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Research on D2D Resource Fair Allocation Algorithm in Graph Coloring

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Abstract. In a heterogeneous network composed of cellular users and device-to-device (D2D) users, D2D users multiplex the spectrum resources of cellular users in heterogeneous networks, which improves the shortage of spectrum resources. But this will bring a series of interference problems, which will greatly affect the throughput of the system and the service rate of users. On the premise of ensuring the service quality and throughput of users in the system in a heterogeneous network, to improve the user service rate, a fair distribution algorithm of D2D resources in graph coloring is proposed. First, in a heterogeneous network system, allowing multiple D2D users to share the resources of the same cellular user at the same time can improve the utilization of spectrum resources; Secondly, the interference graph is constructed by users and the interference between users in the heterogeneous network, and then the resource allocation colored by the D2D graph is added with a priority factor so that the fairness of user resource acquisition in the system is improved. Finally, it is verified by simulation, the algorithm improves the fairness of D2D users' access to resources while maintaining stable system throughput. It also reduces the system's packet loss rate and improves the user's service quality.

Keywords: Heterogeneous network · Resource allocation · Graph coloring · Throughput · Fairness

1 Introduction

At present, the continuous development of mobile communication technology and Internet technology has promoted the popularization of various intelligent terminals and the increase in the number of users, which ultimately led to a serious shortage of spectrum resources [1]. Device-to-device (D2D) technology is a communication method under the control of a cellular system, which can communicate directly by sharing the resources of cellular users. At the same time, D2D users will share the spectrum resources of cellular users, so that the utilization of spectrum resources is improved, and the problem of shortage of spectrum resources for wireless communications is solved. Therefore, D2D communication technology is listed as one of the key technologies in the new generation mobile communication system [2]. However, when D2D communication is introduced

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into a cellular network, it will cause serious interference [3, 4]. It is of great practical significance and research value on how to allocate resources reasonably to improve the spectrum utilization rate of the system and enhance the fairness of users receiving services.

In [5], when ensuring the user's service quality requirements, a pair of D2D users multiplex multiple channel resource blocks for communication, and a resource allocation algorithm based on Kuhn-Munkres optimal matching is proposed, thereby improving the overall system throughput. In [6], by analyzing the mathematical characteristics of the uplink and downlink interference area of D2D communication under the cellular network, the D2D communication system is designed and optimized. In [7], the problem of maximizing the system and the rate is transformed into an integer programming problem. On this basis, a resource allocation algorithm based on a bipartite hypergraph is proposed. In [8], through the proposed channel assignment scheme of hypergraph theory, the interference coordination between D2D users and cellular users are studied. In [5–8], they only consider the situation that one D2D user can only reuse the channel spectrum resources of one or more cellular users. However, when there is more available channel spectrum in the system, the remaining spectrum resources cause a waste of resources, thereby reducing the spectrum utilization rate of the system.

In [9], the capacity-oriented restricted (core) area is introduced into the traditional Stackelberg game method, which reduces the interference suffered by cellular users, and a resource allocation scheme for fair and safe capacity is proposed. In [10], by proposing graph theory coloring and QoS clustering method to allocate channel resources to D2D users, the satisfaction of D2D users, and the fairness of the system are solved. In [11], by using polynomial time proportional fair resource allocation schemes, it meets the requirement of the user's rate. However, it is considered that multiple resource blocks are allocated to one D2D user, which will cause a waste of resources. In [12], it is proposed to design a heuristic D2D resource allocation scheme based on the proportional fair scheduling algorithm. This scheme guarantees the data rate requirement of D2D communication improves the system throughput, and at the same time, the fairness of user scheduling is also taken into account. In [11, 12], on the premise of meeting the requirements of the cellular user signal-to-noise ratio (SINR), a resource allocation algorithm is proposed to achieve proportional fairness. In [13], in order to improve the overall performance of the cellular network system and reduce the fairness of D2D users to the cellular network system, improved proportional fairness (IPF) interference control scheme is proposed, but the scheme does not consider the fairness of D2D users' access to resources.

