Research on Relay Selection Algorithm for Joint D2D Mode Selection and Resource Allocation

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Abstract

For the setup considered in this work, D2D communication cannot be performed due to poor channel quality of D2D users, relay-assisted D2D communication technology was successively proposed. This paper proposes a two-stage relay selection algorithm with low computational complexity, joins mode selection and D2D resource allocation, maximizes system throughput while maintaining users communication quality. First of all, considering whether the D2D user needs to relay. Secondly, adjusting the location and residual energy factors of idle users by weighting, selecting the optimal relay node for the user who needs to relay. Finally, the optimal spectrum resource is selected for the two-hop communication link through the first-level sealed quotation auction mechanism. The simulation results show that compared with the algorithm based on region division, the proposed algorithm for maximizing system throughput in this paper, which not only meets the actual requirements, but also can expand the network coverage and improve the system throughput.

Keywords: Mode selection, Relay selection, Residual energy, Resource allocation, Throughput

1 Introduction

With the rapid growth of mobile multimedia services and the number of mobile communication devices, the demand of spectrum resources in system networks is becoming intense [1-2]. Traditional D2D communication (under the control of cellular system, two close users can directly communicate without passing through a base station), as one of the key technologies of future wireless communication networks, has significant effects in mitigating base station load, improving spectrum efficiency, increasing system throughput and reducing transmission delay [3-4]. However, due to limitations of the spatial distance of D2D communication and the quality of the channel link, D2D communication cannot be performed, as well as the problem of same-frequency interference when reusing the spectrum resources of the cellular users, the relay-assisted communication technology is applied to D2D communication. And relay nodes that meet the actual application requirements are selected from a large number of idle users to assist communication was successively proposed. It can effectively improve the D2D communication quality, anti-interference ability, and network throughput [5-9].

In recent years, there have been many studies on relay selection and resource allocation. How to choose the optimal relay is a key issue, [10] selected the optimal relay through the system energy efficiency evaluation index, which significantly reduces the energy consumption of the system compared with the traditional fixed relay assist mode. But [10] only considerd a single energy consumption factor. In [11], a cooperative system model was proposed, which considered the distance and social relationship factors to select the optimal relay to improve the performance of D2D cooperative communication. In [12], a new cooperative relay mode of D2D was established, by utilizing two social factors: social ties and reputation. However, the above research did not consider the spectrum resource allocation problem of the two-hop communication link. [13] proposesd a two-level distributed algorithm to maximize the cell edge users throughput, that is, firstly, using Stackelberg to select relays in the inner layer, where the relay is the leader, the cell edge user is the follower, secondly, allocating resource for the communication link based on the interference limitation in the outer layer. [14] optimized system throughput through joint consideration of mode selection and relay selection, decomposed it into two parts and transferred mode selection and relay selection into the maximum weighted independent set problem. [15] proposed a novel time reuse model to manage spectrum resource in D2D cooperative communication. And filtered relays based on the user's wishes, users with sufficient spectrum are selected as relays, but [15] only considered spectrum resource and did not consider users' energy. In addition, the above research did not consider reducing the number of candidate relay users in the process of relay selection. [16] proposed a two-stage

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relay selection and resource allocation joint scheme to maximize system throughput and determined the optimal reusing resource of the two-hop communication link. However, none of the above papers considerd the key issue of whether D2D users need to relay in practical application scenario, which caused a waste of resource to a certain extent. [17] proposed a novel cooperative USV-UAV platform and improved the collaboration capabilities of coupled system. Although considering the impact of airflow on USV, it did not consider the willingness of SUV.

The above related research did not consider whether the user needs relay-assisted communication in the relay selection process. And only the ability of idle users to relay was considered, ignoring the willingness of idle users in the actual application scenario. In addition, the user equipment is powered by the battery, energy needs to be continuously consumed in the communication process. Based on the above problems, in order to maximize system throughput and reduce the computational complexity of optimal relay selection, this paper proposes a two-stage relay selection algorithm for joint mode selection and resource allocation. That is, firstly, determining whether the user needs to relay for assisted communication, secondly, selecting an optimal relay for the user who needs to relay. In the first stage of relay selection, the geographic location and the residual energy of the idle users are filtered to determine candidate relay users, so as to reduce the number of candidate relay users and reduce the computational complexity of relay selection. In the second stage, the geographic location and residual energy of the idle users are weighted, according to the actual situation, considering the geographical location and the residual energy comprehensively, selecting the optimal relay smartly. Finally, based on the first-level sealed quotation auction mechanism, the optimal reusing link is selected for the two-hop communication link. The scheme minimizes the number of candidate relay users, reduces the computational complexity of relay selection, and improves the network coverage and system throughput.

