

Uplink Resource Allocation in Device-to-Device Communication System

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Abstract. In this paper, we study uplink resource allocation problem to maximize the overall system capacity while guaranteeing the signal-to-noise ratio of both D2D users and cellular users (CUs). The optimization problem can be decomposed into two subproblems: power control and channel assignment. We first prove that the objective function of power control problem is a convex function to get the optimal transmit power. Then, we design an optimal selection algorithm for channel assignment. Numerical results reveal the proposed scheme is capable of improving the system's performance compared with the random selection algorithm.

1 Introduction

With the explosive increase of the intelligent devices, the cellular systems are suffering an unprecedented pressure imposed by the rapid increasing of cellular data [1]. To address the above-mentioned challenges, D2D communication has received great attention [2]. It can significantly improve the performance of tradition cellular network in several aspects, such as improving the efficiency of spectrum and allowing more users to access the network [3]-[5].

Any two neighboring D2D users can set up direct transmission under the control of base station by the D2D communication [6]. D2D communication uses the same spectrum resource with the cellular links, D2D transmitter sends signal to the D2D receiver, which can increase the system capacity and spectrum efficiency [7]. But when the spectrum resource are not allocated reasonably, co-channel interference between CUs and D2D pairs can result in the performance mitigation. Therefore resource allocation has become a research hotspot in academia. In order to solve this challenging problem, various resource allocation problems have been explored in D2D communication to enhance performance, including mode selection, power control and channel assignment[8]-[10]. In [8], the joint power control, channel assignment, and mode selection problem are investigated in D2D communication within cellular network. They optimize the aggregate system capacity while guaranteeing the SINR for cellular and D2D links. Article [9] addresses the optimal resource allocation problem relying on a lot of techniques, including joint power control, mode selection, range division, etc., with the goal of the maximum sum data rate. In [10], a dynamic resource allocation scheme for D2D communication based on cellular network is proposed. The proposed scheme maximize the number of D2D communication pairs allowed in the system. At the

same time, the strong interference of D2D communication to the cellular communication is avoided.

Inspired by the existing research, we consider the resource allocation problem under the full load mode, and aiming at maximizing system capacity by allocating resources. We divide the objective function into two subproblems: power control and channel assignment. We prove that the objective function is a convex function and propose power control algorithm. Finally, we design an optimal selection algorithm for channel assignment.

The rest of the paper is organized as follows. In Section 2, we introduce the system model and objective function of the proposed optimal problem. Then, in Section 3, the formulated optimization problem is resolved by jointing power control and channel assignment algorithm. After that, Section 4 provides the numerical results to demonstrate the performance of the proposed schemes. Finally, the concluding remarks are expressed in section 5.

2 System model

In this section, we first propose the system model, then we develop the optimization problem.

2.1 System model

In the paper, we consider a single cell area as shown in Figure 1, in which the cell comprises K D2D pairs, M CUs. Let D_A and D_B denote the transmitter and receiver of D2D pair. In particular, we assume that the licensed uplink spectrum is reused by D2D users and the cell's radius is R , with the base station (BS) located at the cell's geometrical center. Moreover, it is also assumed that each CUs is pre-allocated with orthogonal sub-channel to reduce the interference between CUs. Meanwhile, we assume that each D2D link is allowed to reuse no more than one sub-channel. Finally we assume

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that all channels are occupied by CUs. In this case, all D2D pairs can only choose the reuse mode.

We consider the slow fading concluding shadowing and the fast fading due to multi-path propagation. Therefore, the channel gain between the transmitter of D2D pair j and the BS can be expressed as

$$h_{jB}^d = \kappa \beta_{jB} \zeta_{jB} d_{jB}^{-\alpha} \quad (1)$$

where β_{jB} is fast fading gain with exponential distribution, ζ_{jB} is the slow fading gain with log-normal distribution, d_{jB} is the distance of D2D pair j and the BS, α is the pathloss exponent, and κ is a constant in system parameters. Thus, we can express the channel gain between CU i and the BS as g_{iB}^c , the channel gain between CU i and the receiver of D2D pair j as h_{ij}^c , and the channel gain between D2D pair j as g_{jj}^d . The power of additive white Gaussian noise on each channel is described as σ^2 .

