Resource Allocation Scheme for D2D Communication Based on ILA

Zhifang Gu(✉), Pingping Xu, Guilu Wu, and Hao Liu

National Mobile Communications Research Laboratory, Southeast University, Nanjing, China
{zhifang_gu,xpp,wgl,liuhao_seu}@seu.edu.cn

Abstract. Resource allocation is one of the most crucial issues in Device-to-Device (D2D) communication, which can achieve high spectrum efficiency and enhance system capacity. However, the interference generated by multiplexing users makes resource allocation more complicated. In this paper, a resource allocation algorithm based on interference limited area (ILA-based) is proposed to manage the interference. First, the system capacity of D2D communication is analyzed. Next, the ILA is divided and the resource pool is selected. Finally, it is verified that the proposed algorithm can effectively improve the overall capacity of the communication system with a relatively low complexity.

Keywords: D2D communication · Resource allocation algorithm · ILA

1 Introduction

With the rapid development of mobile communication technologies, every industry has undergone tremendous changes. The 5G standardization process has been completed recently. D2D technology, as one of the key technologies of 5G, increasingly attracts the attention of researchers. It is a kind of communication method that directly communicates between user terminals without passing through a base station or the core network, but uses the operator-authorized spectrum for point-to-point communication under the system control.

D2D communication underlaying cellular network can bring significant improvement to system capacity and spectrum efficiency [4]. While D2D technology brings numerous advantages, it also increases the complexity of the existing communication system. More importantly, it is inevitable to guarantee that the D2D communication does not generate excessive interference to the original cellular system. Therefore, an effective resource allocation is necessary to manage the interference and improve the overall performance of the system.

Many efforts have been taken in order to deal with the problem of interference. The research in [1] proposed an interference management algorithm to maximize the performance of the D2D communication while satisfying the

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quality-of-service requirements of the cellular communications in both uplink and downlink phases. Specifically, the admission control and power allocation were conducted to ensure that the interference from D2D communication does not affect to the cellular communications. In [6], an iterative resource allocation algorithm combined with power control was proposed to achieve higher performance of the system. A pricing framework for interference management was proposed in [3], where the base station protects itself (or its serving cellular users) by pricing the cross-tier interference caused from the D2D users. A social-community-aware D2D resource allocation framework in [5] was adopted to D2D communications, which exploited social ties in human-formed social networks.

The above algorithms generally adopt the method of traversing all the available resources and have a high system complexity. A resource allocation algorithm based on ILA is proposed to manage the interference generated by multiplexing users. For the scenario of D2D users multiplexing with cellular network uplink, the proposed algorithm filters the reusable resource pool instead of traversing all the resources, which can greatly reduce the complexity of the system and approximate the optimal ergodic algorithm.

The rest of this paper is organized as follows. Section 2 introduces the system model and analyses the performance of D2D communication multiplexing with cellular uplink network. In Sect. 3, the interference limited area and the proposed resource allocation algorithm are discussed in detail. The simulation results are presented and analyzed in Sect. 4. Finally, the conclusions are given in Sect. 5.

2 System Model

2.1 Scenario Description

The uplink of the D2D multiplexing cellular system model is shown in Fig. 1. The figure includes cellular users to base station uplink communication links, D2D multiplexing uplinks, cellular users to D2D users and D2D users to base station interference links. Assume that there are M cellular users in the cellular system, which are denoted as Cellular User Equipment (CUE) and are uniformly distributed in the cell. In addition, there is a pair of D2D users randomly distributed in the cell, and they are all managed by the base station. The base station transmits signals to M $CUEs$, at the same time, D2D Transmitting User Equipment (TUE) transmits signals to D2D Receiving User Equipment (RUE). In order to facilitate the analysis of the interference of the D2D multiplexing mode, it is assumed that the frequency band resources of CUE_1 are multiplexed by D2D users, and then the D2D receiver is subject to uplink multiplexing interference from CUE_1. On the other hand, the base station receives interference from the D2D sender while receiving the CUE_1 useful signal. Because the main user in the cellular system is the CUE, it is necessary to manage the interference caused by the D2D multiplexing mode through a reasonable resource allocation algorithm.

