Sequential Bargaining Game for Reuse of Radio Resources in D2D Communication in Dedicated Mode

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***Abstract*—Device-to-device communication (D2D) is expected to accommodate high data rates and to increase the spectral efficiency of mobile networks. We focus on the dedicated mode where D2D pairs exploit channels that are different from the channels allocated to conventional cellular users. Such mode is suitable for scenarios of crowded areas with many D2D pairs where interference management between cellular and D2D users would be very complicated. We propose a novel solution that enables the reuse of multiple channels by multiple D2D pairs in order to increase the throughput of D2D users. The proposed channel reuse is facilitated via grouping D2D pairs into coalitions. The D2D pairs within the same coalition then mutually reuse the channels of each other. The coalitions are defined via sequential bargaining games played among the D2D pairs. The coalitions are created if individual D2D pairs involved in the game benefit from participation in the coalition. The proposed algorithm based on sequential bargaining reaches a throughput gain of $28-64\%$ comparing to the best performing existing algorithm.**

***Index Terms*—Device-to-device, Dedicated mode, Game theory, Resource allocation, Channel reuse.**

I. INTRODUCTION

Higher data rates and lower latencies are required to enable new services and to increase the number of connected devices in the mobile networks. These demands can be accommodated via a direct communication between user equipments (UEs) in proximity of each other, i.e., via Device-to-Device (D2D) communication [1], [2]. Two D2D UEs (DUEs) communicating with each other create a D2D pair. Contrary to the conventional cellular communication through a base station (denoted as gNB), the data is sent directly from a transmitting DUE ($\mathrm{DUE_T}$) to a receiving DUE ($\mathrm{DUE_R}$) without being relayed by the base station [3].

The DUEs can access radio channels in two modes: shared and dedicated [4]. In the shared mode, the DUEs are allowed to reuse the channels that are already allocated to common cellular UEs (CUEs) communicating via the gNB. Thus, the CUEs and the DUEs mutually interfere with each other. In contrast, the DUEs operating in the dedicated mode access only the channels that are not used by the CUEs. Hence, the DUEs do not interfere with the CUEs, but the spectral efficiency in the dedicated mode can be decreased due to the lower reuse of the channels [5]. Algorithms allocating channels for the DUEs can be classified into those that target channel allocation: i) solely for the shared mode (see, e.g., [6]–[14]); ii) solely for the dedicated mode (e.g., [15], [16]); and iii) combining both the shared and dedicated modes (e.g., [17], [18]).

Besides the selection of D2D mode, the spectral efficiency of the whole system is strongly influenced also by the reuse of the channels among the D2D pairs. The research works related to the reuse of the D2D channels can be classified into papers where: i) each D2D pair uses only one channel and the channel cannot be reused by any other D2D pair [6]–[16]; ii) multiple D2D pairs are allowed to reuse a single channel [7]–[9], [17], [18]; iii) more than one channel can be allocated for each D2D pair, but each D2D pair uses only one channel [10]–[12]; and iv) multiple D2D pairs can reuse multiple channels [13], [14].

The most generic case is, of course, the reuse of multiple channels by multiple D2D pairs. Both [13] and [14] addressing this general case target only the shared mode where the channel bandwidth and the number of channels are given by the CUE's allocation. However, the channel allocation schemes dealing with the shared mode cannot be easily extended to the dedicated mode due to two reasons. The first reason is that the shared mode assumes a D2D power allocation in order to protect the quality of service of the CUEs (see, e.g., [8], [10]–[14]). In contrast, the D2D pairs in the dedicated mode are not constrained by the CUEs and the D2D pairs are commonly supposed to transmit with maximum power (see, e.g., [15] and [16]). The second reason is that the channel allocation for D2D pairs in the shared mode is heavily influenced by the level of interference from the CUEs [9]. The interference from the CUEs affects the D2D pairs on individual channels differently due to various distances between the CUEs and the D2D pairs [6], [7], [17]. This is, however, not the case of dedicated mode where the allocation of channels depends only on the D2D pairs and on the interference among D2D pairs reusing the same channels. In the dedicated mode, the existing works are focused either on no-reuse resource allocation schemes ([15], [16]); or on the channel reuse only if the number of available channels is higher than the number of the D2D pairs ([17], [18]). However, none of these papers allows the reuse of multiple channels by multiple D2D pairs in the dedicated mode.