In response to the above problems, this paper uses multiple D2D users to reuse the same cellular user resource allocation scheme, so that the spectrum utilization rate and throughput of the system are improved.

2 System Model

2.1 Network Scenario

In a single-cell cellular network, when multiplexing uplink spectrum resources is compared with multiplexing downlink spectrum resources, the base station can control the allocation of system spectrum resources through its own interference, and the interference received by D2D users is also less. Therefore, this article considers the scenario where the uplink spectrum resources are multiplexed by D2D users in a network scenario where cellular users and D2D users share resources [14]. As shown in Fig. 1, assuming that the base station (BS) is located in the center of the cell, M cellular users and N D2D users are randomly distributed in the cell. Cellular users in the cell network are expressed as $CUE = \{C_1, C_2, \cdots, C_m, \cdots, C_M\}$, D2D users expressed as $DUE = \{D_1, D_2, \cdots, D_n, \cdots, D_N\}$, and the number of D2D users in the system is greater than the number of cellular users (M < N). Each D2D user exists in pairs, consisting of a transmitter (DT) and a receiving terminal (DR), and it is assumed that the initial transmission power of the data transmission of the D2D users is the same.

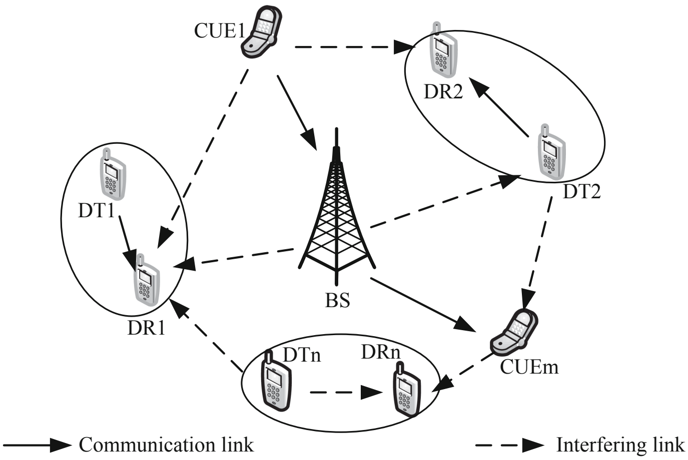

Fig. 1. Single-cell network system model

2.2 Mathematical Model

As shown in Fig. 1, when the uplink channel of the cellular user is multiplexed by the D2D user, there will be interference from D2D users and other D2D users' DR who reuse the same resources, between D2D users' DR and cellular users, and between D2D users' DT and base station. It can be seen that the interference caused by D2D users multiplexing the channel resources of cellular users is more complex. In order to avoid that the quality of service of users in the system can't be guaranteed when improving the spectrum utilization and throughput of the system, it is necessary to coordinate the complex interference in the cell network through reasonable resource allocation. In addition, it can prevent users with poor channel quality from being unable to allocate resources for a long time, which makes resource scheduling unfair. Therefore, the optimization goal of this paper is to find an optimal matching matrix for resource allocation and to ensure the user quality of service of the system's throughput level, as much as possible to improve the fairness of user resource acquisition.

$$R = nax(\sum_{m=1}^{M} B_0 \log(1 + SINR_m^c) + \sum_{m=1}^{M} \sum_{n=1}^{N} \alpha_{nm} B_0 \log(1 + SINR_n^d)) \quad (1)$$

When the spectrum resources of cellular users are multiplexed and shared by multiple D2D users at the same time, the signal-to-noise ratio (SINR) of the cellular users is:

$$SINR_m^c = \frac{p_m^c G_{c,b}}{\sum p_n^d G_{d,b} + N_0} \quad (2)$$

Among them, p_m^c represents the transmit power of the mth cellular user; $p_{n_m}^d$ represents the power sent from the DT of the nth D2D user to the mth cellular user; $G_{c,b}$ represents the channel gain between the cellular user and the base station; $G_{d,b}$ represents the channel gain between the DT of the D2D user and the base station; N_0 represents the noise power in the system.