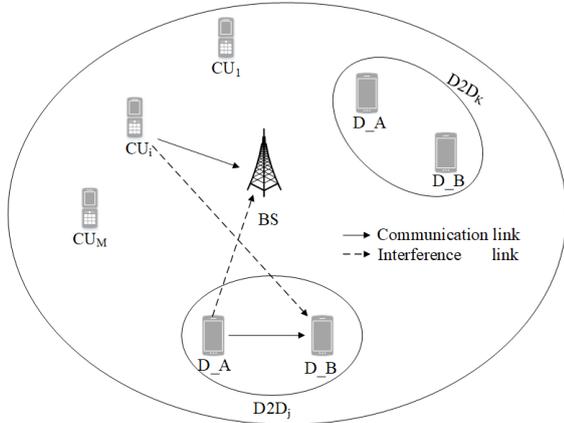


Figure 1. System model

2.2 Problem formulation

In the paper, we consider the channel resource allocation problem under full load conditions. We maximize overall system capacity while maintaining SINR for CUs and D2D pairs by jointing power control and channel assignment.

Then, the overall system capacity optimization problem can be expressed as

$$P1: (P^*) = \arg \max_P \left[\sum_{i \in C} \sum_{j \in D} \log_2 \left(1 + \frac{P_{ij}^c g_{iB}^c}{P_{ij}^d h_{jB}^d + \sigma^2} \right) + \log_2 \left(1 + \frac{P_{ij}^d g_{jj}^d}{P_{ij}^c h_{ij}^c + \sigma^2} \right) \right] \quad (2)$$

subject to

$$\frac{P_{ij}^c g_{iB}^c}{P_{ij}^d h_{jB}^d + \sigma^2} \geq \xi_{\min} \quad (3)$$

$$\frac{P_{ij}^d g_{jj}^d}{P_{ij}^c h_{ij}^c + \sigma^2} \geq \xi_{\min} \quad (4)$$

$$0 < P_{ij}^d < P_{\max} \quad (5)$$

$$0 < P_{ij}^c < P_{\max} \quad (6)$$

3 Resource allocation algorithm

In this section, we present an optimal method to solve the problem of (2). First of all, we can divide the original problem into two sub-problems and solve them separately:

- 1) Sub-problem of *power control*;
- 2) Sub-problem of *channel assignment*.

3.1. Power control

Suppose D2D link j can reuse the resource of cellular link i , the power control problem can be expressed as

$$P2: (P_{ij}^{c*}, P_{ij}^{d*}) = \arg \max_{P_{ij}^c, P_{ij}^d} \left[\log_2 \left(1 + \frac{P_{ij}^c g_{iB}^c}{P_{ij}^d h_{jB}^d + \sigma^2} \right) + \log_2 \left(1 + \frac{P_{ij}^d g_{jj}^d}{P_{ij}^c h_{ij}^c + \sigma^2} \right) \right] \quad (7)$$

subject to (3),(4),(5),(6).

In order to meet the minimum QoS requirements, the SINR of both CUs and D2D links must be greater than the threshold ξ_{\min} . The transmit power of CUs and D2D pairs cannot exceed its maximum value. According to restrictions (3), (4), (5) and (6), we have

$$P_L < P_{ij}^d < P_H \quad (8)$$

where

$$P_L = \max \left\{ 0, \frac{\xi_{\min} (P_{ij}^c h_{ij}^c + \sigma^2)}{g_{jj}^d} \right\} \quad (9)$$

$$P_H = \min \left\{ P_{\max}, \frac{P_{ij}^c g_{iB}^c - \xi_{\min} \sigma^2}{\xi_{\min} h_{jB}^d} \right\} \quad (10)$$

In view of the fact that $\arg \max_x [\log_2(1 + f(x)) + \log_2(1 + g(x))]$ is equivalent to $\arg \max_x [(1 + f(x))(1 + g(x))]$, (7) can be rewritten as

$$P3: (P_{ij}^{c*}, P_{ij}^{d*}) = \arg \max_{P_{ij}^c, P_{ij}^d} \left(1 + \frac{P_{ij}^c g_{iB}^c}{P_{ij}^d h_{jB}^d + \sigma^2} \right) \left(1 + \frac{P_{ij}^d g_{jj}^d}{P_{ij}^c h_{ij}^c + \sigma^2} \right) \quad (11)$$

In [9], it also proves that $(P_{ij}^{c*}, P_{ij}^{d*})$ is a convex function with respect to P_{ij}^d when the other variable P_{ij}^c is fixed at its maximal power.