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In this paper, we focus on the maximization of the sum capacity of the D2D communication in the dedicated mode. The dedicated mode is preferred in scenarios with high density of the CUEs in small areas where a high interference among the CUEs and the D2D pairs would be extremely hard to manage [19]. We propose a novel solution that enables the reuse of multiple D2D channels by multiple D2D pairs in the dedicated mode to maximize the sum capacity of the D2D pairs. The proposed solution exploits sequential bargaining games to define coalitions of the D2D pairs mutually reusing multiple channels. We show that our proposed sequential bargaining solution leads to a significant improvement in the sum capacity of the D2D pairs when compared to related works. We also demonstrate the low complexity of our proposed algorithm allowing its implementation in real networks.

The rest of the paper is organized as follows. In Section II, the system model is described and the problem is formulated. In Section III, the proposed channel reuse scheme for D2D in dedicated mode is presented. The simulations results are discussed in Section IV. Last, Section V concludes the paper and outlines possible future research directions.

II. SYSTEM MODEL AND PROBLEM FORMULATION

In this section, we first describe the system model and, then, we formulate the problem, which is solved in the next sections of this paper.

A. System model

The model considers N D2D pairs deployed within a single gNB. The distance (d) between any $\mathrm{DUE_T}$ and any $\mathrm{DUE_R}$ creating a D2D pair is assumed to be no longer than a maximum distance d_{max} (i.e., $d \leq d_{max}$) guaranteeing a reliable D2D communication similarly as considered in, e.g., [20]–[22]. Thus, the scenario where the $\mathrm{DUE_T}$ and the $\mathrm{DUE_R}$ are not able to communicate directly and data is sent via the gNB (i.e., if $d > d_{max}$) is out of scope of this paper.

The whole communication bandwidth B is split into $K = N$ channels (as in [15] and [16]) to serve all N D2D pairs. Thus, the capacity $C_{n,k}$ of the n-th D2D pair at the k-th channel is defined as:

$$C_{n,k} = B_k log_2 \left(1 + \gamma_{n,k}\right) = B_k log_2 \left(1 + \frac{P_{n,k}\, g_{n,n}}{\sigma_k + \sum_{\substack{t \in N_k \\ t \neq n}} p_{t,k} g_{t,n} + I_d}\right) \quad (1)$$

where B_k is the bandwidth of the k-th channel, $\gamma_{n,k}$ is the signal to interference plus noise ratio (SINR) for the n-th D2D pair (D_n) at the k-th channel, $p_{n,k}$ is the transmission power of the n-th $\mathrm{DUE_T}$ at the k-th channel, $g_{n,n}$ is the channel gain between the n-th $\mathrm{DUE_T}$ and the n-th $\mathrm{DUE_R}$, $p_{t,k}$ is the transmission power of the t-th $\mathrm{DUE_T}$ at the k-th channel, $g_{t,n}$ is the channel gain between the t-th $\mathrm{DUE_T}$ and the n-th $\mathrm{DUE_R}$, I_d stands for the background interference received from adjacent cells, N_k represents the set of D2D pairs communicating at the k-th channel, and σ_k is the thermal noise affecting the k-th communication channel. The noise σ_k is calculated as $\sigma_k = \sigma_o B_k$, where σ_o is the white noise power spectral density on the carrier frequency. As we focus on the dedicated mode, the D2D pairs experience no interference from the CUEs, which communicate at separated channels. Thus, the CUEs are left out form the model. The maximal transmission power P_{max} of any D2D pair communicating over a set of reused channels K_n is divided equally among the $|K_n|$ channels so that $P_{n,k} = \frac{P_{max}}{|K_n|}$.

