Selection of Relays in Multi-Pair D2D Communication with Multicast

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Abstract

This paper investigates Device-to-Device (D2D) communication with multiple user equipments (UEs) acting as sources intending to transmit information to their respective destinations via intermediate relay represented by, e.g., UEs or unamnned aerial vehicles (UAVs). We propose a novel solution for the selection of the relays serving multiple D2D pairs. We allow multiple D2D pairs to use the same relay while the D2D pairs reuse the same channel to increase spectrum usage. To mitigate interference, we exploit a multicast transmission with precoding to distinguish the transmission for each D2D pair and to increase the system capacity. The simulations demonstrate that our proposed scheme provides a significant gain (up to two times) in terms of capacity compared to the competitive schemes.

1 Introduction

Device-to-device (D2D) communication allows a direct communication of two user equipments (UEs) in vicinity of each other without sending data via a base station (gNB) [1][2]. The D2D communication introduces several benefits, such as, an enhancement of the system capacity, an increase in the spectral efficiency of mobile networks, or a reduction in the power consumption, to name a few [3]. In addition, the D2D communication also allows to extend the network coverage without a new infrastructure deployment by means of D2D relaying [4]. The D2D relaying allows a D2D source to send data to a D2D destination via a relay represented by an intermediate UE [5].

Typically, there are three forms of the D2D relaying: decode-and-forward (DF) [6], amplify-and-forward (AF) [7], and compress-and-forward (CF) [8]. In [6], the authors present the DF relaying for D2D communication and improve the system capacity via a power allocation. In [7], the AF relaying is proposed to improve the capacity of D2D communication. Then, in [8], the authors propose the CF relaying based on a physical-layer network coding for the D2D communication. However, the above-mentioned papers limit their scope only to the scenario with one D2D source, one D2D destination, and one relay. However, a practical scenario with multiple D2D pairs and relays is not addressed.

The D2D relaying for multiple D2D pairs is considered, e.g., in [9]-[11]. In [9], the authors investigate a cooperative relays with the UEs acting as the relays for multiple cellular UEs (CUEs) in exchange for an opportunity to use the spectrum of these CUEs. The authors propose a channel allocation for the D2D pairs to maximize the capacity. Joint allocation of the channels and the transmission power for the D2D communication is addressed in [10] to minimize the interference. In [11], the authors also propose a cooperative relays and the channel allocation to improve the performance of the network. However, above-mentioned papers do not investigate a selection of a suitable relay in a general scenario with multiple D2D pairs.

The selection of a suitable relay for multiple D2D pairs is investigated in [12]-[14]. In [12], the authors propose a distributed relay selection to coordinate interference to and from the gNB. The relay selection is addressed also in [13] for the scenario with a large number of the relays. In [14], the authors investigate the relay selection problem, where multiple D2D pairs cooperate with the relays. The authors propose a sub-optimal relay selection for multiple D2D pairs. However, [12]-[14] assume that each D2D pair exploits only one relay, and each relay helps only to one D2D pair. Thus, the scenario with one D2D UE performing relaying for multiple D2D sources and destinations is not considered.

In the recent literature, there are also several works assuming that one relay assists to multiple D2D pairs. For example, the authors in [15] propose a joint relay selection and power allocation to minimize the total transmission power and, simultaneously, to maximize the capacity of the D2D pairs. Due to orthogonality of the channels, there is no interference, however, an available spectrum is not used efficiently. In [16], a joint scheme for the relay selection and the channel allocation to the relays and the D2D pairs is proposed. When compared to [15], the channel in [16] is assumed to be shared by multiple D2D pairs and relays. However, the capacity is significantly degraded if there are many D2D pairs in proximity of each other sharing the same channel without any interference mitigation. In addition, none of the above-mentioned papers addresses the problem of the relay selection when multiple D2D pairs reuse the same channel using multicast transmission.

