Joint Power Control and Resource Allocation Game Algorithm Based on Non-cooperative D2D

Jingqiu Ren[1], Liguang Du[1], Lin Zhang[1], Piao Chen[1], Guanghua Zhang[1](✉),
and Weidang Lu[2]

[1] Northeast Petroleum University, Daqing 163318, China
dqzgh@nepu.edu.cn
[2] Zhejiang University of Technology, Hangzhou 310014, China

Abstract. With the continuous development of modern mobile communication technology. D2D (device to device) communication technology, as a research hotspot of a new generation of communication technology. It has become an urgent problem to be solved in D2D communication in terms of solving its spectrum utilization, improving communication quality, improving system fairness, and reducing system delay. This paper studies the interference generated by multiple pairs of D2D users in the network spectrum resources of multiple pairs of cellular users. In order to reduce the interference when reusing resources, this paper establishes a non-cooperative game theory. The cost factor is introduced to determine the utility function. Through the power control of D2D communication link and the resource allocation algorithm, the optimal response function of D2D users participating in the game is obtained. This paper analyzes the equilibrium in the game, determines the existence and uniqueness of the Nash equilibrium, and proves that the strategy of the model can reach a stable state. This paper proves the effectiveness of the algorithm through experimental simulations. Compared with other algorithms, the D2D joint power control and resource allocation algorithm based on non-cooperative game in this paper has higher fairness and lower system delay on the premise of ensuring communication quality.

Keywords: D2D · Game theory · Power control · Resource allocation

1 Introduction

At present, D2D communication is one of the key technologies of 5G communication technology, and it will also be the key technology of next generation communication technology in the future [1]. At present, the main challenge of D2D communication is how to correctly allocate the reusable channel resources, transmit power and reduce the interference between D2D users and cellular users. Therefore, how to reduce interference and improve system resource utilization has become a research hotspot. Game theory is a method of using a mathematical model to resolve actual conflicts of interest [2]. In recent years, it is used to solve the interference problem in mobile communication.

S. Shi et al. (Eds.): 6GN 2021, LNICST 439, pp. 107–119, 2022.
https://doi.org/10.1007/978-3-031-04245-4_10

Game theory is different from other optimization decision theories. The participants in the game theory have conflicts of interest; Each participant should choose the decision to maximize their own interests; The decision-making of each participant will interact with each other; Every participant can carry out rational and logical thinking [3].

Game theory can be divided into cooperative games and non-cooperative games [4]. The cooperative game emphasizes the collective optimal decision-making; Non-cooperative games emphasize the individual optimal decision-making. In non-cooperative games, according to the order of actions of participants it can be divided into static games and dynamic games. The game model is mainly composed of the following three basic elements [5]:

Players: The decision-making body of the game, who will choose their own strategies according to their own interests.

Strategy: The action plan that each participant can choose to adopt during the game. Remember that the strategy i chosen by the participant is $s_i \in S_i$, where S_i is the set of strategies i that participants can choose, known as strategic space. The vector composed of the strategies $s = \{s_1, s_2, \cdots, s_N\}$ selected by the N participants is called the strategy combination.

Preference and utility function: The utility function reflects the participant's preference for the possible output of the game. The output of the game is directly determined by the behavior of the participants, thus establishing a certain relationship between the behavior space and the output space [6]. In the game process, participants choose actions according to their own preferences, that is, participants always choose actions that can increase their utility function.

Non-cooperative game includes repeated game, potential game and so on [7]. Repeated game is that participants choose strategies based on the knowledge of the game. In the potential game model, each participant only chooses the strategy with the greatest interests according to the current situation. This paper chooses potential game model, because it has good mathematical characteristics and can easy to converge to Nash equilibrium point.