Initially, as in [15] and [16], each n-th D2D pair occupies the n-th channel with a bandwidth of $B_n = \frac{g_{n,n}}{\sum_{n=1}^{n=N} g_{n,n}} B$ without channel reuse. Consequently, before any reuse, every n-th D2D pair achieves the capacity $C_{n,n}^{nr}$ at its n-th dedicated channel, i.e., without neither reuse nor interference from other D2D pairs. Based on all $C_{n,n}^{nr}$, the minimal communication capacity that can be guaranteed to all D2D pairs even without reuse is defined as: $C_{min} = min\{C_{n,n}^{nr} \mid n \in \{1, ..., N\}\}$. Thus, C_{min} represents the minimum capacity that is guaranteed to every D2D pair disregarding whether the reuse is considered or not. Note that C_{min} depends on the number of D2D pairs, because the more D2D pairs are active, the narrower dedicated channel is available to each pair and, thus, a lower C_{min} can be guaranteed to the pairs.

Note that, although the DUEs communicate directly via D2D communication, the allocation of the channels and the communication control are assumed to be decided centrally by the gNB. Therefor, we consider that the channel state information (CSI) is reported periodically to the gNB and, thus, a full knowledge of CSI is assumed to be available in our system, like in [10],[11],[23]. Based on the CSI knowledge, the gNB is able to determine capacity and the channel reuse rules.

B. Problem formulation

The objective of this paper is to maximize the sum communication capacity of the D2D pairs in the dedicated mode by enabling the reuse of multiple channels by multiple D2D pairs. To determine which D2D pairs should mutually reuse their channels, we formulate the problem as a coalition structure generation problem [24]–[26]. To that end, we denote the set of L coalitions of the D2D pairs as $\mathbf{CS} = \{cs_1, cs_2, \ldots, cs_L\}$, where each coalition $cs_l \in \mathbf{CS}$ includes a subset of D2D pairs that mutually reuse all channels allocated to these D2D pairs in cs_l. Note that any D2D pair can belong only to a single coalition. As the global objective of this paper is to maximize the sum communication capacity of D2D pairs, the coalitions are formed so that the sum capacity of D2D pairs is maximized while the minimal capacity C_{min} is still guaranteed for all D2D pairs. Then, the problem is formulated as:

$$\mathbf{CS} = argmax \textstyle\sum_{n=1}^{n=N} \sum_{k \in K_n} B_k log_2(1 + \gamma_{n,k}) \quad (2)$$

$$\text{s.t.} \sum_{k \in K_n} B_k log_2(1 + \gamma_{n,k}) \geq C_{min}\ \forall n \in \{1, 2, ...N\}$$

where the constraint ensures that the sum capacity of any D2D pair n over all channels K_n allocated to the n-th D2D pair

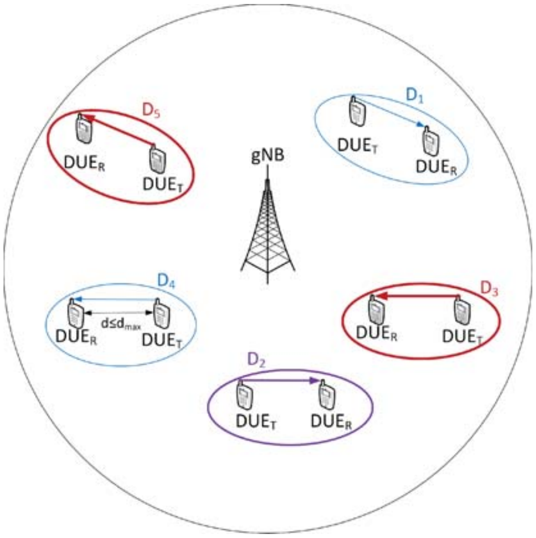

Fig. 1: An example of a coalition structure in a scenario with five D2D pairs, where $\mathbf{CS} = \{cs_1 = \{D_1, D_4\}, cs_2 = \{D_2\}, cs_3 = \{D_3, D_5\}\}$

(including reused channels within the coalition) is not below C_{min}.

Fig. 1 shows an example of five D2D pairs composing a coalition structure $\mathbf{CS}$ that is composed of three coalitions cs_1, cs_2 and cs_3 containing two, one and two D2D pairs, respectively.

Intuitively, we can expect that the D2D pairs that are far from each other have a higher probability to be in the same coalition based on the proposed coalition structure generation. However, finding such pairs simply based on the distance is a very complex problem as we have multiple D2D pairs and there are no limitations neither on how many D2D pairs can be in the same coalition nor on how many coalitions should be created. Thus, the coalition structure generation problem is NP-complete [26]. Moreover, the problem cannot be simply transformed to pure distance-based problem due to a consideration of mutual interference among the D2D pairs reusing the same channel.