According to the property of convex function, we notice that the maximum of a convex function is obtained at the boundary points. So when $P_{ij}^{c*} = P_{\max}$, the optimal P_{ij}^{d*} in (7) can be obtained by evaluating the objective function at two points of the constraint $P_{ij}^{d*} \in \{P_L, P_H\}$ in (8) by taking the one which the value is greater.

3.2 Channel assignment

In the above, we have discussed the optimal power control scheme. Now, when the D2D pair j shares the channel of the CU i , the achievable system capacity can be expressed as

$$R_{ij} = \log_2\left(1 + \frac{P_{ij}^{c*} g_{iB}^c}{P_{ij}^{d*} h_{jB}^d + \sigma^2}\right) + \log_2\left(1 + \frac{P_{ij}^{d*} g_{jj}^d}{P_{ij}^{c*} h_{ij}^c + \sigma^2}\right) \quad (12)$$

where $(P_{ij}^{c*}, P_{ij}^{d*})$ is given by sub-problem of power control.

For different multiplexing methods, we can get the system capacity matrix

$$\mathfrak{R} = \begin{bmatrix} R_{1,1} & \cdots & R_{1,i} & \cdots & R_{1,M} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ R_{j,1} & \cdots & R_{j,i} & \cdots & R_{j,M} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ R_{K,1} & \cdots & R_{K,i} & \cdots & R_{K,M} \end{bmatrix} \quad (13)$$

In order to maximize the system capacity, we introduce an optimal selection algorithm to achieve channel resource assignment.

Algorithm:

step 1: Calculating the maximum system capacity when the all D2D pair to reuse the first CU channel, and marking the corresponding D2D pair as j^* . The j_{th}^* D2D pair is allocated the 1_{th} CU' channel.

step 2: As for the second CU' channel, traversing all D2D pairs those have not been allocate them to any channel, and calculate the maximum system capacity. Furthermore, marking the corresponding D2D pair and allocates it the second CU' channel.

step 3: Repeating this step for M times until the number of CU' channels is 0.

The details of the algorithm 1 can be seen below in Table 1.

Table 1. Optimal resource allocation algorithm.

Algorithm	Optimal selection algorithm
1:	Initialization
2:	$K = \{D_1, D_2, \dots, D_K\}$ $M = \{CU_1, CU_2, \dots, CU_M\}$
3:	Calculate $P_{ij}^{d*} \in \{P_L, P_H\}$
4:	for $i = 1:K$
5:	for $j = 1:M$
6:	calculate $\mathfrak{R}_{K \times M}$
7:	end
8:	end
9:	for $m = 1:M$
10:	$R_max = \max(\mathfrak{R}_{K \times M}(:,m))$
11:	end

4 Numerical analysis

In this section, we evaluate the performance of proposed resource allocation algorithm.

4.1. Simulation parameters

We consider a single cellular network with a radius of 1000m. There are one BS, 20 uplink CUs, and 20 D2D pairs in the system. The CUs and D2D pairs in the cell are evenly distributed. Simulation parameters are elaborated in Table 2.

Table 2. Simulation parameters.

Parameter	Value
Cell radius R	1000m
D2D distance r	30-60m
Noise spectral density σ^2	-144dBm
Pathloss exponent α	4
Pathloss constant κ	0.01
SINR threshold ξ_{min}	13dB
Maximum transmit power P_{max}	27dBm

We compare the performance of two algorithms in the simulation. One is the optimal selection algorithm: the proposed algorithm for channel assignment, which is described detailed as algorithm 1. The other is the random selection algorithm: the random algorithm for channel assignment, which is described as algorithm 2.