In recent years, many scholars have proposed power allocation and resource allocation schemes for D2D communication. In reference [8], for pure game and mixed game, an iterative distributed power allocation method based on SINR (Signal to Interference Noise Ratio) is proposed to improve the performance of D2D users and cellular users. Reference [9] uses the idea of game theory, a relay selection algorithm is proposed, by analyzing the location information and transmission capacity of relay nodes, the system throughput is effectively improved and the coverage is expanded. In reference [10], a mode selection method based on predetermined SINR threshold is proposed. Combining with mode selection and power control methods to meet the minimum power required by users and improve the overall performance of the communication system. In reference [11], D2D communication system is modeled as a Stackelberg model, based on this, a joint scheduling and resource allocation algorithm is proposed to manage interference and optimize network throughput. In reference [12], the power allocation problem is modeled as a reverse iterative combinatorial auction game, using a joint radio resource and power allocation scheme to improve the performance of the uplink system. In reference [13], studied the problem of joint resource allocation and power control, using the characteristics of fractional planning to improve the solution of energy efficiency optimization problems. But the common point of the appeal scheme is that it has high complexity and only needs sub-optimal solution.

The interference in "many-to-many" D2D communication is more complicated. Most of studies focus on power control unilaterally. Facing the complex relationship of "many-to-many" communication. It is necessary to consider the problem of resource division of cellular users. Therefore, this paper considers the resource allocation and power control algorithm to further solve the complex problem of "many-to-many" multiplexing.

On the basis of the above mentioned documents, this paper presents the following conclusions. Considering the characteristics of D2D communication, a game algorithm of joint power control and resource allocation based on non-cooperative D2D is proposed. In view of the power control problems in D2D networks, establishing a potential game model, at the same time, the users of the reused cellular resources act as the players. According to the interference between systems. Using a cost factor combined with channel gain. Using the best strategy to co-ordinate the transmit power of each D2D terminal, so that the system can better achieve Nash equilibrium. In order to improve the fairness of the system and reduce the interference of the system.

2 System Model and Problem Analysis

2.1 System Model

This paper uses multi-user single-cell uplink power control, there is a BS (Base Station), multiple cellular user equipment CUE (Cell User Equipment), and multiple D2D user equipment DUE (Device User Equipment) in the cell. Among them, DT (Device Transmitter) represents the D2D device transmitter, DR (Device Receiver) represents the D2D device receiver, DUE communicates directly by multiplexing the spectrum resources of CUE, that is, a "many-to-many" multi-D2D device multiplexing multi-cellular user resources model is given. As shown in Fig. 1. It can be seen from the figure that there is no communication interference between each CUE, the BS is interfered by the DT, and the DR is interfered by the CUE and other DTs that reuse the same frequency band resources at this time.

CUE_j represents the j-th CUE, $D2D_i$ represents the i-th pair of D2D users, DR_i represents the receiving end and DT_i represents the transmitting end. When the i-th pair of D2D multiplexes the n-th channel, the SINR is:

$$SINR_i^n = \frac{p_i^n g_{i,i}}{p_j^n g_{j,i} + \sum_{k=1,\, k \neq i}^{K} p_k^n g_{k,i} + N_0} \tag{1}$$

where p_i^n represents the transmission power of the i-th pair of D2D users, p_j^n represents the transmission power of the j-th CUE, p_k^n represents the transmit power of the k-th D2D users multiplexing the n-th channel, $g_{i,i}$ represents the channel gain from the transmitting end to the receiving end of the i-th pair of D2D, $g_{j,i}$ represents the interference channel

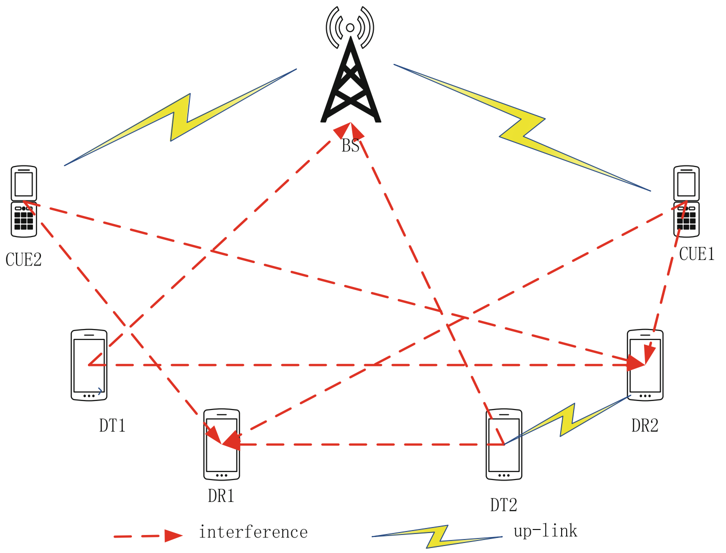

Fig. 1. Uplink D2D communication system model

gain from CUE_j to DR_i, $g_{k,i}$ represents the interference channel gain from DT_k to DR_i, N_0 represents the noise power, $p_j^n g_{j,i}$ represents the CUE interference received when the n-th channel is reused by $D2D_i$, Then the interference of other D2D users can be expressed as $\sum\limits_{k=1,k\neq i}^{K} p_k^n g_{k,j}$.