III. THE PROPOSED CHANNEL REUSE SCHEME

This section describes the novel channel reuse scheme. We propose a low-complexity algorithm solving coalition structure generation problem via sequential bargaining games.

The proposed solution based on the sequential bargaining allows multiple D2D pairs to reuse multiple channels. As a basement, we consider that every D2D pair occupies a single channel allocated initially without reuse (see [15] and [16]).

The proposed sequential bargaining process is defined as follows. First, a utility function is calculated for all possible coalitions of any two D2D pairs (D_i and D_j) in the system. The utility function is defined as:

$$U_{i,j} = \begin{cases} -1 & \text{if } C_{i,i} + C_{i,j} < C_{min} \quad (a) \\ -1 & \text{if } C_{j,i} + C_{j,j} < C_{min} \quad (b) \\ G_{i,j} & Otherwise \qquad\qquad\quad (c) \end{cases} \tag{3}$$

where $C_{i,i}$ and $C_{i,j}$ are the capacities of the i-th D2D pair at the i-th and j-th channels, respectively. Similarly, $C_{j,i}$ and $C_{j,j}$ represent the capacities of the j-th D2D pair at the i-th and j-th channels, respectively. Note that D_i as well as D_j communicate over both channels k_i and k_j in parallel and at the same time. If the reuse would lead to a decrease in the capacity below C_{min} for either of the D2D pairs, the coalition is not created and the utility function $U_{i,j}$ is set to -1. Contrary, if both D2D pairs keep the capacity at least at C_{min} (i.e., neither (a) nor (b) in (3) is fulfilled), a gain $G_{i,j}$, introduced by the new coalition of the D2D pairs D_i and D_j, is calculated. The gain $G_{i,j}$ is understood as the gain in capacity due to mutual sharing of both channels (k_i and k_j) by both pairs (D_i and D_j). Therefore, the gain $G_{i,j}$ is defined as:

$$G_{i,j} = (C_{i,i} + C_{i,j} + C_{j,i} + C_{j,j}) - (C_{i,i}^{nr} + C_{j,j}^{nr}) \tag{4}$$

where $C_{i,i}^{nr}$ and $C_{j,j}^{nr}$ correspond to the capacities of the i-th and the j-th D2D pairs without channel reuse. The pairs D_i and D_j are willing to share their channels among each other if $U_{i,j}$ is positive, i.e., if $G_{i,j} > 0$.

The utility $U_{i,j}$ is obtained for all possible coalitions created by two pairs (i.e., $U_{i,j}$, $\forall D_i, D_j \in N$). We do not calculate utilities for more pairs to keep the complexity of the proposed scheme low. The individual utilities $U_{i,j}$ are, then, inserted into a bilateral utility matrix $\boldsymbol{U}$:

$$\boldsymbol{U} = \begin{bmatrix} 0 & \dots & U_{1,N} \\ \vdots & \ddots & \vdots \\ U_{N,1} & \dots & 0 \end{bmatrix} \tag{5}$$

From the structure of the utility function $U_{i,j}$ and from (4), we can see that the bilateral utility matrix is symmetric (i.e., $U_{i,j} = U_{j,i}$). Moreover, the diagonal values in $\boldsymbol{U}$ are set to 0 as D2D pairs cannot create a coalition with themselves. Since the D2D pairs should create coalition only if $U_{i,j} > 0$, the non-positive elements in (5) are omitted in the remainder of the process. This significantly reduces the complexity of the whole bargaining procedure, since the search space (i.e., number of possible combinations for the coalitions among the D2D pairs) is decreased. Then, the positive elements of $\boldsymbol{U}$ are sorted in a descending order taking into account that every couple of symmetric positive elements is considered as one element ($U_{i,j} = U_{j,i}$). The sorting serves further for the indication of the coalitions' creation priorities so that the coalitions yielding the highest gains are created preferentially.