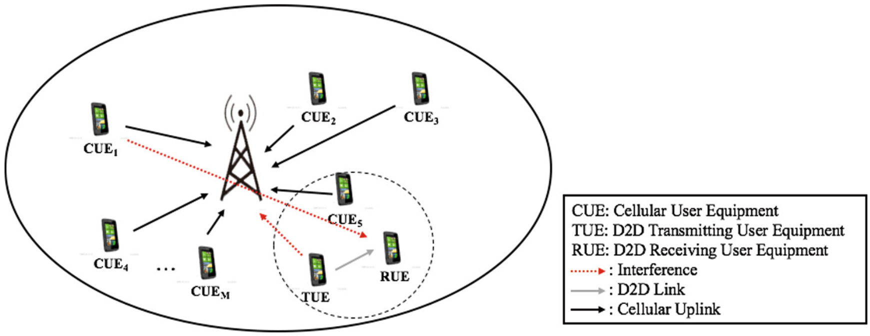

Fig. 1. D2D communication system model with multiplexing interference

2.2 System Capacity

According to the system model shown in Fig. 1, the Signal to Interference plus Noise Ratio ($SINR$) of a cellular user without multiplex interference, a cellular user with multiplex interference, and a D2D user can be obtained as

$$SINR_{CUE_i} = \frac{P_{CUE_i} G_{_{BS,CUE_i}}}{N_0 + I_{d,CUE_i}}, \tag{1}$$

$$SINR_{CUE_j} = \frac{P_{CUE_j} G_{_{BS,CUE_j}}}{N_0}, \tag{2}$$

$$SINR_d = \frac{P_d G_d}{N_0 + I_c}, \tag{3}$$

where P_{CUE_i} is the transmit power of CUE_i, I_{d,CUE_i} is the multiplexing interference to CUE_i, I_c is the multiplexing interference to D2D user. N_0 is the power spectral density of the Additive White Gaussian Noise (AWGN). $G_{_{BS,CUE_i}}$, $G_{_{BS,CUE_j}}$ are the channel coefficients between the base station and cellular users with interference, between the base station and the cellular users without interference, respectively. G_d is the channel coefficient between D2D users. Therefore, the total capacity of the cellular users and the D2D users can be expressed as

$$R_c = \sum_{i=1}^{K} log_2(1 + SINR_{CUE_i}) + \sum_{j=1}^{M-K} log_2(1 + SINR_{CUE_j}), \tag{4}$$

$$R_d = K log_2(1 + SINR_d), \tag{5}$$

where K is the number of resources needed to be multiplexed. The total capacity, R_{total}, of the system can be shown

$$R_{total} = R_c + R_d. \tag{6}$$

3 ILA-Based Resource Allocation Scheme

3.1 ILA Construction

In a cellular communication system, geographic location information of each cellular user is easily acquired by the base station and can be used to better allocate resources for D2D users [2]. The allocation of resources based on ILA is a scheme for utilizing geographic information. First, the number of physical resource blocks required by a D2D user is estimated when satisfying the preset transmission rate requirement. Secondly, the interference limited area is divided by using the ILA-based scheme. At the same time, to satisfy the quality of service of the base station, the power control of the cellular user is required. Then to meet the D2D receiver's quality of service, D2D transmitter power needs to be controlled. Finally, the resources are allocated after analyzing the interference generated by D2D multiplexing with the ILA-based scheme.