Therefore, when the i-th pair of D2D users multiplexing the n-th channel, the data rate is expressed as:

$$R_i^n = \log_2\left(1 + SINR_i^n\right) \tag{2}$$

The SINR of the j-th CUE at the base station is as follows:

$$SINR_j^n = \frac{p_j^n g_{j,B}}{\sum\limits_{i=1}^{K} p_i^n g_{i,j} + N_0} \tag{3}$$

where $g_{j,B}$ represents the channel gain from CUE_j to the BS, $g_{i,j}$ represents the gain of the interference channel from DT_i to the BS of the n-th channel of D2D multiplexing, $\sum\limits_{i=1}^{K} p_i^n g_{i,j}$ represents all the interference caused by the DUE in the n-th channel of multiplexing.

Therefore, the data rate of the j-th cellular user at the base station is:

$$R_j^n = \log_2\left(1 + SINR_j^n\right) \tag{4}$$

2.2 Problem Analysis

This paper mainly analyzes the power control problem in the "many-to-many" D2D communication. In this paper, the transmission data rate is the optimization objective, and the mathematical expression of optimization problem can be expressed as follows:

$$\max_{p_i^n, p_j^m} \sum_{i \in N} \sum_{j \in M} \left\{ R_j^m \left(p_i^n, p_j^m \right) + R_i^n \left(p_j^m, p_i^n \right) \right\} \tag{5}$$

$$s.t. \quad 0 \le p_i^n \le p_n^{\max}, \forall i \in N \tag{6}$$

$$SINR_i^n \ge SINR_n^{th}, \forall i \in N \tag{7}$$

$$0 \le p_j^m \le p_m^{\max} \tag{8}$$

$$SINR_j^m \ge SINR_m^{th} \tag{9}$$

$p_n^{\max}$ represents the maximum transmission power of D2D users, $p_m^{\max}$ represents the maximum transmission power of a cellular user. The above formulas (6) and (8) ensure that the transmission power of D2D users and cellular users in the communication system is within the maximum transmission power, $SINR_n^{th}$ represents the minimum SINR threshold required to guarantee the QoS (Quality of Service) of D2D users in the communication system, $SINR_m^{th}$ represents the minimum SINR threshold required to guarantee the QoS of cellular users in the communication system. The above formulas (7) and (9) ensure the communication quality between D2D users and cellular users in the communication system.

Formula (1) is brought into formula (7), which can be deduced as

$$p_j^m \le \frac{p_i^n g_{i,i}}{SINR_n^{th} g_{i,i}} - \frac{N_0 + \sum\limits_{k \in M, k \ne j} p_k^m g_{k,i}}{g_{i,i}} = p_m^{\max 1} \tag{10}$$

According to the above formula (8), it can be concluded that

$$0 \le p_j^m \le p_m^{\max\_th} \tag{11}$$

Among, $p_m^{\max\_th} = \min\left\{ p_m^{\max\_1}, p_m^{\max} \right\}$.

Similarly, substituting (3) in the above formula into (9), we can deduce that

$$p_i^n \le \frac{p_j^m g_{j,B}}{SINR_m^{th} g_{i,j}} - \frac{N_0 + \sum\limits_{k \in N, k \ne i} p_k^n g_{k,j}}{g_{i,j}} = p_i^{n\_\max} \tag{12}$$

It can be seen from the above formula (6)

$$0 \le p_i^n \le p_i^{\max\_th}, \forall i \in N \tag{13}$$

Among, $p_i^{\max\_th} = \min\left\{ p_n^{\max}, p_i^{d\_\max} \right\}$.

