more freedom, where D2D transmissions can utilize both subframes [20].

An important factor in optimizing D2D resource sharing and allocation is the channel information. In a regular cellular scenario all that is needed is the channel state between the BS and each CU. On the other hand, in D2D-enabled networks new parameters are added to the problem, such as 1) Channel gains from each D2D transmitter to the BS, 2) Channel gains from each CU to each D2D receiver, 3) Channel gains from each D2D transmitter to each D2D receiver. This points to a dramatic increase in the number of channels to be estimated. In almost all of the above works the authors assume to have complete channel state information. In [12] the BS is assumed to know the pathloss and shadowing and throughput is maximized subject to outage probability constraints based on small scale fading. The authors in [23] propose a distance based channel allocation, but do not take into account intracell interference. The work in [13] also addressed limited CSI, but authors formulate only a probabilistic channel access mechanism.

In this work we assume that through a signaling scheme, each device knows its set of neighbors. Based on this neighborhood information, we formulate the D2D channel allocation as a mixed integer program (MIP), which is solved by the BS in a centralized manner. Then we propose a greedy algorithm that performs quite close to the MIP-based solution.

II. System Model

We consider L D2D pairs of set $\mathcal{D}$ that coexist with K CUs of set $\mathcal{C}$ in an isolated cellular area. Sample cellular network topology is shown in Figure 1. Each D2D pair communicates in the uplink subframe by reusing the resource blocks that are primarily allocated to the CU's. More than one D2D pair can use the same channel if they satisfy the QoS (interference) requirements. We assume that the uplink spectrum is divided into N subchannels and each channel is assigned to a single CU. We assume that all the terminals in the system transmit with their fixed transmit power. Power control and optimal power allocation will be subject of future research.

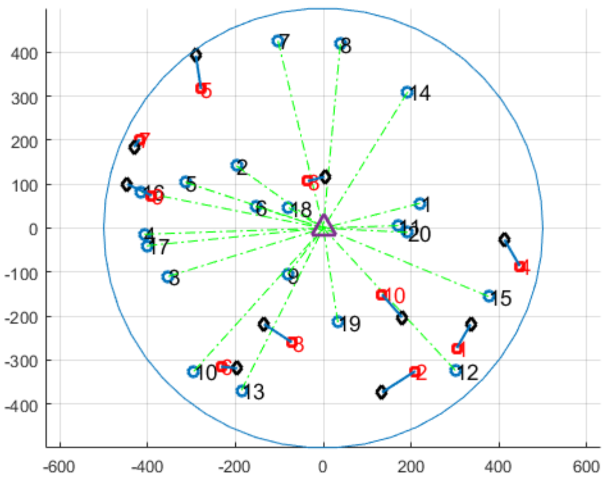

Fig. 1: A sample network topology. Dashed green lines show to cellular transmission links. Solid blue lines show the D2D links.

Channel gain between any two terminals consists of distance based pathloss, slow fading due to shadowing and fast fading due to multipath propagation effects. Multipath fading is independent for each subchannel and user. We assume a block fading model, where the channel gain is constant in a time slot and each slot is independent.

Parameter	Explanation	CSI
$g_{BS}^{(i)}$	From CU i to the BS	available
$g_{j,D}^{(i)}$	From CU i to D2D rx j	not available
$h_{j,BS}^{(i)}$	From D2D pair j to BS at CU i's channel	available
$h_{j,C}^{(i)}$	From D2D tx j to CU i	not available
$h_{j,j',D}^{(i)}$	From D2D tx j to D2D rx j' in channel i	available

TABLE I: Channel gain parameters, their explanations and their availability at the BS.

Table I shows the channel parameters in the network, along with their explanations and status of their availability at the BS. Channels directed to BS ($g_{BS}^{(i)}, h_{j,BS}^{(i)}$) can be obtained at the BS by the classical channel estimation methods and the BS gets information about D2D channel gain ($g_{j,D}^{(i)}$) when D2D connection request is sent. Thereby we assume that the BS has perfect knowledge of $g_{BS}^{(i)}, h_{j,BS}^{(i)}, g_{j,D}^{(i)}, \forall i, j$. However, the channels $h_{j,j',D}^{(i)}, h_{j,C}^{(i)}$ are not perfectly known. We assume that the BS only knows the neighborhood information of CU's and D2D pairs based on an assumed beacon based discovery scheme. The power of additive white Gaussian noise on each channel is assumed to be σ^2.