The interference received by the D2D user DR in the system includes interference from cellular users and interference from other D2D users that multiplex the same resource at the same time, so the SINR of the D2D user's DR is:

$$SINR_n^d = \frac{p_n^d G_{dt,dr}}{\sum p_{n'}^d G_{dt',dr} + p_m^c G_{c,d} + N_0} \quad (3)$$

Among them, $G_{dt,dr}$ represents the channel gain between the DT and DR of the nth D2D user; $G_{dt',dr,}$ represents the channel gain between DTs of other D2D users multiplexing the same resources as the DR of the nth D2D user; $G_{c,d}$ represents the channel gain between the DR of the cellular user and the D2D user. In order to ensure the user's communication quality requirements, the default minimum SINR threshold for cellular users is $SINR_{th}^c$, the SINR threshold of normal communication for D2D users is $SINR_{th}^d$, and under the conditions of fairness, the throughput should be improved as much as possible. Then:

$$\begin{aligned} s.t. SINR_m^c &\geq SINR_{th}^c, \forall m \\ SINR_n^d &\geq SINR_{th}^d, \forall n \\ p_m^c &\leq p_{\max}^d, \forall m \\ \sum_{m=1}^{M} p_{n_m}^d &\leq p_{\max}^d, \forall n \\ \sum_{m=1}^{M} \alpha_{n,m} &\geq 1, \forall n \\ \sum_{n=1}^{N} \alpha_{n,m} &\geq 1, \forall m \end{aligned} \quad (4)$$

Among them, B_0 is the bandwidth of the channel resource, $p_{\max}^c$ and $p_{\max}^d$ represent the maximum transmission power of cellular users and D2D users, $\alpha_{n,m} \in \{0, 1\}$ It indicates whether the same channel resources can be shared simultaneously cellular users and user

D2D, $\sum_{m=1}^{M} \alpha_{n,m} \geq 1, \forall n$ Indicates that the spectrum resources of multiple cellular users can be reused by one D2D user, $\sum_{n=1}^{N} \alpha_{n,m} \geq 1, \forall m$. It means that the spectrum resource of one cellular user can be multiplexed by multiple cellular D2D users. This objective function is the resource allocation problem of interference control, which can be solved by graph coloring theory.

3 Fair Color Allocation Based on Graph Coloring

According to the actual situation, in a single-cell network system in which D2D users and cellular users coexist, D2D users exist in the system as an auxiliary communication method, which causes a decrease in the service rate of D2D users. In order to avoid this situation and a certain occupied channel resource is excessive, a priority factor is added to the resource allocation to adjust the user coloring order, which is used to improve the fairness of user resource acquisition. In the fair resource allocation based on graph coloring, all users in the network system are abstracted as "vertices" in the graph and the interference suffered by the users is abstracted as "edges" in the graph, so a piece of interference can be constructed Figure G.