2 System Model and Problem Formulation

2.1 System Model

Consider a single cell relay-assisted D2D communication scenario, and establish a system model as shown in Figure 1. The system includes a base station (BS) located in the center of the cell, M cellular users are denoted by the set C={1, ⋯, c, ⋯, M}, N D2D user pairs (TX-RX) are denoted by the sets D_T={1, ⋯, d_t, ⋯, N}, D_R={1, ⋯, d_r, ⋯, N}, and $D_T \in D$, $D_R \in D$, $D_T \cap D_R = \varnothing$, L idle cellular users as candidate relays (RS) are denoted by the set R={1, ⋯, r, ⋯, L}. The specific interference situation is shown in Figure 1: Since the base station allocates orthogonal resources for each cellular user, and deploys orthogonal frequency division multiple access (OFDMA) technology for D2D users, there is no interference between ~~the~~ cellular users, and there is no interference between D2D user pairs. In order to improve the utilization of the spectrum resources, the D2D users share the uplink spectrum resources of the cellular users through the non-orthogonal mode, so in the D2D direct communication or the relay-assisted communication mode, the D2D users will interfere the cellular users who are reused resources. That is, when DT1 performs relay-assisted communication with DR1 through RS, the DT1-RS link completes communication by reusing C1's spectrum resource, at this time, DT1 will interfere with the BS and C1 will interfere with the RS; Similarly, the RS-DR1 link completes communication by reusing C2's spectrum resource, the RS will interfere with the BS, and C2 will interfere with DR1. When DT2 and DR2 communicate directly by reusing C4's spectrum resource, DT2 will interfere with the BS and C4 will interfere with DR2. It is assumed that the base station can acquire channel state information of all links, and in the channel model consider Rayleigh fading.

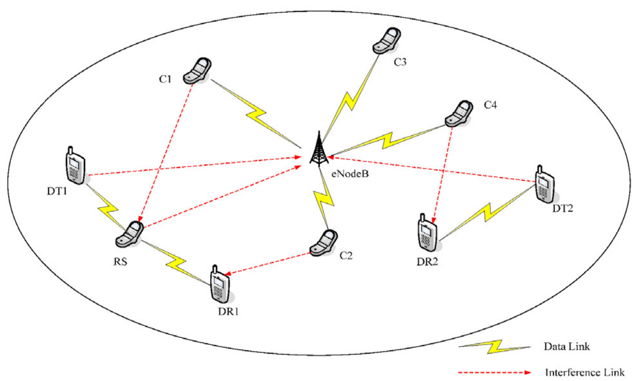

Figure 1. System model

The paper assumes that there are two communication modes between D2D users: D2D direct communication mode and relay-assisted communication mode. The D2D direct communication mode refers to direct communication between D2D users without going through the RS. When a D2D user directly communication by reusing cellular user uplink spectrum resource, the signal to interference and noise ratio (SINR) of the BS and the D2D RX are respectively expressed as formula (1). Where P_c and P_{d_t} are the transmit powers of the cellular user and D2D TX, respectively. H_{cB} 、H_{d_tB} 、$H_{d_td_r}$ and H_{cd_r} are the channel gains of the cellular user to the BS, the D2D TX to the BS, the D2D TX to the D2D RX, and the cellular user to the D2D RX, respectively. N is the additive Gaussian white noise unilateral power spectral density, and it is the same for all receivers.

$$\gamma_B^1 = \frac{P_c H_{cB}}{P_{d_t} H_{d_t B} + N}$$
$$\gamma_{d_r}^1 = \frac{P_{d_t} H_{d_t d_r}}{P_c H_{c d_r} + N} \quad (1)$$