In this paper, we propose a novel solution for the selection of the relays serving multiple D2D pairs. We consider each D2D pair is assisted by one relay, but unlike as in re-

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lated works [12]-[14], multiple D2D pairs can use the same relay. To increase the capacity, we exploit the multicast transmission with precoding to differentiate the transmission for each D2D pair. By using the precoding at both the D2D source and relay, the proposed relay selection scheme maximizes the sum capacity of the system while interference among D2D pairs is suppressed. The benefit of the proposed concept is not limited only to pure D2D communication, but it is suitable for any relaying concept, including unamnned aerial vehicles (UAVs) relaying data for other UEs such as in [17]. The proposed scheme provides a significant gain (up to two times) with respect to a common DF relaying and state-of-the-art distance-based relay selection.

The rest of the paper is organized as follows. The system model and the problem formulation are presented in Section II. In Section III, we describe the proposed relay selection scheme. In section IV, simulation results are presented and discussed to demonstrate the effectiveness of the proposed solution. The paper is concluded in Section V.

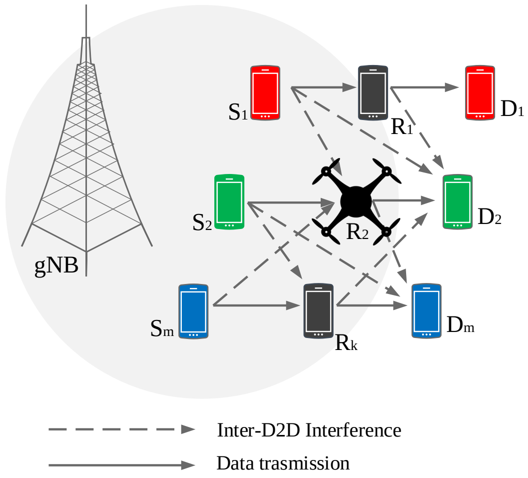

Figure 1 System model with M D2D pairs relaying data via K relays ($K \leq M$). The D2D sources send data to the D2D destinations via relays represented by another D2D UE or UAV.

2 System Model and Problem Formulation

In this section, we present the system model, and then, we formulate the problem of the relay selection in a scenario with multiple D2D pairs served by the relay.

2.1 System Model

The system model consists of M D2D sources, K relays represented by either UEs or UAVs, and M D2D destinations. Thus, in total, there are $U = 2M + K$ D2D UEs in the system. The D2D sources and destinations are assumed to create M D2D pairs. We assume that the number of relays is not higher than number of D2D pairs (i.e., $K \leq M$) in order to make the proposal practical also for common relaying or relaying via UAVs. Hence, multiple D2D pairs can actually exploit the same relay. In order to maximize the overall system capacity of these M D2D pairs, we consider that any relay is willing to relay data to any other UE, as considered in many recent papers (see, e.g., [18],[19]). To this end, any of the existing approaches motivating UEs to act as relays based on token/virtual currency [20] or social-aware incentives [21] can be adopted to overcome a selfish nature of the users.

The D2D UEs exploit dedicated channels to avoid interference between the CUEs and the D2D pairs. However, the D2D pairs reuse the same frequency channel, as the reuse increases the spectral efficiency compared with orthogonal channels [22][23]. Moreover, we consider time division duplex (TDD) to separate the reception and transmission of data by the D2D UEs. Consequently, the D2D pairs mutually interfere to each other as shown in Figure 1. We consider that perfect channel state information (CSI) is available in the system, so the relay knows the CSI of the D2D source to the relay and from the relay to the D2D destination [14].

If the m-th D2D source is assisted by the k-th relay, the Signal to Interference Noise Ratio (SINR) $\gamma_{m,k}$ at the relay is formulated as:

$$\gamma_{m,k} = \frac{P_{m,k} g_{m,k} w_{m,k}}{\sum_{n \neq m}^{N} P_{n,k} g_{n,k} + \sum_{k \neq l}^{L} P_{l,k} g_{l,k} + \sigma_k^2} \tag{1}$$

where $P_{m,k}$ represents the transmission powers of the m-th D2D source, $P_{n,k}$ is the transmission power of the interfering n-th D2D source, $P_{l,k}$ is the transmission power of the l-th relay, $g_{m,k}$ is the gain of the channel from the m-th D2D source to the k-th relay, $g_{n,k}$ is the gain of the channel from the n-th interfering D2D source to the k-th relay, $g_{l,k}$ is the channel gain from the l-th relay to the k-th relay, $w_{m,k}$ is the precoding of the m-th D2D source to the k-th relay, and σ_k^2 is the thermal noise power at the relay.