3.1 Construct an Interference Graph

In a network system where cellular users and D2D users coexist, a specific interference graph G can be established through the interference relationship between users and users. Among them, the vertices abstracted by all users in the system, the set is V, which includes the set of vertices composed of cellular users and the set of vertices composed of D2D users, then V is expressed as $V = \{v_i, i = 1, 2, \cdots, M, \cdots, N+M\}$, it is a vector of length $N+M$. The first M elements represent the vertices of the cellular user, and the last N elements represent the vertices of the D2D user. If the mutual interference edge matrix between vertices using the same spectrum resource is E, then the set of matrix E is represented as $E = \{e_{i,j}, i = 1, 2, \cdots, N+M, j = 1, 2, \cdots, N+M\}$, $e_{i,j} \in \{0, 1\}$, which is a (N + M) × (N + M) matrix. When $e_{i,j} = 1$, it means that vertex i and vertex j are both cellular users, or it can be compared by the distance $d_{i,j}$ between vertex i and vertex j and the interference distance threshold d_{th} between vertices, if it is less than the interference distance threshold ($d_{i,j} < d_{th}$), it indicates that there is interference between vertex i and vertex j, so user i and user j cannot reuse the same spectrum resource; When $e_{i,j} = 0$ indicates that there is no interference between vertex i and vertex j, then user i and user j can reuse the resources of the same spectrum. Thus, the interference matrix $E(G)$ between the vertices of the interference graph G can be obtained. By using C to indicate that the set of available subchannel resources in the heterogeneous network where the cellular and D2D coexist is the color set $C(G)$ of the interference graph G, then $C = \{c_1, c_2, \cdots, c_N\}$. If the cellular users in the system are fully loaded with $|C| = N$, it means that each cellular user can be assigned a subchannel. Therefore, the interference graph is constructed as G = (V, E, C), and the sub-channel allocation problem of cellular users and D2D users in the system is transformed into the problem of coloring the interference graph G.

3.2 Improve Resource Allocation Coloring Process

In order to avoid the problem that users with poor channel quality cannot be allocated resources for a long time and improve the service rate of D2D users, this paper proposes a graph coloring fair resource allocation strategy. In order to improve the fairness of users' access to resources during the graph coloring process, it avoids the problem of node coloring due to excessive user occupation of channel resources, so the priority factor of user coloring can be set during resource allocation.

Suppose that the sub-channels assigned by the cellular user $C_1, C_2, \cdots, C_m, \cdots, C_M$ to the vertex $v_1, v_2, \cdots, v_m, \cdots, v_M$, that is, the color of the graph coloring, respectively correspond to $c_1, c_2, \cdots, c_m, \cdots, c_M$. Therefore, the resource allocation problem of system throughput can be transformed into the resource allocation problem of D2D users. When a D2D user whose vertex is v_{M+n} reuses the color c_m corresponding to cellular user C_m, the utility value of vertex v_{M+n} to the network is:

$$R_{v_{M+n},c_m} = \frac{\log(1 + SINR^c_{m,c_n}) + \log(1 + SINR^d_{n,c_n})}{\deg(v_{M+n})} \quad (5)$$

Among them, $SINR^c_{m,c_m}$ represents the SINR of the cellular user C_m when the user assigns the color c_m; $SINR^d_{n,c_m}$ represents the SINR of the D2D user D_n when the user assigns the color c_m; $\deg(v_{M+n})$ represents the degree of the vertex v_{M+n}.

Assuming that the color c_m corresponding to the cellular user C_m is multiplexed for the D2D user vertex v_{M+n}, the priority factor of the colored c_m is w_{v_{M+n},c_m}. The priority factor is the utility value R_{v_{M+n},c_m} of the vertex v_{M+n} to the network and the number of colors assigned to the value of v_{M+n} which is:

$$w_{v_{M+n},c_m} = \frac{R_{v_{M+n},c_m}}{\sum_{m=1}^{M} A_{MN} + 1} \quad (6)$$

Among them, A_{MN} is a D2D user spectrum allocation matrix composed of $\alpha_{n,m}$ elements; adding 1 to the denominator is to avoid the problem of infinite priority factor. An improved resource allocation algorithm based on graph coloring, the implementation steps are as follows:

(1) Construct the interference graph and initialize the graph G = (V, E, C);
(2) for i = 1: M, coloring cycle;
(3) According to whether the vertices in E(G) interfere with each other, obtain a D2D user set K that can use the color c_m occupied by the vertex v_m;
(4) According to the set K, determine whether this vertex can be colored;
(5) According to formula (5), the vertex corresponding to the maximum network utility value is obtained and colored;
(6) According to formula (6), the coloring order, that is, the order of resource allocation, is determined.