The relay-assisted communication: the D2D user performs two-hop link transmission through the RS, the D2D TX to the RS is the first hop link, the RS to the D2D RX is the second hop link. The cellular users corresponding to the RBs reused by the first hop link and the second hop link are respectively recorded as c_T and c_R, and $c_T \in c$, $c_R \in c$, $c_T \cap c_R = \emptyset$. The RS uses decode-and-forward relay strategy to assist D2D user communication. The specific communication process is shown in Figure 1: Firstly, D2D TX sends the signal to the RS, secondly, the RS forwards the signal to the D2D RX. Each RS can only serve one D2D user pair, and each D2D user pair can only utilize one RS. Therefore, on the first hop link, the SINR of the RS and the cellular user are respectively expressed as:

$$\gamma_r = \frac{P_{d_t} H_{d_t r}}{P_{c_T} H_{c_T r} + N}$$
$$\gamma_{c_T} = \frac{P_{c_T} H_{c_T B}}{P_{d_t} H_{d_t B} + N} \quad (2)$$

Where P_{c_T} is the transmit power of cellular user c_T, $H_{d_t r}$, $H_{c_T r}$ and $H_{c_T B}$ are the channel gains of D2D TX to RS, cellular user c_T to RS, and cellular user c_T to BS, respectively. On the second hop link, the SINR of the D2D RX and the cellular user are respectively expressed as formula (3). Where P_r and P_{c_R} are the transmit powers of the RS and cellular user c_R, respectively. H_{rd_r}, $H_{c_R d_r}$, $H_{c_R B}$ and H_{rB} are the channel gains of RS to D2D RX, c_R to D2D RX, c_R to BS, and RS to BS, respectively.

$$\gamma_{d_r} = \frac{P_r H_{rd_r}}{P_{c_R} H_{c_R d_r} + N}$$
$$\gamma_{c_R} = \frac{P_{c_R} H_{c_R B}}{P_r H_{rB} + N} \quad (3)$$

2.2 Problem Formulation

The purpose of this paper is to maximize system throughput through relay-assisted communication, reduce computational complexity, and ensure the communication quality of D2D users and cellular users. The binary variable χ_{mr} is used to define the mode selection and the allocation of the two-hop link resources, $\chi_{mr} \in \{0, 1\}$, when the D2D TX communicates with the D2D RX through the RS, and the two-hop communication link reuse the resources of the cellular user c_T and c_R, respectively, $\chi_{mr}=1$, otherwise $\chi_{mr}=0$. Based on the above analysis, the data rates of the cellular link and the D2D link are expressed as:

$$R_C = (1-\chi_{mr}) R_C^d + \chi_{mr} R_C^r$$
$$R_D = (1-\chi_{mr}) R_D^d + \chi_{mr} R_D^r \quad (4)$$

Where

$$R_C^d = B\log_2\left(1+\gamma_B^1\right) \quad (5)$$

$$\mathrm{R}_\mathrm{C}^\mathrm{r} = \mathrm{R}_{\mathrm{c_T}} + \mathrm{R}_{\mathrm{c_R}} = \frac{B}{2}\log_2\left(1+\gamma_{\mathrm{c_T}}\right) + \frac{B}{2}\log_2\left(1+\gamma_{\mathrm{c_R}}\right) \quad (6)$$

$$R_D^d = B\log_2\left(1+\gamma_{d_r}^1\right) \quad (7)$$

$$R_D^r = \min\left\{R_r, R_{d_r}\right\} \quad (8)$$

$$R_r = \frac{B}{2}\log_2\left(1+\gamma_r\right) \quad (9)$$

$$R_{d_r} = \frac{B}{2}\log_2\left(1+\gamma_{d_r}\right) \quad (10)$$

The optimization problem proposed in this paper is expressed as:

$$\max_{\{\chi_{mr}\}} \sum_{c=1}^{M}\sum_{d=1}^{N}\left(R_C + R_D\right) \quad (11)$$

$$\begin{aligned}
s.t.\, C1 &: 0 \le P_c, P_{d_t}, P_r \le P^{\max}, \\
&\forall c \in C, d_t \in D_{T,} r \in R \\
C2 &: \sum_{r\in R, c\in C, d\in D} \chi_{mr} \le 1 \\
C3 &: \sum_{r\in R, c\in C} \chi_{mr} \le 1, \forall d \in D \\
&\sum_{d\in D, c\in C} \chi_{mr} \le 1, \forall r \in R \\
&\sum_{r\in R, d\in D} \chi_{mr} \le 1, c \in C \\
C4 &: R_D^d \ge R_D^{\min}, R_r \ge \frac{1}{2}\chi_{mr} R_D^{\min}, \\
&R_{d_r} \ge \frac{1}{2}\chi_{mr} R_D^{\min}, \\
&\forall d \in D, d_t \in D_t, d_r \in D_r \\
C5 &: R_C^d \ge R_C^{\min}, R_{c_T} \ge \frac{1}{2}\chi_{mr} R_C^{\min}, \\
&R_{c_R} \ge \frac{1}{2}\chi_{mr} R_C^{\min}, \forall c, c_{T,} c \in C
\end{aligned} \quad (12)$$