3 Joint Power Control and Resource Allocation Game Algorithm Based on Non-cooperative D2D

After the above analysis, D2D communication will increase system interference by reusing frequency resources. In order to solve the above problems, this paper models the resource allocation problem of the D2D system in the uplink as a game theory model. Proposed joint resource allocation and power control algorithm (PRAG), Through resource allocation and power control, the interference between users is coordinated to ensure the good communication performance of each link.

3.1 Utility Function for D2D Users

Based on the game theory model, CUE and DUE can form a pair of trading relationships, as a seller, CUE has channel spectrum resources, DUE as a buyer reuses channel spectrum resources [12]. The reuse process can be expressed as: Multiple CUEs allocate channel resources in advance. At this time, multiple DUEs must select the CUE channel resources that need to be multiplexed. However, how to reuse cue resources requires dues to play games at their own cost. Finally, through the game, DUE obtains the required channel resources and realizes the communication requirements, at the same time, the PRAG algorithm can also better control the interference of D2D users to cellular users, thereby increasing the communication rate of the communication system.

The utility function of D2D users include two parts: income function and cost function. The mathematical formula can be expressed as:

$$U_i\left(p_i^n\right) = B\log_2\left(1 + SINR_i^n\right) - \lambda p_i^n \tag{14}$$

λ represents the power cost factor of D2D users, so the optimization problem required for the utility function is: By matching the transmission power of suitable D2D users and selecting and reusing suitable cellular user channel resources, to make the utility function reach the optimal:

$$\max U_i\left(p_i^n\right) \tag{15}$$

$$s.t.\quad p_{\min} \le p_i^n \le p_{\max} \tag{16}$$

$p_{\min}$ represents the minimum transmit power of D2D user to transmitter, $p_{\max}$ represents the maximum transmit power of D2D user to transmitter, by introducing Eq. (1) into Eq. (14), we get the following result:

$$U_i\left(p_i^n\right) = B\log_2\left(1 + \frac{p_i^n g_{i,i}}{p_j^n g_{j,i} + \sum\limits_{k=1,k\ne i}^{K} p_k^n g_{k,i} + N_0}\right) - \lambda p_i^n \tag{17}$$

Carrying out the p_i^n first-order partial derivative on the above utility function (17), we can get:

$$\frac{\partial U_i\left(p_i^n\right)}{\partial p_i^n} = \frac{B}{\ln 2} \frac{g_{i,i}}{N_0 + p_j^n g_{j,i} + p_i^n g_{i,i}} - \lambda \tag{18}$$

If the first-order partial derivative is 0, we can get:

$$p_i^n = \frac{B}{\lambda \ln 2} - \frac{N_0 + p_j^n g_{j,i}}{g_{i,i}} \tag{19}$$

It can be seen from the above formula that the utility function of D2D users has extreme values. Therefore, to calculate the p_i^n second-order partial derivative of (17), the following formula can be obtained:

$$\frac{\partial^2 U_i\left(p_i^n\right)}{\partial \left(p_i^n\right)^2} = -\frac{B}{\ln 2} \left(\frac{g_{i,i}}{N_0 + p_j^n g_{j,i} + p_i^n g_{i,i}} \right)^2 < 0 \tag{20}$$

Therefore, it can be seen from the above (20) that the utility function of D2D users can have a maximum value. If it is the maximum $p_i^n \in \left[p_{\min}, p_{\max}\right]$, p_i^n is the maximum point of utility function; On the contrary $p_i^n \notin \left[p_{\min}, p_{\max}\right]$, then $p_{\min}$ or $p_{\max}$ is the maximum point of the utility function. According to the derivation of the above formula. It can prove that the Nash equilibrium solution exists and it is unique.

In summary, D2D users reuse all the resources of cellular users, so it can choose the reuse object which can make its utility function maximum, at the same time, it will also determine the transmission power of the D2D user's transmitter.