When the D2D user uses the multiplexing uplink mode, the RUE may receive uplink interference from the cellular user, and the D2D transmitter may interfere with the base station which should receive the cellular user uplink signal. In the proposed resources allocation method, first, with the ILA-based algorithm, cellular users that can be multiplexed with D2D are divided to ensure that D2D communication will not cause excessive interference to normal cellular communication. At the same time, it is analyzed whether the distance between D2D users is appropriate and whether the communication quality meets the requirements, so as to ensure that D2D links can be establish normally. When the D2D user uses the multiplexing uplink mode, the base station receives the signal from the cellular user, which can be expressed as

$$y_{CUE_i} = \sqrt{P_{CUE_i} d_{CUE_i,BS}^{-\alpha}} h_{CUE_i,BS} x_i + \sqrt{P_{TUE_i} d_{TUE_i,BS}^{-\alpha}} h_{TUE_i,BS} x_{TUE,i} + n_i. \quad (7)$$

where P_{CUE_i} is the transmit power of CUE_i on the i-th Resource Block (RBi), with the bandwidth of W. P_{TUE_i} is the transmit power of the D2D sender on RB_i. $d_{CUE_i,BS}^{-\alpha}$ is the large-scale fading from CUE_i to the base station, $d_{CUE_i,BS}$ is the distance from CUE_i to the base station, and α is the path loss index. Similarly, $d_{TUE_i,BS}^{-\alpha}$ is the large-scale fading from TUE_i to the base station on RB_i, and $d_{TUE_i,BS}$ is the distance from the D2D sender to the base station. $h_{CUE_i,BS}$ is the channel coefficient between the cellular user and the base station, while $h_{TUE_i,BS}$ is the channel coefficient between the D2D sender and the base station on RB_i. x_i and $x_{TUE,i}$ represent the signal that the CUE sends to the base station and the signal that the D2D sender sends to the D2D receiver on RB_i, respectively. It is assumed that $E\{|x_i|^2\} = 1$ and $E\{|x_{TUE_i}|^2\} = 1$. n_i is AWGN signal.

Since the signal from the CUE received by the base station is subject to interference from the TUE, the $SINR$ on RB_i is:

$$SINR_{CUE_i} = \frac{P_{CUE_i} d_{CUE_i,BS}^{-\alpha} |h_{CUE_i,BS}|^2}{N_0 + P_{TUE_i} d_{TUE_i,BS}^{-\alpha} |h_{TUE_i,BS}|^2}. \quad (8)$$

In order to make the interference to the CUE under the control of the base station, it is assumed that the $SINR$ of the CUE should be greater than a certain threshold value which is set to δ_{CUE_i}, that is

$$SINR_{CUE_i} > \delta_{CUE_i}. \tag{9}$$

Therefore, to meet the QoS requirements of cellular users, $d_{TUE_i,BS}$ needs to meet:

$$d_{TUE_i,BS} > \left(\frac{P_{CUE_i} d_{CUE_i,BS}^{-\alpha} |h_{CUE_i,BS}|^2 - N\delta_{CUE_i}}{\delta_{CUE_i} P_{TUE_i} |h_{TUE_i,BS}|^2}\right)^{1/\alpha} = D_{TUE,BS,min}, \tag{10}$$

TUE should be far away from the base station, and the minimum distance for normal D2D communication is $D_{TUE,BS,min}$. Similarly, the minimum distance between RUE and the CUE whose resources are multiplexed can be expressed by

$$d_{CUE_i,RUE} > \left(\frac{P_{TUE_i} d_{TUE,RUE}^{-\alpha} |h_{TUE_i,RUE}|^2 - N\delta_{RUE_i}}{\delta_{RUE_i} P_{CUE_i} |h_{CUE_i,RUE}|^2}\right)^{1/\alpha} = D_{CUE,RUE,min}. \tag{11}$$

where all parameters are the counterparts of the CUE and RUE, which are defined in the same way. The cell radius is r. $D_{TUE,BS,min}$ and $D_{CUE,RUE,min}$ can be used to indicate the Interference Limited Area as Fig. 2 shows.