C1 indicates the range of transmit power of the user, where $P^{\max}$ is the maximum transmit power; C2 indicates the D2D user pair can only select one of either D2D direct communication mode or the relay-assisted communication mode; C3 indicates a one-to-one correspondence relationship between the D2D pair, the RS, and the two-hop link reused cellular users, that is, a RS node can only assist one D2D user pair to communicate at most, one cellular user can only be reused by one D2D communication link; C4 and C5 guarantee the communication quality of the D2D and the cellular link, where $R_D^{\min}$ and $R_C^{\min}$ are the data rate thresholds of the D2D and the cellular link, respectively.

3 Two-stage Relay Selection and Optimal Link Selection

Obviously, the optimization goal of this paper is a non-convex joint optimization problem, the reasons are as follows: (1) the variable χ_{mr} is a binary variable; (2) both R_C and R_D in the optimization problem are related to χ_{mr}, that is, the results of communication mode selection and optimal link selection will affect throughput; 3. R_C and R_D in the objective function and constraints, the original problem are not convex; 4. the optimization goal has a large size, because the increasing number of users will make the number of variables become large. And the computational complexity of the resource allocation algorithm is too high, which will lead to relay transmission delay. In order to solve the above problems, this paper proposes a two-stage relay selection and optimal link selection algorithm. Considering whether the D2D user needs relay-assisted communication. Then proposing a new optimal relay selection metric, according to the actual situation. Weighting and adjusting the location and residual energy of idle users, and the optimal relay is selected for the D2D user who needs to relay. Finally the optimal reusing resource is allocated for each hop communication link based on the first-level sealed quotation auction mechanism.

3.1 Mode Selection

If all idle users participate in the assist D2D user communication, the overall performance of the system can be improved. However, some D2D users who can achieve single-hop transmission also use relay-assisted communication, which causes waste of resources. There are also some idle users who have a negative impact on the system. Therefore, as shown in Figure 2, this paper first consider whether D2D users need relay-assisted communication. $R_D^r > R_D^d$ is the standard of relay-assisted D2D communication (The fixed base station is used as a relay node to implement relay-assisted communication, and select idle cellular users to reuse their spectrum resources). When D2D users choose relay-assisted communication to achieve a data rate greater than D2D direct transmission, the relay-assisted D2D communication is used, otherwise the user performs D2D direct communication. which is:

$$\chi_{mr} = \begin{cases} 1, R_D^r > R_D^d \\ 0, R_D^r \le R_D^d \end{cases} \quad \textbf{(13)}$$

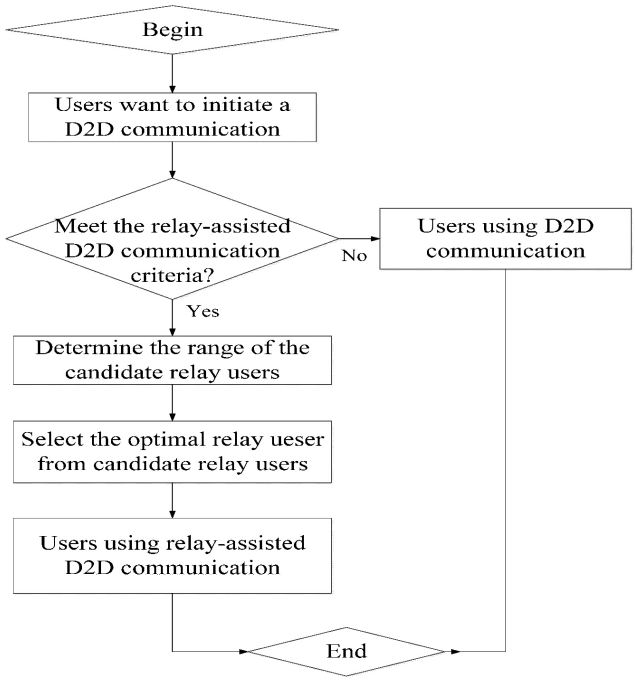

Figure 2. D2D relay assisted communication establishment process

When the user satisfies the relay-assisted D2D communication standard, the first stage we select the candidate relay users, thereby reducing the number of candidate relay users and the complexity of the relay selection; the second stage select the optimal relay users from the candidate relay users.