4.2 Simulation results

Figure 2 demonstrates the performance of system capacity is evaluated versus the number of D2D reuse pairs. First, as optimal selection algorithm traverses all channels for different D2D pairs, it can bring greater system capacity. So it can be seen from the figure that optimal selection algorithm has better performance than the random selection algorithm. Furthermore, system capacity decrease with the number of D2D pairs of the multiplexed channel increasing. This is because as the number of D2D reuse pairs increased, fewer channels are available. In the end, only if the last CU' channel is not reuse, the performance of the two algorithms is consistent.

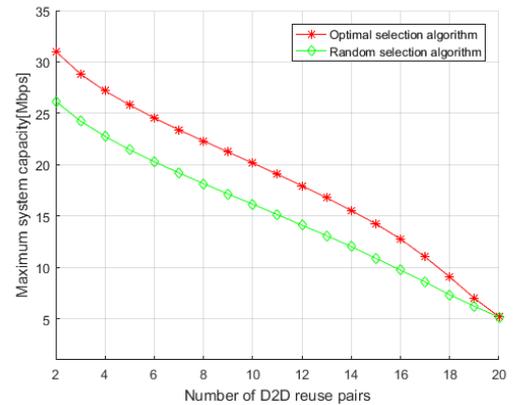


Figure 2. system capacity and the number of D2D reuse pairs

Figure 3 evaluates the system capacity performance versus the number of D2D reuse pairs. As can be seen the performance of the proposed algorithms slight decline with the decline of the maximum transmit power of CUs. Due to the fact that according to formula (8), (9), (10), the optimal transmit power of D2D pairs will decrease with the reduction of the maximum transmit power of the CUs. The effect of reducing the transmit power not only decreases its SINR but also mitigates the interference.

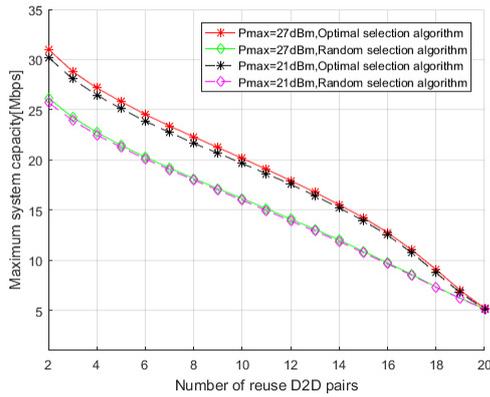


Figure 3. system capacity for different maximum transmit power of CUs and the number of D2D reuse pairs

Figure 4 compares the performance of the two algorithms for different radius of the cell. It can be seen that the performance of the two algorithms decrease with the increase of the radius of the cell. This is because when the cell radius decreases, the distance between various users in the cell will be reduced. Meanwhile, increasing the interference between CUs and D2D users will result to the decrease of system capacity.

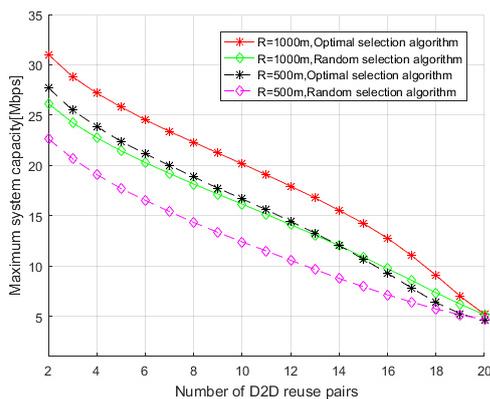


Figure 4. system capacity for different radius of the cell and the number of D2D reuse pairs

5 Conclusions

In this paper, we witness the full load mode, i.e. all channels have already been used by CUs. We build functions with the goal of maximizing system capacity, and divide the objective function into two sub-problems: power control and channel assignment. In the power control problem, we prove the objective function is a convex, the optimal transmit power of the D2D pairs is obtained. In the channel assignment problem, we design an optimal selection algorithm to achieve system capacity maximization. Simulation results demonstrate that our scheme always perform better considering D2D system capacity compared with random selection algorithm.

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