The sorted positive elements $U_{i,j}$ from $\boldsymbol{U}$ represent a vector of sub-games (denoted as U^*) that are played sequentially over time in a way that one sub-game is played in every time step. The sub-game is played only between two D2D pairs (e.g., D_i and D_j) over their respective channels (k_i and

Algorithm 1 sequential bargaining algorithm to solve channel reuse problem for N D2D pairs

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Estimate utility matrix $\boldsymbol{U}$ with size $N \times N$
Extract the positive utilities from the matrix $\boldsymbol{U}$
Sort positive utilities in descending order to a vector $\boldsymbol{U}^*$
Initialize $\mathbf{CS} = \{cs_1, .., cs_N\}$; $cs_i = \{D_i\}$, $\forall i \in \{1, ..., N\}$
for $s = 1$ : length($\boldsymbol{U}^*$) do
    $\boldsymbol{U}^*(s) \sim U_{i,j}$ is sub-game between pairs $D_i$ and $D_j$
    for every pair $D_x$ from $cs_x$ where $D_i \in cs_x$ do
        for every pair $D_y$ from $cs_y$ where $D_j \in cs_y$ do
            Determine $U_{x,y}$ from $\boldsymbol{U}^*$
        end for
    end for
    if $U_{x,y} > 0, \ \forall D_x \in cs_x$ and $\forall D_y \in cs_y$ then
        Update $\mathbf{CS}$ (i.e., replace $cs_x$ and $cs_y$ with $cs_z$)
    end if
end for
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k_j) allocated in the initial phase. In this case, the coalition is simply created if both D_i and D_j agree to reuse their dedicated channels among each other. However, when some coalitions already exist, the sub-game is extended to all members of all related coalitions. Thus, if the pair D_i wants to join the coalition cs_x composed of two or more D2D pairs, the game is played between the pair D_i and all the D2D pairs already included in the coalition cs_x. The pair D_i joins the coalition cs_x if and only if all the D2D pairs in the cs_x agree, i.e., if $U_{i,j} > 0, \ \forall D_j \in cs_x$.

When all sub-games are finished, the coalitions of the D2D pairs are formed and all D2D pairs included in the same coalition reuse the multiple communication channels belonging to all D2D pairs in the coalition. The algorithm proposed for sequential bargaining-based channel reuse is summarized in Algorithm 1.

IV. PERFORMANCE EVALUATION

Simulations in Matlab are carried out to evaluate the performance of the proposed resource allocation scheme and to compare it with competitive algorithms. To this end, simulation scenario and parameters are presented in the next subsections. Then, the competitive algorithms are introduced. Last, the simulation results are described and thoroughly discussed.

A. Simulation scenarios

We consider an area of 500×500 meters. The simulations are performed for 1000 drops. For each drop, the positions of N D2D pairs are generated uniformly within the area. The maximum distance between two devices of the same D2D pair (d_{max}) is set to a default value of 50 m in line with related works ([20]–[22]).

For the modeling of radio channel, we follow 3GPP recommendation for D2D communication defined in [27]. Hence, the path loss model is defined as $PL = 89.5 + 16log_2(d)$, where d is the distance between the transmitter and the receiver. Each D2D pair transmits with a maximum power $p_{max} = 20$ dBm. The background interference from neighboring cells I_d is the same for all D2D pairs at all channels in one drop, and it is modeled over drops randomly using a normal distribution with a mean value of -80 dBm and a standard deviation of 15 dBm. This level of interference from neighboring cells represents a high interference scenario, which can be expected in future mobile networks with dense small cell deployment. The detailed simulations' parameters are summarized in Table I.

TABLE I: Simulation parameters.