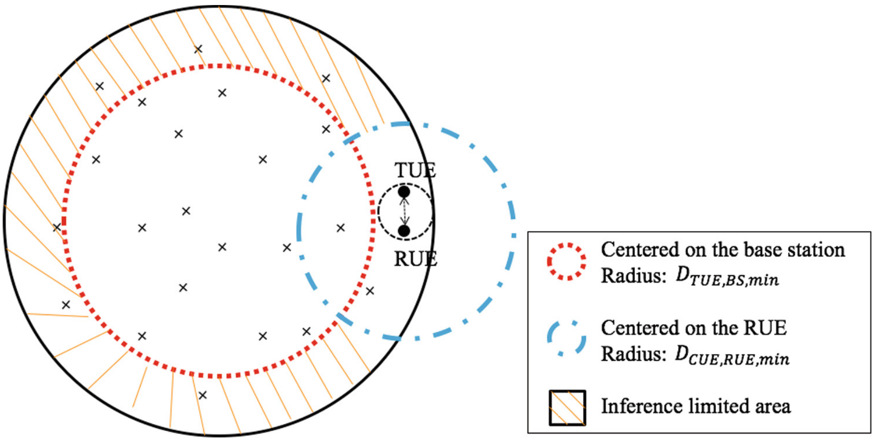

Fig. 2. Interference limited area in D2D communication system

3.2 ILA-Based Resource Allocation Algorithm

According to the interference limited area shown in Fig. 2, a complete ILA-based resource pool can be established as

$$pool = [RB'_1, RB'_2, RB'_3, \ldots, RB'_{M'}], \tag{12}$$

where RB_i' represents the resource blocks occupied by the cellular users that satisfy the ILA requirement, and M' is the total number of resource blocks that satisfy the ILA requirement. Obviously, assuming that there are many cellular users in the application scenario of the D2D user, when solving the above optimization problem, the base station needs to control all cellular users in the resource pool to measure the channel status of each link. In an actual situation, this traversal scheme is obviously not practical.

Secondary modification is conducted to the original resource pool, which greatly reduces the size of the resource pool, thereby reducing system complexity and adapting to future large-scale D2D scenarios. In the proposed method, L times the number of cellular users for the demand of D2D users are randomly selected, and the total selected number is far less than the original resource pool size. Next, the optimization problem is calculated in the modified resource pool to allocate the resource block for the D2D user. At the same time an optimized resource list is established:

$$List_L = \begin{bmatrix} SINR_{CUE_R B_1'} \dots SINR_{CUE_R B_L'} \\ SINR_{RUE_R B_1'} \dots SINR_{RUE_R B_L'} \end{bmatrix}. \tag{13}$$

$List_L$ records $SINR$ of CUE and RUE, which can be used to more easily calculate the optimization problem. The proposed resource allocation algorithm uses a slight drop in performance in exchange for time-consuming reduction and the reduced complexity.

4 Simulation Results

The design of the D2D simulation platform is mainly modified on the basis of the traditional cellular system by adding D2D users and their related links. Through simulation results, the performance of the proposed ILA-based D2D resource allocation method is evaluated. The simulation is based on orthogonal frequency division multiple access in a cellular system. Resources are divided into resource blocks, and each resource block does not interfere with each other. Considering the limited capacity of the base station in the future, the pool of D2D reusable resources is reduced to simulate the occurrence of congestion. The simulation parameters are shown in Table 1. In Fig. 3, the comparison of the total capacity of the cellular system in the proposed algorithm, random algorithm and traversal optimal algorithm is conducted. As can be seen from Fig. 3, the total system capacity increases first and then decreases with the base station interference threshold increasing. The performance of the proposed algorithm is obviously better than the random allocation method because the proposed solution makes full use of the ILA information, which excludes cellular users with heavy interference from the resource pool. In contrast, random allocation method may allocate these resource blocks to D2D users. The reason why the performance of the proposed scheme is slightly lower than the optimization scheme is that the system reduces the computational complexity and the signaling overhead to adapt to the actual scenario. By setting the $SINR$ threshold, some reusable resources are eliminated. Therefore, the size of the resource pool and the system load pressure is reduced by the slight sacrifice in performance. When the $SINR$ threshold rises in the initial stage, resource blocks with relatively low transmitting power or poor link condition are excluded from the resource pool. Because this algorithm ensures that the interference received by the base station is within a certain range, the curve increases at the beginning. However, when the $SINR$ continues to increase, the decrease of the average TUE transmit power in the resource pool reduces the multiplexing gain of D2D. In this case, the overall capacity of the system finally showed a downward trend. The simulation results show that the threshold should be set reasonably according to the actual situation of the system.