3.2 Steps of Power Allocation Algorithm

The proposed algorithm not only ensures the maximum throughput of the system, but also takes into account the communication quality of the system. This paper adopts the optimal response strategy design algorithm flow in a decision-making environment. In each iteration, the randomly selected DUE will choose the power allocation scheme with its maximum utility function value. After several iterations, the system will converge to Nash equilibrium. The optimization model of the DUE in the game model is as follows:

$$\min \quad -U_i(s_i, s_{-i}) \tag{21}$$

$$s.t. \quad -p_r^{i,n} \leq 0 \tag{22}$$

$$\sum_{r=1}^{RB} p_r^{i,n} - p_{\max}^n = 0 \tag{23}$$

The ultimate purpose of the above optimization model is to maximize utility functions, and the variables p of the optimization problem are finite sets of real numbers, which are convex sets. According to the above formula (20), the utility function is a concave function, so $-u$ is convex, this optimization problem can be transformed into a convex optimization problem. Because the local solution of the convex optimization problem must be the global solution, Therefore, the solution of the optimization model in this paper is a non-empty convex solution set, so there is an optimal solution.

When solving constrained optimization problems, the constrained optimization problem is transformed into unconstrained optimization problem by using penalty function of constraint condition, the main methods are internal penalty function method and Lagrange multiplier method. When solving convex optimization problems, KKT condition is used to solve the problem, The KKT condition is the necessary and sufficient condition for the optimal solution of convex optimization. Therefore, the optimization problem in this paper can be solved by using KKT of the Lagrange condition.

First construct the Lagrange function:

$$L\left(p_r^{i,n}\right) = -u_i(s_i, s_{-i}) - \lambda p_r^{i,n} - \nu\left(\sum_{r=1}^{RB} p_r^{i,n} - p_{\max}^n\right) \tag{24}$$

The corresponding KKT conditions are as follows:

$$\sum_{r=1}^{RB} p_r^{i,n} - p_{\max}^n = 0 \tag{25}$$

$$\lambda p_r^{i,n} = 0 \tag{26}$$

$$\frac{\partial\left(L\left(p_r^{i,n}\right)\right)}{\partial p_r^{i,n}} = -b\sum_{j=1}^{M} g_{ij,r}^{nm} - b\sum_{j=1,j\neq i}^{N} g_{ij,r}^{nn} + \frac{g_{ii,r}^{nn}}{1 + p_r^{i,n} g_{ii,r}^{nn}} - \lambda + \nu = 0 \tag{27}$$

To sum up, the calculation results are as follows:

$$p_r^{*i,n} = \max\left(\frac{1}{ab-\nu} - \frac{1}{g_{ii,r}^{nn}}, 0\right) \tag{28}$$

$a = \sum_{j=1}^{M} g_{ij,r}^{nm} + \sum_{j=1,j\neq i}^{N} g_{ij,r}^{nn}$, ν constraints for equality, it can be obtained by (25) of the above formula.

The flow chart of power allocation algorithm is shown in the figure below. Firstly, specify an initial value for the transmit power of the D2D terminal. Each iteration randomly selects a user, at the same time, calculate the optimal power distribution plan under this condition. When the number of iterations is more than the preset maximum number of iterations, the calculation is stopped. The condition at this time is that the Nash equilibrium has been reached, other D2D user terminals can no longer obtain better benefits by changing their own strategies (Fig. 2).