3.2 Optimal Relay Selection

3.2.1 Select Candidate Relay Users

A: Select Candidate Relay Users Based on Geographic Location

The goal of the first stage is to select candidate relay users, reducing the number of candidate relay users and the computational complexity of optimal relay selection. Firstly, the users who are transmitting data are not considered, that is, the relay users must be idle; Secondly, most current research on selection strategies have idealized idle users, that is, idle users are willing to assist D2D users, and the actual situation of idle users is not considered. However, if the willingness of idle users to assist D2D communication is not strong, the user experience and the communication quality will be poor. Therefore, this paper considers that users with close geographical location have strong contact, and the willingness to assist D2D users is stronger. When the system network layout is determined, the location of each user is also generally determined, a circular area H is set, centered on the midpoint *O* of the distance between D2D user pair, and a quarter of the distance L_D between D2D user pair is the radius. According to the above analysis, the idle user located in the area H can be used as a candidate relay user, that is, the idle user should satisfy:

$$L(O,r) \le \frac{L_D}{4} \tag{14}$$

B: Select Candidate Relay Users Based on Residual Energy

When selecting candidate relay users, not only the willingness of idle users but also the ability to assist D2D communication should be considered. In actual application scenario, there are situations where idle users carry limited battery energy, due to communication exhaustion and user equipment damage, so that the idle users cannot continue to assist the D2D communication. Therefore, this paper considers that when the residual energy E of the idle user is greater than the threshold E_{min}, that is, $E>E_{min}$, it indicates that the idle user can complete data forwarding.

According to the channel energy mode of [16], the transmission distance is P, and the energy required to transmit Q-bit data can be expressed as:

$$E(P,Q) = QE_e + \varepsilon QP^4 \tag{15}$$

Where E_e is the circuit loss constant and ε is the energy consumption coefficient. Assuming that the current energy of the idle user is E_t, the residual energy after the idle user forwards the data can be expressed as:

$$E_s = E_t - E(P,Q) \tag{16}$$

3.2.2 Select the Optimal Relay User

When selecting the optimal relay user, if only a single dimension is considered, the optimal relay user selected cannot meet the requirements of the real application scenario. Therefore, this paper proposes a new optimal relay selection metric, weighting the geographic location and residual energy of idle users, select the optimal relay users who have the willingness to assist D2D users, as well as with the ability to maintain energy balanced consumption and improve communication quality. The optimal relay selection metric is expressed as:

$$R^* = \alpha L(O,r) + \beta E_s \tag{17}$$

where α and β are weight coefficients. In the actual application scenario, if there is a candidate relay user with the smallest distance and the largest residual energy, it is determined to be the optimal relay user. If not, the appropriate optimal relay user is selected by adjusting the weights of α and β. When the idle user is close to the center of area H, the weight is adjusted so that β»α, the residual energy of the idle user becomes the dominant factor; When the residusal energy of the idle user is sufficient, the weight is adjusted such that α»β, ignoring the influence of the residual energy on the optimal relay user selection.

In summary, the two-stage relay selection algorithm for joint mode selection proposed in this paper is described as follows:

Step 1: Assuming that the base station can acquire the position coordinates and channel state information of all users, and get D2D users set D and idle cellular users set R ;

Step 2: The D2D user $j(j \in d)$ initiates a communication request, calculating its data rate in two communication modes according to formula (7) and (8) respectively, then deciding whether it satisfies the standard of relay-assisted D2D communication according to formula (13), if not, the user performs direct communication, if satisfied, relay-assisted D2D communication, and put it into set D_r ;

Step 3: Repeating step 2, traversing set D to find all D2D users who need relay-assisted communication, and put them into set D_r;

Step 4: Set a circular area H with the center point of the D2D user pair j`( $j` \in D_r$) as the center, a quarter of the distance between users as radius. Traversing set R and identifing all idle cellular users in area H as candidate relay users. Then calculating the distance L(*O*, r) between each candidate relay user and the center of area H, and according to the size of L(*O*, r), rank the candidate relay users in descending order into set R_1 ;

Step 5: According to formulas (15) and (16), Calculating the residual energy E_s of each user in set R. Setting the users whose residual energy is greater than the threshold as candidate relay users, and according to the size of E_s, arranging the candidate relay users in descending order into set R_2 ;

Step 6: Putting the users that appear in both the sets R_1 and R_2 into the set R_3;

Step 7: If there is a nearest candidate relay user in set R_3, the residual energy is also the largest, the candidate relay user is determined to be the optimal relay user. If not, according to formula (17) based on the optimization principle, traversalling set R_3 the candidate relay user whose L(O, r) value is small and whose E value is large is determined to be the optimal relay user ;

Step 8: Repeating steps 4-7, traversalling the set D_r to get the optimal relay user for each user.