III. Optimization Problem

Each CU has a minimum rate constraint in order to satisfy its QoS requirements. Since we know all the related channel gains, $g_{BS}^{(i)}$, $h_{j,BS}^{(i)}$, rate constraint can be translated into an SINR constraint (1),

$$\Gamma_i^c := \frac{P_i^c g_{BS}^{(i)}}{\sigma_N^2 + \sum_{j \in \mathcal{D}} \phi_{i,j} I_j^{(i)}} \geq \Gamma_i^{min} \quad (1)$$

$$I_j^{(i)} = P_j^d h_{j,BS}^{(i)}, \quad (2)$$

where $\phi_{i,j}$ is a binary indicator, which takes value 1 if D2D pair j shares the channel of CU i, and becomes 0 otherwise. P_i^c is the fixed transmit power of CU i, $I_j^{(i)}$ is the interference from D2D pair j, and Γ_i^{min} is minimum required SINR which satisfies the QoS requirement of CU i. Due to fixed SINR constraint and fixed transmit power, constraint (3) is the interference constraint for the D2D pairs that reuse the subchannel of CU i,

$$\frac{P_i^c g_{BS}^{(i)}}{\Gamma_i^{min}} - \sigma_N^2 \geq \sum_j \phi_{i,j} I_j^{(i)}, \forall i \in \mathcal{C} \quad (3)$$

Interference channels are from CU's to D2D pair receivers and from D2D pair transmitters to another D2D pair's receiver ($h_{j,C}^{(i)}$ and $h_{j,j',D}^{(i)}$) are assumed to be unknown. However it is reasonable to assume that devices apply a beacon-based neighbor discovery procedure and know their neighbors. Let $a_{i,j}$ and $b_{j,j'}$ be the neighborhood indicators. $a_{i,j} = 1$ if the CU i and D2D receiver j are not neighbors and 0 otherwise. $b_{j,j'} = 1$ if neither the transmitter of D2D pair j and receiver of D2D pair j' nor the transmitter of D2D pair j' and receiver of D2D pair j are neighbors and 0 otherwise. The neighborhood parameter is related to the signal to noise ratio between the nodes. We assume that if the SNR between a pair of nodes,which causes interference to other nodes, is above a certain threshold, beacon signal can be heard and the pair of nodes are considered to be neighbors.

With the known channel $g_B^{(i)}$, the maximum interference limit for a CU i can be expressed as,

$$I_{Lim}^{(i)} = \frac{P_i^c g_B^{(i)}}{\Gamma_i^{min}} - \sigma_N^2, \forall i, \tag{4}$$

where $I_{Lim}^{(i)}$ denotes interference limit to satisfy required SINR in CU i's channel.

In this model both the D2D receiver and BS considers interference as noise. CUs transmission need to satisfy minimum signal to interference noise ratio (SINR) requirements, because CUs are primary users of the network. D2D pairs are close enough to satisfy SINR limit unless the interference is too strong. Channels can be allocated to D2D pairs only if the corresponding CU suffers an interference below its interference limit. Our aim is to maximize the number of D2D pairs that can be served subject to these SINR (interference) constraints. The problem is formulated as follows,

$$\max_{\phi_{i,j}, \forall i \in \mathcal{C}, j \in \mathcal{D}} \left\{ \sum_i \sum_j \phi_{i,j} \right\} \tag{5}$$

s.t.:

$$\begin{aligned} \phi_{i,j} &\leq a_{i,j}, \forall, i \in \mathcal{C}, j \in \mathcal{D} && (6) \\ \phi_{i,j} + \phi_{i,j'} &\leq b_{j,j'}, \forall i \in \mathcal{C}, j \neq j' \in \mathcal{D} && (7) \\ \sum_{i \in \mathcal{C}} \phi_{i,j} &\leq 1, \forall j \in \mathcal{D} && (8) \\ \sum_{j \in D2D} \phi_{i,j} I_j^{(i)} &\leq I_{Lim}^{(i)}, \forall i \in \mathcal{C} && (9) \end{aligned}$$

The objective in (5) is to maximize the served D2D pairs. Constraint (6) allows that a D2D pair j can reuse the CU i's channel if and only if the CU i and D2D pair j are not neighbors. Constraint (7) enforces that D2D pairs j and D2D pairs k can together reuse CU i's channel if j and k are not neighbors. Constraint (8) implies that each D2D pair can use only one CU's channel. Total interference in channel i must be lower than the interference limit of CU i as seen in constraint (9). This is a mixed-integer programming problem and can be solved via the CPLEX solver.

IV. Proposed Suboptimal Algorithms

We proposed three Algorithms to solve previously defined problem. All of the algorithms require neighborhood information of the all nodes and CUs interference limit for desired transmission quality. With these information, channel allocation problem is solved in centralized way by the BS. First two algorithm only slightly differ. Last algorithm is less complex than the first two.