Figure 4 shows the relationship between the total system capacity and the simulated distance between D2D users. The power threshold of the base station

Table 1. Simulation parameters in D2D communication system

System parameter	Value
Cell radius, r	500 m
Resource block bandwidth, W	180 KHz
Maximum transmit power of the terminal, P_{TUE}	23 dBm
Power spectral density of AWGN, N_0	−174 dBm/Hz
System outage probability threshold, p	0.8

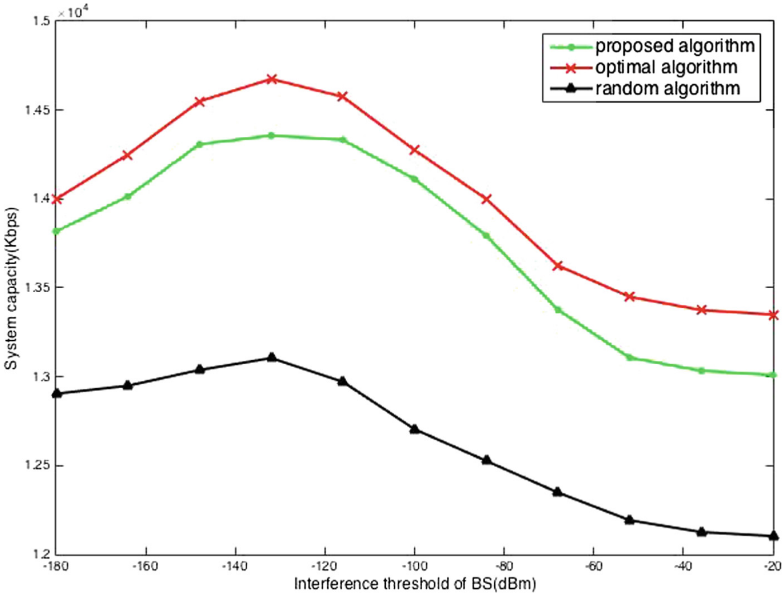

Fig. 3. The capacity of the system with various interference threshold of BS

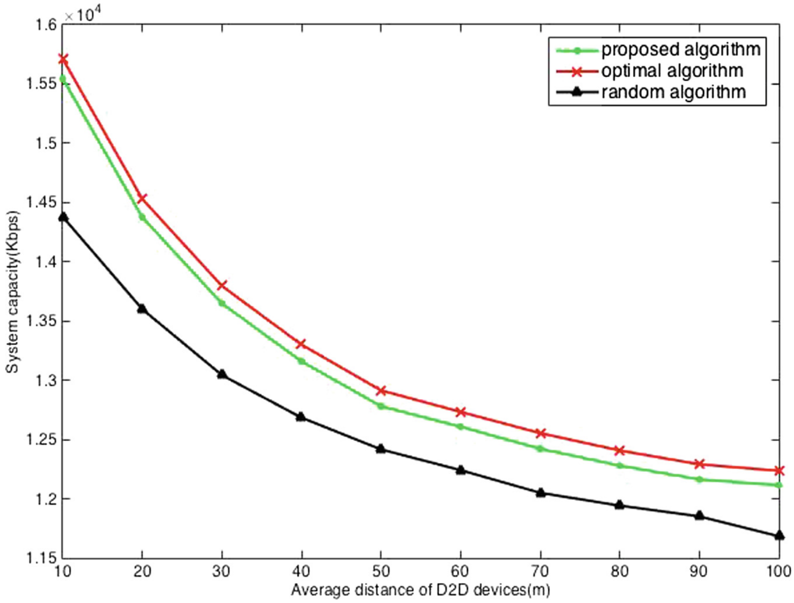

Fig. 4. The capacity of the system with various distances of D2D devices

receiving RUE is set to $-110\,\text{dBm}$, and other parameters of the system remain unchanged. From this figure, it can be seen that the system capacity decreases with the increase of the simulation distance between D2D users. The performance of the proposed scheme is significantly better than the randomization scheme, while it is slightly lower than that of the optimization scheme. As the distance of the D2D devices increase, the average power of the received signal transmitted from TUE to RUE decreases, so that the gain of the multiplexed signal between the D2Ds and the overall capacity of the system decrease. This is the reason that the total system capacity decreases as the distance between D2Ds increases. Because of the proposed ILA-based algorithm, the initial resource pool has removed some resource blocks that may generate excessive reuse interference. Therefore, the overall system performance can still approach the optimal solution but with a relatively low complexity.