4 Analysis of Simulation Results

4.1 Simulation Parameters

In order to verify the effect of D2D resource fairness allocation algorithm (IFCA) on the graph coloring proposed in this paper on the system performance. The three aspects of system fairness, system throughput, and system packet loss rate are respectively compared with the random coloring allocation algorithm (RCA), the graph coloring resource allocation algorithm (DVCA) considering the delay and saturation, the traditional graph coloring allocation algorithm (TGCA) for simulation comparison. Assuming that the cell radius is 500 m, the base station BS is located in the center of the cell, and other main simulation parameters are shown in Table 1.

Table 1. System simulation parameters.

Parameter	Value
Cell radius/m	500
Total system bandwidth/MHz	10
Maximum transmit power of cellular users/dBm	24
Distance between D2D users/m	10–25
Maximum transmit power of D2D users/dBm	20
Noise power spectral density/dB/HZ	−174
Path loss model for D2D link/dB	$148 + 40\lg d$
Path loss model for cellular link/dB	$128.1 + 37.6\lg d$
SINR threshold/dB for normal communication of D2D users	30
SINR threshold for normal communication for cellular users/dB	20

4.2 Analysis of Simulation Results

Figure 2 shows the relationship between the fairness of system D2D resource allocation under different graph coloring resource allocation algorithms. It can be seen from Fig. 2 that the greater the number of D2D users accessed in the system, the worse the fairness of resource allocation in the system. Among them, when the number of D2D users accessed in the system is within 30 pairs, because the number of D2D users accessed in the cell network is not large, there is not much interference, so the fairness of resource allocation of the four algorithms is particularly different small. However, when the number of D2D users connected in the system is between 80 and 100 pairs, the IFCA algorithm proposed in this paper can be improved by about 4% compared with the DVCA algorithm. This is because a priority factor is added on the basis of the DVCA algorithm so that users who cannot obtain channel resources due to poor channel communication quality in the system can obtain resources preferentially. Therefore, the fairness of resource allocation in the system is improved.

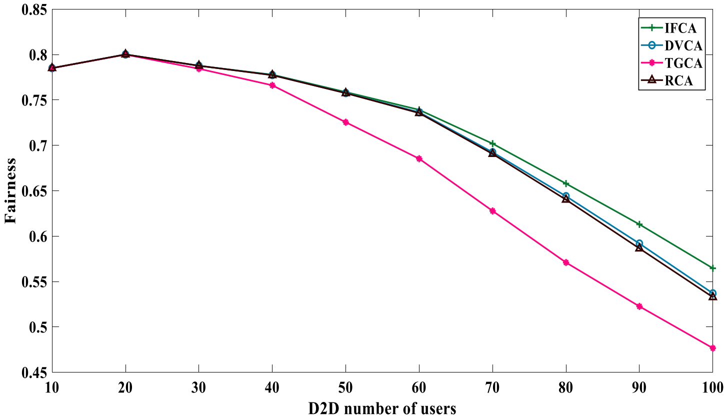

Fig. 2. Comparison of the fairness of different algorithms

Figure 3 shows the relationship between the number of D2D users accessing the system and the throughput. It is known from the simulation results that the three algorithms of IFCA, DVCA, and TGCA are based on ensuring normal communication between users and allow multiple pairs of D2D users to reuse the resources of the same cellular user to achieve maximum utilization of channel resources. However, when more D2D users are connected to the system, the higher the throughput of the system, the worse the communication service quality of the users. It can be seen from Figs. 3 and 4 that IFCA compares with DVCA and TGCA, the throughput of the system will be slightly different, but when more and more D2D users in the system, the service quality of IFCA users is better. Although the TGCA algorithm has improved the system throughput compared with the IFCA algorithm, it seriously sacrifices the fairness of user resource scheduling. Except for the RCA algorithm, the other three algorithms have no significant difference in system throughput.