A. Interference Aware Channel Allocation (IACA)

The proposed algorithm requires interference values from the D2D transmitters to the BS, neighborhood information of the CU's and the D2D pairs and interference limits of the CU's. At each iteration the available CU's and D2D pairs are searched and the CU-D2D pair (i^*, j^*) that obeys the constraints (6), (7) and results in minimum interference is found (Lines 5-14). If there is no such pair, then the algorithm terminates (Line 22). If there is such (i^*, j^*) and if the resulting total interference to CU i^* is below its limit and j^* is not neighbor with $(\phi_{i^*, j'^*} = 1, \forall j'^*$) previously allocated D2D pairs j'^* that use CU i^*'s channel (Line 8), then the allocation is successful and the D2D pair j^* is dropped from the set of available D2D pairs (Line 17). Otherwise, the CU i^* is dropped from the list of available CU's. Algorithm continues until there is no available D2D pair or CU.

Algorithm 1 Interference Aware Channel Allocation (IACA)

1: **Inputs:** Sets $\mathcal{C}$ and $\mathcal{D}$, interferences $I_j^{(i)}$, interference limits $I_{Lim}^{(i)}, \forall i$ and neighborhood parameters $a_{i,j}$, $b_{j,k}$
2: **Output:** $\phi_{i,j}$.
3: **Initialize:** $\phi_{i,j} = 0, \forall i, j$. $I^{(i)} = 0, \forall i$, $\mathcal{D}_{rem} = \mathcal{D}$, $\mathcal{C}_{rem} = \mathcal{C}$
4: **while** $\mathcal{D}_{rem} \neq \emptyset$ and $\mathcal{C}_{rem} \neq \emptyset$ **do**
5:     $i^* = 0, j^* = 0, I_{min} = \infty$
6:     **for** $\forall i \in \mathcal{C}_{rem}$ **do**
7:         **for** $\forall j \in \mathcal{D}_{rem}$ s.t. $a_{i,j} = 1$ **do**
8:             **if** $\nexists k \in \mathcal{D}$ s.t. $\phi_{i,k} = 1, b_{j,k} = 0$ **then**
9:                 **if** $I_j^{(i)} \leq I_{min}$ **then**
10:                     $i^* = i, j^* = j, I_{min} = I_j^{(i)}$
11:                 **end if**
12:             **end if**
13:         **end for**
14:     **end for**
15:     **if** $i^* \neq 0$ and $j^* \neq 0$ **then**
16:         **if** $I_{i^*} + I_{j^*}^{(i^*)} \leq I_{Lim}^{(i^*)}$ **then**
17:             $\phi_{i^*, j^*} = 1$, $\mathcal{D}_{rem} = \mathcal{D}_{rem} - j^*$
18:         **else**
19:             $\mathcal{C}_{rem} = \mathcal{C}_{rem} - i^*$
20:         **end if**
21:     **else**
22:         **return**
23:     **end if**
24: **end while**

B. Weighted Interference Aware Channel Allocation (W-IACA)

Weighted minimum algorithm is very similar to the previous IACA algorithm. In this algorithm while searching the optimal (i^*, j^*) pair normalized interference information is used. Interference is normalized with number of D2D neighbors of D2D pair j, $\frac{I_j^{(i)}}{\sum_k b_{j,k}}$. This normalization brings advantage for D2D pairs with fewer neighbors. Thus, conflicts are avoided more and more D2D pairs are expected to reuse the same channel.

C. Cellular User Based Selection (CUBS)

This algorithm differs from the others as follows: the BS checks the CUs one-by-one. For CU i the BS allocates the feasible D2D pairs(not neighbor with CU i and all other D2D pairs) in the ascending order of created interference, until $I_{Lim}^{(i)}$ is reached. Allocated D2D pairs are dropped from the set of available D2D pairs. Then the BS passes to the next CU and the same procedure is repeated, either until all CU's are finished or all feasible D2D pairs are finished.

V. Numerical Evaluations

A single cellular network is considered and a BS is located at the cell center. CUs and D2D pairs are distributed uniformly over the system area. CUs are the primary users of a cellular network. D2D pairs aim to use the frequency spectrum efficiently without harming CUs . Used simulation parameters are provided in Table II We consider a simulation model that is similar to that of [24].