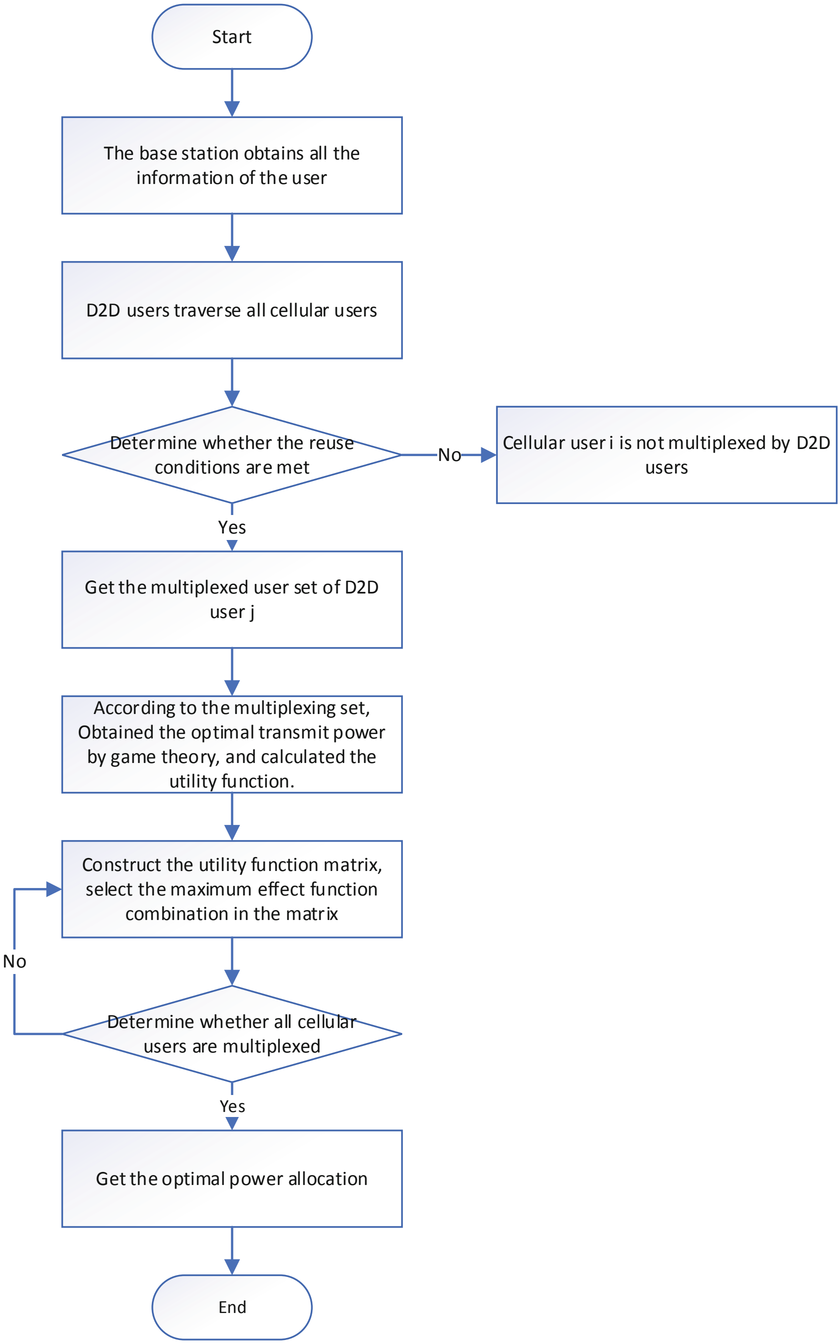

Fig. 2. Flow chart of power control algorithm.

4 Simulation Results and Analysis

This paper assumes that the environment is a single cell environment, cellular users and D2D users are randomly distributed in the cell. The receiver of D2D user is distributed in a 50 m radius circle with the transmitter of D2D user as the center. The cell radius is 500 m. The simulation parameters are shown in Table 1.

Table 1. Values of simulation parameters

Parameter	Numerical value
Cell radius	500 m
System bandwidth	10 MHz
Number of cellular terminals	20
Number of D2D users	20
Path loss between terminals	$148 + 40 \times \log 10(d[km])$
Path loss between terminal and BS	$128.1 + 37.6 \times \log 10(d[km])$
Maximum distance between D2D user pairs	50 m
User maximum transmit power	24 dBm
Noise power spectral density	−174 dBm/Hz
Cellular scheduling algorithm	Polling algorithm
Number of resource blocks	50

In this paper, Matlab is used to simulate and analyze the communication performance, an approximate value is obtained by taking the average value through multiple static simulation analysis. Firstly, setting up an initial network environment. According to the corresponding power control algorithm, resources are allocated for D2D users. Then the throughput of the communication system is calculated by transmitting power, SINR, channel path loss and other parameters.

1. The influence of D2D communication distance of different algorithms on system communication quality
   This paper simulates and compares three algorithms, Power and Resource Allocation Game algorithm (PRAG), Joint power control and resource allocation game algorithm based on non-cooperative D2D (NC-PRAG) and Random algorithm (RA). As shown in Fig. 3 below, comparative analysis of the changes in the utility function of different algorithms when the communication distance changes. It can be seen from the figure that when the communication distance increases, the utility function decreases, The closer the distance, the better the communication effect. By analyzing the three algorithms. The communication quality of RA is the lowest, followed by PRAG, and the algorithm NC-PRAG proposed in this paper is better. It can be seen that when D2D users change with distance, the communication effect will decrease, but the communication quality can be improved by reasonable power control and resource allocation.