Similarly, SINR of the channel from the k-th relay to the m-th D2D destination is defined as:

$$\gamma_{k,m} = \frac{P_{k,m} g_{k,m} w_{k,m}}{\sum_{n \neq m}^{N} P_{n,m} g_{n,m} + \sum_{k \neq l}^{L} P_{l,k} g_{l,k} + \sigma_m^2} \tag{2}$$

where $P_{k,m}$ represents the transmission power of the k-th relay, $P_{l,m}$ stands for the transmission power of the interfering l-th relay to the m-th D2D destination, $g_{l,k}$ is the channel gain from the l-th relay to the k-th relay, $g_{n,k}$ is the channel gain from the interfering n-th D2D pair to the m-th relay, $w_{k,m}$ is the precoding of the k-th relay to the m-th D2D destination, and σ_m^2 is the thermal noise powers at the D2D destination.

The communication capacity of the channel between the the m-th D2D source and the selected k-th relay and of the channel between the k-th relay $C_{m,k}$ and the m-th D2D destination $C_{k,m}$ are described as:

$$C_{m,k} = B\log_2(1 + \gamma_{m,k}) \tag{3}$$

$$C_{k,m} = B\log_2(1 + \gamma_{k,m}) \tag{4}$$

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where B is the channel bandwidth. Then, the overall capacity of the m-th D2D pair communicating over the k-th relay is:

$$C_m^k = \min\left(C_{m,k}, C_{k,m}\right) \tag{5}$$

2.2 Problem Formulation

The objective of this paper is to increase the sum capacity of D2D pairs via a selection of a suitable relay for each D2D pair. Thus, the problem is formulated as:

$$\begin{aligned} &\alpha^* = \arg\max_{\alpha\in A} \sum_{m=1}^{M} \alpha_{k,m} C_m^k \\ &s.t \quad \textstyle\sum_{k=1}^{K} \alpha_{k,m} \leq 1, \forall m \in M, \forall m \in K \end{aligned} \tag{6}$$

where $\alpha_{k,m} \in \{0,1\}$ is the control variable indicating whether the m-th D2D pair is matched with the k-th relay $\{\alpha_{k,m} = 1\}$ or not $\{\alpha_{k,m} = 0\}$ and α^* represents the targeted $\alpha_{k,m}$ that maximizes the system capacity of the multiple D2D pairs. The constraint limits each D2D pair to relay data via at most one relay at a time. Note that multiple D2D pairs can still exploit the same relay.

3 Proposed Relay Selection

In this paper, we propose a novel solution for the selection of the cooperative relays serving multiple D2D pairs. The goal of the relay selection is to improve the system capacity. For example, as shown in Figure 2, the relay R_1 assists the data transmission from S_1 and S_2 to D_1 and D_2, respectively, and another relay R_2 assists the data transmission from S_3 and S_4 to D_3 and D_4, respectively. However, the system capacity would decrease due to inter-D2D pair interference, if the same channel is exploited by all of them while, at the same time, there is no cooperation among D2D pairs and relays. Therefore, we present a sharing scheme in which multiple D2D pairs using the same relay exploit a multicast transmission.

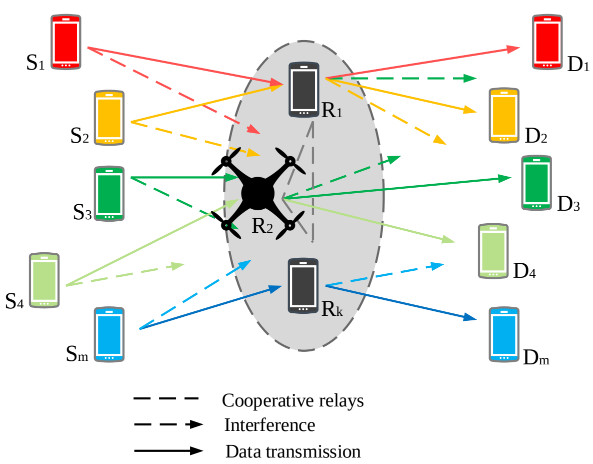

Figure 2 Proposed scheme for the selection of the cooperative relays (represented by UEs or UAVs) serving multiple D2D pairs, $K < M$.