TABLE II: Simulation Parameters

Parameter	Value
Cellular Layout	Isolated cell sector
System Area	Devices are uniformly distributed within a range of 500 m from the BS
Pathloss model for BS link	$15.3 + 37.6 \log_{10}(d_m)$
Pathloss model for device link	$2.8 + 40 \log_{10}(d_m)$
Noise spectral density	-174 dBm/Hz
Cellular User Bandwidth	200kHz
Antenna Gain	BS: 14 dBi, Device: 0dBi
Maximum distance between D2D transmitter and receiver	50 meters
Cellular User Transmit Power	P_i^c = 24dBm
D2D transmitter power	P_j^d = 21dBm
CU SINR Constraint	15dB
Neighborhood Constraint	15dB
Number of cellular users	5 - 10 - 15 - 20
Number of D2D pairs	25 - 30 - 35 - 40 - 45 - 50 - 55 - 60

All results were obtained from 100 different scenarios for all number of CUs and D2D pairs. Average number of allocated D2D pairs for all Algorithms are demonstrated in Fig. 2. All proposed algorithm results are close to optimal results and the proposed algorithms do not differ much in terms of performance. Table III shows the average number of D2D pairs served within the network with 20 CUs for 100 different scenarios. Among the proposed algorithms, IACA is the best algorithm even if there is a very small difference between IACA and W-IACA. The performance gap is approximately 5% from the optimal.

In Fig. 3 the empirical c.d.f. of the performances (number of D2D pairs served) are shown, normalized by the performance of the optimal solution. The graph reveals that in 95% of the scenarios IACA and IACA-W perform within 10% of the optimal result. From Fig. 2, Fig. 3 and Table III the best algorithm among the proposed ones is the IACA.

TABLE III: Numerical Evaluations for 20 CUs in network

D2D Numbers	35	40	45	50	55	60
Optimal	31.99	36.32	40.68	44.87	49.28	53.99
IACA	31.12	35.22	39.11	43.02	47.02	51.28
W-IACA	31.11	35.17	39.15	42.96	46.98	51.22
CUBS	30.94	35.02	38.88	42.68	46.82	50.85

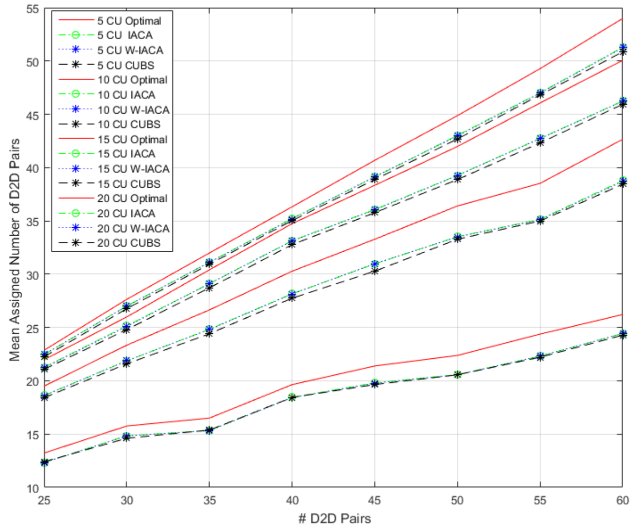

Fig. 2: Average number of allocated D2D pairs vs available number of D2D pairs. Proposed algorithms perform within 5% of the MIP-based solution.

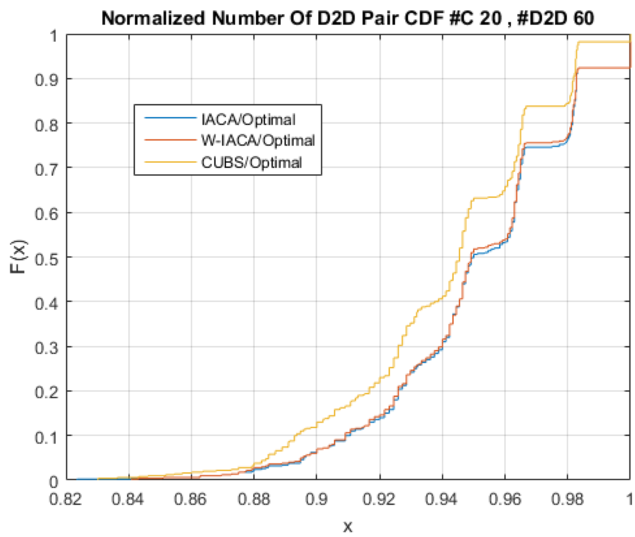

Fig. 3: Perfomance ratio of proposed algorithms. IACA Algorithm performs within 10% of the optimal in 95% of the cases.

VI. Conclusion

We studied the problem of resource allocation for D2D pairs that reuse the subchannels of regular CU's. We assume a system where each device is able to learn its set of neighbors and feeds it back to the BS. An optimization problem is formulated that is based on neighborhood information of CU's and D2D pairs in order to limit the interference to the BS and maximize the served D2D pairs. Then, greedy algorithms are proposed and performances are compared by simulations. Results reveal that the proposed algorithms perform on average within 5% of the mixed integer programming based solution. Future work will analyze the resulting interference to the CU's and D2D receivers. Detailed comparison with limited CSI algorithms in the literature is also a subject for future work. Optimal power allocation is also a promising area for future research.

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