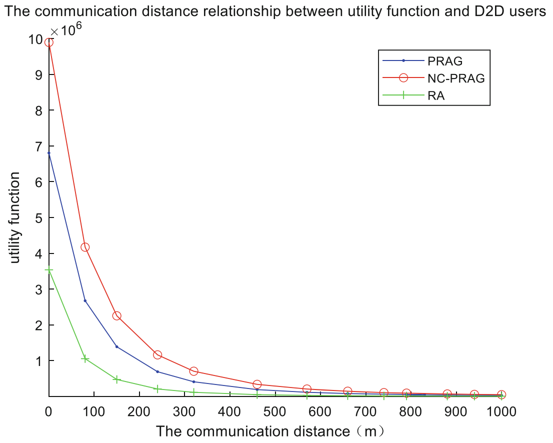

Fig. 3. Variation curve of communication quality with D2D communication distance

2. The influence of D2D communication distance of different algorithms on transmission power
   As shown in Fig. 4 below, analyzed and compared the transmission power of different algorithms with the change of communication distance. It can be seen from the figure that with the increase of communication distance, the transmission power of the system will also increase. Through simulation comparison, the transmission power of the RA algorithm increases faster. When the PRAG algorithm is introduced, the increase of transmission power decreases obviously. The NC-PRAG algorithm proposed in this paper further reduces the transmission power and saves the waste of transmission resources. Therefore, the algorithm proposed in this paper can reduce the waste of resources and improve the utilization of the system on the premise of ensuring the quality of communication.

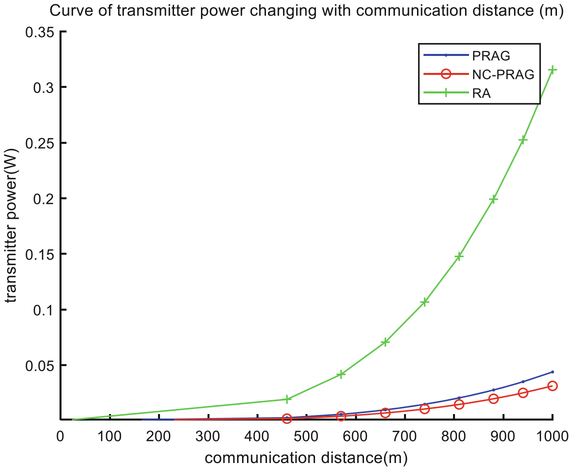

Fig. 4. Transmission power variation curve with communication distance

3. The influence of different algorithms on system delay.
   As shown in Fig. 5 below, the simulation analyzes the system delay changes under three different algorithms. It can be analyzed from the figure below that compared to the RA algorithm, both the PRAG algorithm and the NC-PRAG algorithm significantly reduce the system delay. The system delay is increased by 1.25 times and 1.38 times respectively. It improves the transmission rate of communication system better, compared with the PRAG algorithm, the NC-PRAG algorithm is also improved by 1.1 times. The system delay is reduced accordingly. The simulation results show that NC-PRAG algorithm can better reduce system delay and increase transmission rate.