It can be seen from Fig. 5 that the overall system capacity increases as the number of cellular users in the system increases. The performance of the proposed algorithm is lower than but close to the optimal solution, and is superior to the randomized resource allocation method. Simulation results show that for a single pair of D2D users, the greater the number of cellular users in the system, the better the overall capacity of the system. Because the larger the D2D resource pool, the more likely the system allocates resources that have less interference to D2D users.

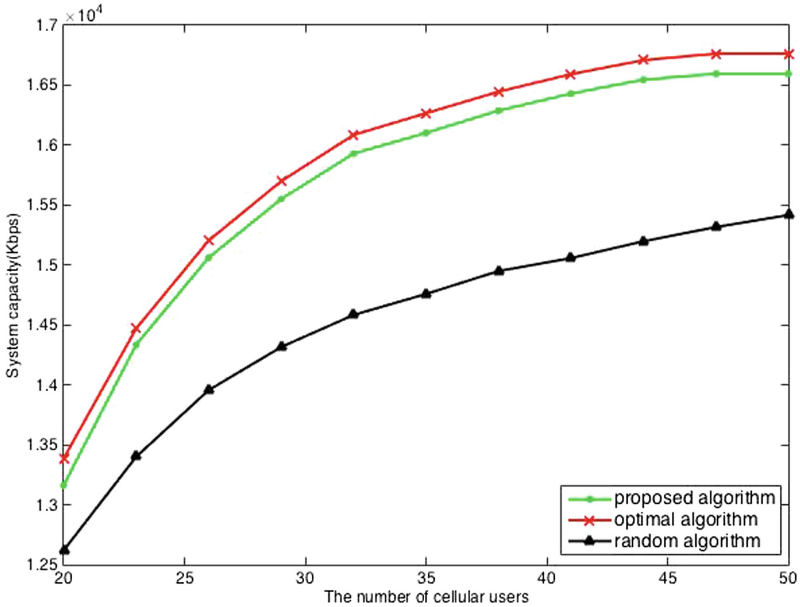

Fig. 5. The capacity of the system with various numbers of cellular users

5 Conclusion

An ILA-based resource allocation algorithm is proposed to effectively manage resources and reduce interference in D2D multiplexing communication. With the proposed algorithm, the system resource pool is modified to reduce the complexity of the system and can be more competitive in future dense communications networks. Through the simulation experiments, the performance of the proposed algorithm can be very close to the optimal traversing method, and with a significantly lower system complexity.

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