Figure 4 compares the system packet loss rate of the number of D2D users connected to the system under different algorithms. It can be seen from the figure that as the number of D2D users in the system increases, the data packets in the system are more likely to be lost. In the TGCA algorithm, only the saturation of user vertices is considered, and no delay is considered. Therefore, some users occupy the channel resources too much, which causes an increase in the rate of packet loss. The algorithm IFCA considers the delay and adds a priority factor for the fairness of user resource scheduling, which avoids some users from occupying too many resources, improves the service rate of D2D users, and reduces the system's packet loss rate.

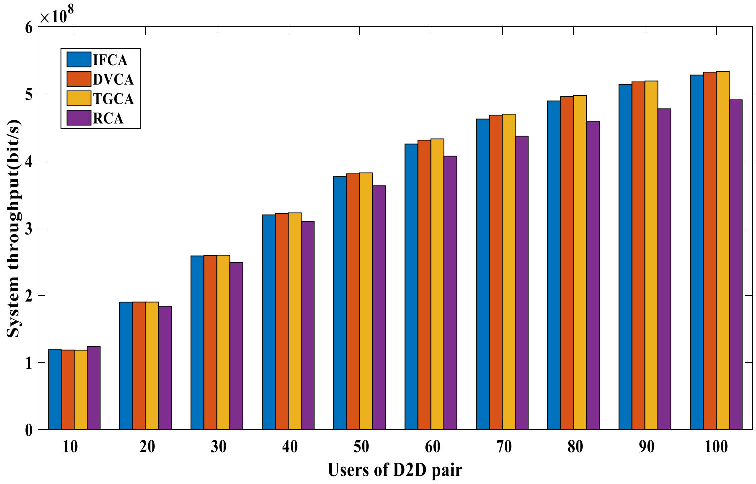

Fig. 3. Comparison of system throughput under different.

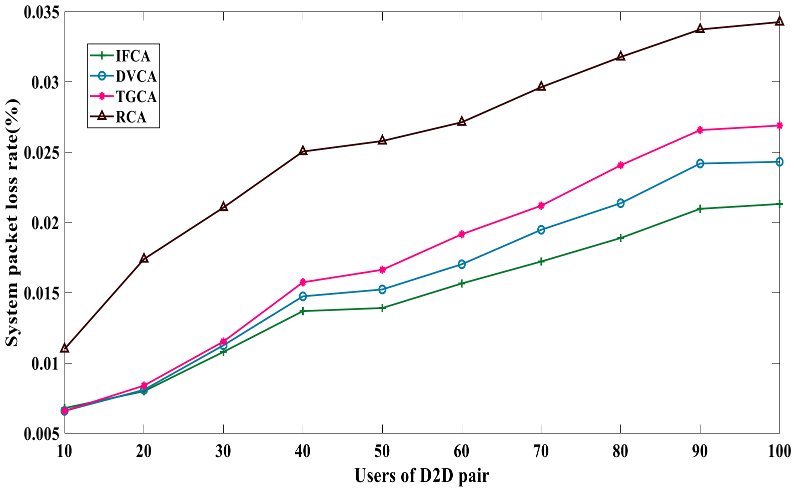

Fig. 4. Comparison of system packet loss rate under different algorithms.

5 Conclusion

In this paper, through the communication model of a heterogeneous network, the problem of resource allocation in the environment where D2D users are much larger than cellular users is studied, so that the spectrum utilization rate has been effectively improved. In order to ensure the throughput of the system and the fairness of users' access to resources, a resource fairness allocation algorithm based on graph coloring theory is proposed. Simulation results show that the proposed algorithm can improve the fairness of D2D users to obtain resources and reduce the packet loss rate on the premise of ensuring the system throughput, which can better guarantee the quality of service of users in the system. However, in this paper, we only consider the interference problem when D2D users and cellular users coexist in a single cell. While ignoring the interference between users in multiple cells, further research can be done in this regard in the future.

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