RF channel model parameters		
Parameter		Value
Carrier frequency	f_c	2 GHz
Bandwidth	B	20 MHz
Noise power spectral density	σ_o	-174 dBm/Hz
Interference level from neighboring cells	I_d	$\mathcal{N}(-80, 15)$ dBm
General parameters		
Parameter		Value
Number of D2D pairs	N	$10 - 100$
Max. transmission power of D2D pair	p_{max}	20 dBm
Max. distance between DUE_T and DUE_R	d_{max}	50 m

B. Competitive algorithms and performance metrics

To the best of our knowledge, there is no solution targeting the reuse of multiple channels by multiple D2D pairs in dedicated mode. Nevertheless, we compare our proposed algorithm (denoted as "Channel Reuse - SB") with schemes that target similar objectives or address similar problem. Thus, we compare the proposal with the following state of the art schemes:

1) *No reuse* [15],[16]: This scheme, designed for the dedicated mode, distributes the whole available bandwidth B among the D2D pairs in a way that the communication capacity is maximized while C_{min} is guaranteed to each D2D pair. However, the channels cannot be reused by the D2D pairs and each channel is occupied by just one pair.
2) *Single reuse* [17]: In this algorithm, the bandwidth is divided into several (in our case six, according to [17]) channels with equal bandwidths. Every channel is allocated to a single D2D pair (i.e. six D2D pairs are served). The Hungarian algorithm is implemented to solve a matching problem between the six channels and the unserved D2D pairs to enable D2D channel reuse. As defined in [17], up to two D2D pairs can reuse each channel. Thus, the solution allows twelve (2×number of channels) D2D pairs to be served, while the rest of the D2D pairs are provided with no resources. Even if this leads to unfairness among the D2D pairs, it also yields a high sum capacity as only the D2D pairs with high channel quality access the available channels.
3) *Empty channel protocol (ECP)* [18]: For this case, the bandwidth is also divided into several (in our case six according to [18]) channels with equal bandwidths. First, every channel is allocated to a single D2D pair (i.e. six D2D pairs are served). Then, empty channel protocol adds

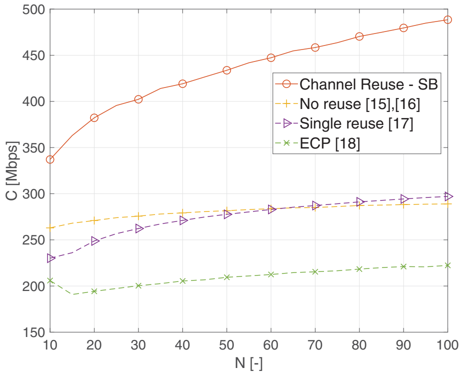
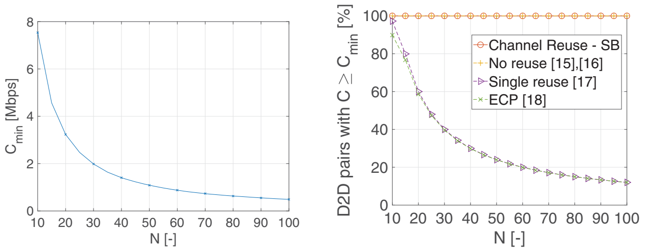


Fig. 2: Sum capacity of D2D pairs over number of D2D pairs for $d_{max} = 50\,m$.



(a) (b)

Fig. 3: Minimum capacity C_{min} that can be guaranteed to all D2D pairs according to [15], [16] (a), and percentage of D2D pairs for which C_{min} is guaranteed by proposed and competitive algorithms (b).

the unserved D2D pairs to the channels so that all unserved D2D pairs reuse the channels already assigned to other D2D pairs. Note that D2D pairs are not allowed to exploit multiple channels simultaneously and only one channel can be used by every D2D pair. Still, each channel can be reused by multiple D2D pairs at the same time.

C. Simulation results

In this section, we compare the performance of the proposed channel reuse scheme with the above-mentioned competitive schemes by means of the sum capacity of D2D pairs defined as $C = \sum_{n=1}^{n=N} \sum_{k \in K_n} C_{n,k}$ and by the ratio of satisfied D2D pairs (i.e., D2D pairs with $C \geq C_{min}$). Further, we analyze feasibility of the proposed scheme via the number of the time steps corresponding to the number of bargaining sub-games needed.