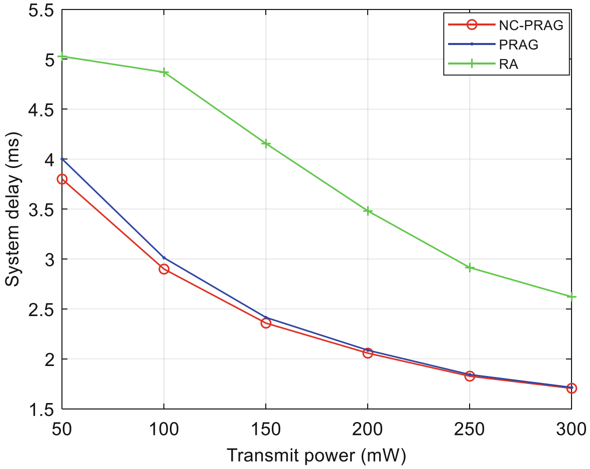

Fig. 5. System delay variation curve

5 Conclusion

With the development of modern wireless communication technology, D2D communication technology has become a research hotspot of a new generation of communication technology. It has become an urgent problem to be solved in D2D communication in terms of solving its spectrum utilization, improving communication quality, improving system fairness, and reducing system delay. This paper proposes a non-cooperative D2D joint power control and resource allocation game algorithm based on the above problems. The "many to many" D2D communication system is designed, Firstly, this paper improves the utility function of the algorithm, which is the product of the throughput and the terminal usage time of the communication system, and optimizes the utility function. Secondly, combined with D2D power control and resource allocation problems, a potential game model is established, and the theory proves that the Nash equilibrium point of this method exists and is unique. The simulation results show that, introduced the algorithm into the D2D communication system. On the basis of ensuring the communication quality, it greatly improves the throughput and fairness of the system, and reduces the system delay. Through system simulation, compared with the random algorithm, the transmission power of the system is reduced by 87.5%, and compared with the joint power control and resource allocation algorithm by 33.4%; Compared with the random algorithm, the throughput of the system is increased by 4.6 times, and compared with the joint power control and resource allocation algorithm by 1.91 times; The system delay is also reduced by 1.38 times and 1.1 times. Therefore, the non-cooperative D2D joint power control and resource allocation algorithm proposed in this paper is obviously better than the comparison algorithm.

References

1. Zhao, S., Feng, Y., Yu, G.: D2D communication channel allocation and resource optimization in 5G network based on game theory. Comput. Commun. **169**, 26–32 (2021)
2. Mohammed, V., Sreenivasa, P.M., Ravishankar, T., et al.: Energy efficient resource allocation for device-to-device communication through noncooperative game theory. Int. J. Commun. Syst. **33**(5), e4279 (2020)
3. Hao, X., Gong, Q., Hou, S., Liu, B.: Joint channel allocation and power control optimal algorithm based on Non-cooperative game in wireless sensor networks. Wireless Pers. Commun. **78**(2), 1047–1061 (2014)
4. Adiwal, M., Singh, N..P.: RAT selection for a low battery mobile device for future 5G networks. Int. J. Commun. Syst. **32**(13), e4055.1-e4055.17 (2019)
5. Shrivastava, T., Pandey, S., Mishra, P. K., Verma, S.: A non-cooperative game theoretic approach for resource allocation in D2D communication. In: Chiplunkar, N.N., Fukao, T. (eds.) Advances in Artificial Intelligence and Data Engineering. Advances in Intelligent Systems and Computing, vol. 1133, pp. 1323–1334. Springer, Singapore (2021). https://doi.org/10.1007/978-981-15-3514-7_99
6. Sun, Y., Miao, M., Wang, Z., Liu, Z.: Resource allocation based on hierarchical game for D2D underlaying communication cellular networks. Wireless Pers. Commun. **117**(2), 281–291 (2021)
7. Najeh, S., Bouallegue, A.: Game theory for SINR based power control in device-to-device communications. Phys. Commun. **34**, 135–143 (2019)
8. Zhang, S., Peng, Y.: D2D communication relay selection algorithm based on game theory. Procedia Comput. Sci. **166**, 563–569 (2020)
9. Sn, A., Ab, B.: Distributed vs centralized game theory-based mode selection and power control for D2D communications - ScienceDirect. Phys. Commun. **38**(C), 100962 (2020)
10. Wang, F., Son, L.Y., Han, Z., et al.: Joint scheduling and resource allocation for device-to-device underlay communication. In: Wireless Communications and Networking Conference (WCNC), Shanghai, China, pp. 134–139. IEEE (2013)
11. Wang, F., Xu, C., Song, L.Y., et al.: Energy efficient radio resource and power allocation for device-to-device communication underlaying cellular networks. In: International Conference on Wireless Communications and Signal Processing (WCSP), Huangshan, China, pp. 1–6. IEEE (2012)
12. Jiang, Y., Liu, Q., Zheng, F., et al.: Energy-efficient joint resource allocation and power control for D2D communications. IEEE Trans. Veh. Technol. **65**(5), 6119–6127 (2016)
13. Zhou, Z., Dong, M., Ota, K., et al.: Game-theoretic approach to energy-efficient resource allocation in device-to-device underlay communications. IET Commun. **9**(3), 375–385 (2015)