The objective of our proposed scheme is to maximize system capacity by selecting the relay for multiple D2D pairs, unlike traditional common DF relaying in [6]. At the beginning, the relays estimate the channel gains between the D2D sources and the D2D destinations. Then, $\gamma_{m,k}$ and $\gamma_{k,m}$ are calculated according to (1) and (2), respectively. The selection of the k-th relay for the m-th D2D pair is based on the highest SINR value over both hops:

$$\gamma_{m,k^*} = \arg\max_{k\in K} \left(\min\left(\gamma_{m,k}, \gamma_{k,m}\right)\right) \tag{7}$$

To avoid interference among the different D2D pairs, the signal transmitted from the D2D source to the relay and then to the D2D destination is precoded. We adopt the precoding suggested in [22][23], where the precoding is exploited such that:

$$g_{n,k} w_{n,k} = 0, \quad \forall n \neq m \tag{8}$$

The precoding eliminates the interference at the selected k-th relay by restricting precoding $w_{m,k}$ to satisfy $g_{n,k} w_{n,k} = 0$. With the precoding, the interfering n-th D2D pair does not interfere to the m-th D2D pair. The precoding of the neighbor D2D pair is expressed as $g_{n,k^*} w_{n,k^*} = u\Lambda v = u\Lambda\left[v_n v_{k^*}\right]$, where u and v are left and right diagonal matrix of the channel gain from the interfering D2D pair g_{n,k^*}, respectively. The matrix implies that the precoding w_{n,k^*} minimizes the interference of the channel gain g_{n,k^*}. Therefore, γ_{m,k^*} denotes the highest SINR with the selected relay and corresponding precoding. To ensure that the relay selection and precoding from the D2D source to the relay and then to the D2D destination reach the highest capacity, the SINR should also satisfy $\gamma_{m,k^*} \geq \min(\gamma_{m,k}, \gamma_{k,m})$.
The relay selection is described in Algorithm 1. The relay for multiple D2D pairs is selected based on the highest SINR over both hops. In order to maximize the system capacity, the relay selection problem when sharing relay is formulated as:

$$\widehat{k}^* = \arg\max_{\widehat{k}\in K} \left\{C_1^k, \cdots, C_m^k\right\} \tag{9}$$

where $\widehat{k}$ is the selected relay. Then, after the k-th relay is chosen based on the highest capacity, we exploit a multicast transmission to send the data. The data received by the selected k-th relay is combined with decoder and forwarded to the corresponding D2D destinations. The received signal at the k-th relays is:

$$\begin{aligned} \gamma_{m,k} &= \begin{bmatrix} \gamma^1_{R_{m,k}} \\ \gamma^2_{R_{m,k}} \end{bmatrix} \\ &= \begin{bmatrix} g_{1,k} & \cdots & g_{m,k} \\ g_{1,k} & \cdots & g_{m,k} \end{bmatrix} \begin{bmatrix} t_{1,\widehat{k}} \\ t_{2,\widehat{k}} \end{bmatrix} \\ &= G \begin{bmatrix} t_{1,\widehat{k}} \\ t_{2,\widehat{k}} \end{bmatrix} \end{aligned} \tag{10}$$

where $\gamma_{m,k} = \left[\gamma^1_{m,\widehat{k}}, \gamma^2_{m,\widehat{k}}\right]^T$ is the received signal at the relay and G is the matrix of the channel gains, $t_{1,\widehat{k}}$ and $t_{2,\widehat{k}}$

are the data from the D2D source 1 and 2, respectively. Then, the relay constructs the data based on the received signals by the k-th relay so that:

$$t = \begin{bmatrix} t_{1,\widehat{k}} \\ t_{2,\widehat{k}} \end{bmatrix} = \begin{bmatrix} w_{1,\widehat{k}} \gamma^1_{R_{m,k}} \\ w_{2,\widehat{k}} \gamma^2_{R_{m,k}} \end{bmatrix} = \begin{bmatrix} w_{1,\widehat{k}} & w_{2,\widehat{k}} \end{bmatrix} \left(G t_{m,\widehat{k}} \right) \quad (11)$$

where $w_{1,\widehat{k}}$ and $w_{2,\widehat{k}}$ are precoding matrixes of $t_{1,\widehat{k}}$ and $t_{2,\widehat{k}}$ respectively. With the multicast transmission $w_{m,\widehat{k}} = g^H_{m,\widehat{k}} \left(g_{m,\widehat{k}} g^H_{m,\widehat{k}} \right)^{-1}$, and according to (8), the n-th D2D pair does not decode the data from the m-th D2D pair. The D2D destination 1 and 2 decode the transmitted data $t_{1,\widehat{k}}$ and $t_{2,\widehat{k}}$ from its corresponding D2D source 1 and 2 via the selected relay, respectively. Then, the received signal at the m-th D2D destination is:

$$\gamma_{m,k*} = \begin{bmatrix} \gamma_{1,k*} \\ \vdots \\ \gamma_{m,k*} \end{bmatrix} = \begin{bmatrix} w_{1,\widehat{k}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & w_{m,k} \end{bmatrix} \left(G t_{m,k*} \right) \quad (12)$$

The proposed scheme ensures that the D2D destination receives data from the respective m-th D2D source through the selected k-th relay. The relay selection and precoding is done together. Therefore, our proposed scheme finds the high sum capacity of D2D pairs.

Algorithm 1 Relay Selection for Multiple D2D Pairs.

1: Deriving $\gamma_{m,k}, \gamma_{k,m}, \forall k \in K, \forall m \in M$
2: **for** $k = 1 : K$
3: Find k^* jointly (8) satisfying $\gamma_{m,k^*} \geq \min(\gamma_{m,k}, \gamma_{k,m})$
4: $K = K - \left\{ \widehat{k} \right\}$
5: **end**
6: $k^* = \arg\max_{k \in K} \left\{ C^k_m \right\}$
7: $C^k_m = C^{k^*}_m$

4 Performance Evaluation

In this section, we describe the simulation scenarios and parameters, and then, we discuss simulation results.

4.1 Simulation Scenario

The simulations are performed in MATLAB. We consider the D2D sources, relays, and destinations distributed within an area of a size of 300 m x 300 m. We consider up to M =20 D2D pairs and up to K =20 relays in the system. For $K < M$, 20 D2D pairs are assisted by at least 10 relays.

Table 1 Simulation parameters

Parameters	Value
Simulation Area	300 m x 300 m
Number of D2D pairs	2-20
Number of relays	up to 20
Carrier Frequency	2 GHz
Channel Bandwidth	20 MHz
Noise Power	-174 dBm/Hz
Transmission Power	5-23 dBm

The maximum transmission power of each D2D UE is limited to 23 dBm. The gains of the channel between the UEs is calculated in line with 3GPP recommendation [24].
We compare the proposed scheme with the common DF relaying (random relay selection (RRS)) [6] and with the state-of-the-art distance-based relay selection (DRS) [25][26]. We also compare the proposed scheme with the optimal relay selection, i.e. Hungarian Algorithm (HA) for $K = M$ and Full Search (FS) for $K < M$. The simulation parameters are summarized in Table 1.