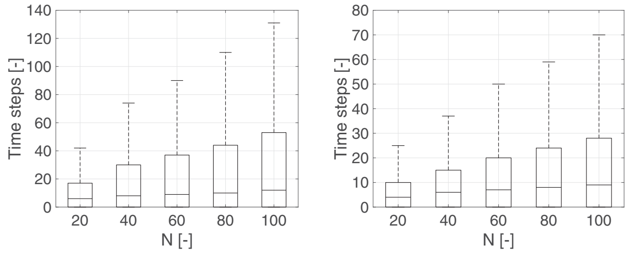
1) Comparison of the proposed scheme with competitive schemes: Fig. 2 illustrates the impact of the number of D2D pairs on the sum capacity of all D2D pairs. The capacity is increasing for the proposed as well as for the competitive algorithms, because the inclusion of a new pair leads to a more efficient exploitation of radio resources over the simulation area. We can see that even for 100 D2D pairs the sum capacity of both No reuse and Single reuse gets only close to 300 Mbps while ECP reaches a sum capacity only slightly above 220 Mbps. The proposed scheme leads to a significant gain with respect to all competitive algorithms. The gain ranges from 28% to 69%, from 46% to 64%, and from 63% to 120% comparing to the No reuse, Single reuse, and ECP algorithms, respectively. The gain increases with the number of D2D pairs, since a higher number of D2D pairs leads to more opportunities for multiple reuse in case of our proposed scheme.

The proposed algorithm is designed to guarantee the minimal capacity C_{min} reached by the D2D pairs without channel reuse (see (2)). The C_{min} is determined according to [15] and [16], as described in Section II-A, and decreases with the number of D2D pairs N, as the bandwidth B is divided among a higher number of the D2D pairs as shown in Fig. 3a. In other words, as explained in Section II-A, Fig. 3a shows the minimum capacity C_{min} guaranteed to every D2D pair depending on the number of deployed D2D pairs disregarding whether the reuse is considered or not. Then, Fig. 3b shows the percentage of the D2D pairs for which the C_{min} is really delivered after the reuse. We can see that our proposed solution for channel reuse guarantees C_{min} to absolutely all D2D pairs. Thus, although every D2D pair is exposed to interference from other D2D pairs in the same coalition, there is no D2D pair that would experience throughput below C_{min}. Also No reuse algorithm (proposed in [15], [16]) can satisfy the C_{min} for all D2D pairs. In contrast, the Single reuse algorithm and the EPC cannot guarantee C_{min} to all D2D pairs due to the equal channel bandwidth allocated to the D2D pairs and due to the limited channel reuse.

2) Feasibility of the proposed scheme: The worst time complexity of Algorithm 1 is $O(N^2 log N)$, but the proposed algorithm is based on bargaining sub-games that are played sequentially over time. Thus, we investigate also the feasibility of the proposed scheme for real networks by the analysis of the convergence of the proposed algorithm. The number of time steps of the proposed algorithm over the number of D2D pairs N to reach 95% and 90% of the maximum capacities is illustrated in Fig. 4a and Fig. 4b, respectively. The figures confirm that reaching 95% and 90% of the maximum capacity is very quick even for a high number of D2D pairs. For realistic scenarios with, for example, 40 D2D pairs, only eight and six steps (bargaining sub-games) are needed in average to reach 95% and 90% of the maximum sum D2D capacity, respectively. Even for 100 D2D pairs (which is rather an extreme case for our considered area of 500 × 500 m), we still need only less than 12 and 9 time steps in average to reach 95% and 90% of the maximum capacity. This confirms the fast convergence of the proposed algorithm and its suitability for practical applications and implementation in real networks.

V. CONCLUSION

In this paper we have proposed a new channel reuse scheme for the D2D communication in dedicated mode allowing multiple pairs to reuse multiple channels. The channel reuse



(a) (b)

Fig. 4: Number of time steps corresponding to number of bargaining sub-games required to reach 95% (a) and 90% (b) of the sum capacity of D2D pairs.

is presented as a coalition structure generation game where the D2D pairs composing one coalition mutually reuse the channels of each other. The coalition structure generation problem is solved by the proposed low complexity sequential bargaining algorithm. The simulation results show that the proposed channel reuse increases the sum capacity of D2D pairs by $28-64\%$ comparing to the best performing existing algorithm. In addition, although the interference is imposed among D2D pairs reusing the same channel, the minimal required capacity for each D2D pair is still guaranteed after the channel reuse.

The future work should focus on deriving the optimal coalition structure as an upper bound for the proposed channel reuse. In addition, a power allocation for each D2D pair over the reused channels should be investigated.

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