4.2 Result and Discussion

Figure 3 shows the capacity of different schemes versus the transmit power for M =20 D2D pairs. It is observed that the proposed scheme outperforms RRS (common DF relaying) and DRS in terms of the sum capacity. The proposed relay selection scheme reaches up to 11% less capacity compared to the optimal relay selection scheme using the HA. The proposed scheme improves the sum capacity up to 38% and 181% compared to DRS and RRS, respectively. The gain of our proposed scheme over DRS is due to the selection of the relay considering inter-D2D pair interference. The DRS scheme only chooses based on the coverage distance between the D2D source and destination via the selected relay. The capacity of the RRS is the lowest because the relay is selected randomly. Even if the number of relay is lower than the number of D2D pairs ($K < M$), our proposal outperforms the DRS scheme by 73% ($P_S = P_R$ =23dBm). The capacity of the proposal is decreased if number of relays is decreased due to self interference at the same relay. Still the proposed scheme also only leads to a slight performance loss up to 15% compared to the optimal scheme derived by the FS. The capacity of DRS decreases due to the interference from the close D2D pairs sharing the same relay.
Figure 4 shows the capacity of the proposal and both competitive schemes if number of D2D pairs is increased up to 20. Results show that our proposed scheme reaches a higher capacity compared to DRS and RRS under a different number of D2D pairs. When K=M= 20 D2D pairs, the proposed scheme achieves 85% and 172% higher capacity than DRS and RRS, respectively. Simulation results also indicate that the capacity improvement by our proposed scheme over competitive schemes increases as the number of D2D pairs increases. When the number of D2D

pairs increases, it is difficult for DRS and RRS to ensure that each D2D pair can manage the interference from the close D2D pair. If the number of relays is lower than number of actual D2D pairs (i.e., $K < M$), the proposed scheme roughly double the capacity provided by DRS scheme, provided that 20 D2D pairs are deployed. Note that the more D2D pairs are attached to the relays, the more significant interference among D2D pairs and relays is introduced.

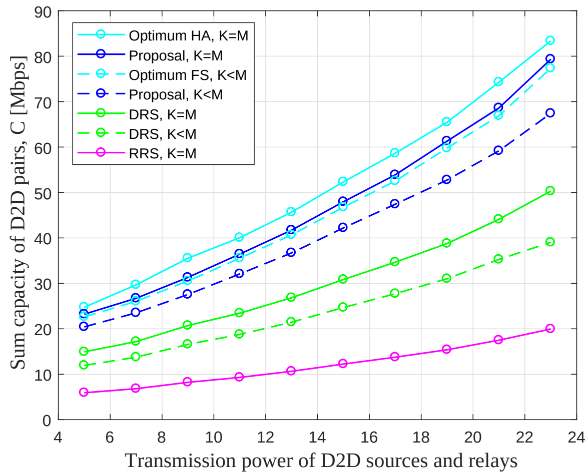

Figure 3 Capacity versus the transmission power, $P_S = P_R$.

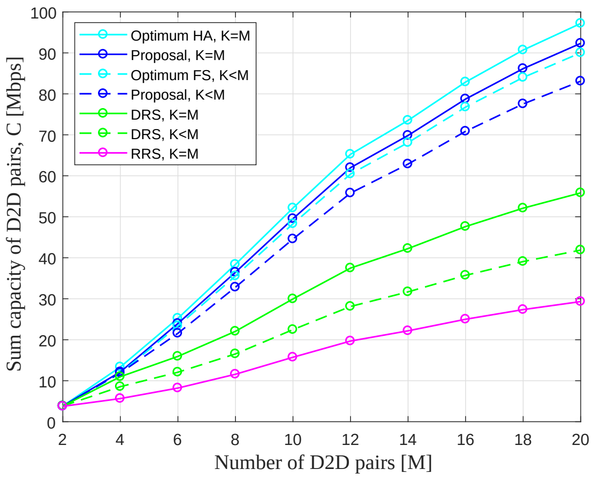

Figure 4 Capacity versus the number of D2D pairs, $P = 23dBm$.

5 Conclusion

In this paper, we have proposed a novel solution for the selection of the relays, represented by UEs or UAVs, serving multiple D2D pairs. We have exploited a multicast transmission with precoding to differentiate the transmission for each D2D pair. According to the simulation results, our proposed scheme provides a significant gain of up to 181% and 85% in terms of the capacity compared to the random and distance-based relay selection for the various number of transmission power and number of D2D pairs, respectively.

The future works should consider a power control at the D2D sources and relays to further increase the capacity. Besides the power control can reduce the energy consumption of the D2D UEs.

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