3.3 Optimal Link Selection

Aiming at the problem that the number of cellular users that can be reused in the two-hop communication link is large and the computational complexity is high, in this paper, the first-level sealed quotation auction mechanism is adopted to select the optimal spectrum resource of the two-hop communication link, that is, the sender of the first hop link D2D user and the second hop link optimal relay user are auctioneers, and the cellular users corresponding to the reusable spectrum resources act as bidders, the quotations are sealed and separately handed over to the auctioneers, each user can only quote once, and the auctioneer selects one of the highest quotes among all the quotes as the reused cellular user. The solution is to maximize system throughput while ensuring the communication quality of cellular and D2D users. Therefore, in the first hop communication link, the reciprocal of the interference caused by the reused cellular user to the receiver relay is used as the quotation. Similarly, in the second hop communication link, the reciprocal of interference caused by the reused cellular user to the D2D receiver is used as the quotation, the quotes of the two-hop link are expressed as:

$$J_1 = \frac{\gamma_r}{P_{d_t} H_{d_t r} - N\gamma_r}$$
$$J_2 = \frac{\gamma_{d_r}}{P_r H_{rd_r} - N\gamma_{d_r}} \quad \textbf{(18)}$$

4 Simulation and Performance Analysis

In order to verify the impact of the optimal relay selection and link selection algorithm proposed in this paper on system performance, Matlab is used to simulate and analyze. The simulation scenario is shown in Figure 3. Each user in the system is randomly arranged. The simulation parameter settings are shown in Table 1.

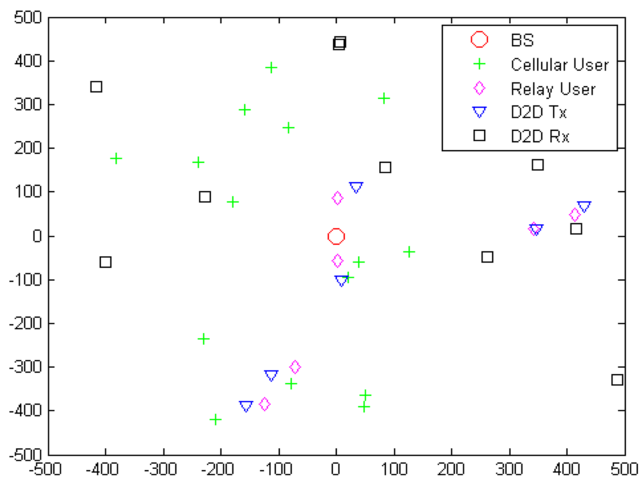

Figure 3. Simulation scenario

The optimization goal of this paper is to maximize the system throughput. As shown in Figure 4, throughput varies with SINR threshold as the number of D2D pairs increases, in the figure, $SINR_1$ and $SINR_2$ are the SINR thresholds of the cellular and D2D users, respectively. Overall, the system throughput is

Table 1. Simulation parameters

parameter	value
Cell radius (m)	500
System bandwidth (MHz)	10
Road loss coefficient	4
Gaussian white noise / (dBm / Hz)	-174
Cellular user transmit power / dBm	46
D2D user transmit power / dBm	24
Minimum SINR /dB for cellular users	Uniform distribution between [0, 25]
Minimum SINR /dB for D2D users	Uniform distribution between [0, 25]

increased with the increase of D2D pairs, but decreases with the increase of the SINR threshold. The more D2D pairs means that the system will access more D2D pairs to communicate, and the throughput will increase accordingly. Moreover, the proposed algorithm introduces a competitive relationship when determining the spectrum resources reused by two-hop communication links, which effectively reduces the interference between D2D links and cellular links, and greatly improves the utilization of the spectrum resources. As the threshold increases, the interference that the user can endure becomes smaller, and it is more difficult to determine the spectrum resources that can be reused in D2D links, so the fewer D2D pairs that the system can access, the correspondingly decreases the system throughput.

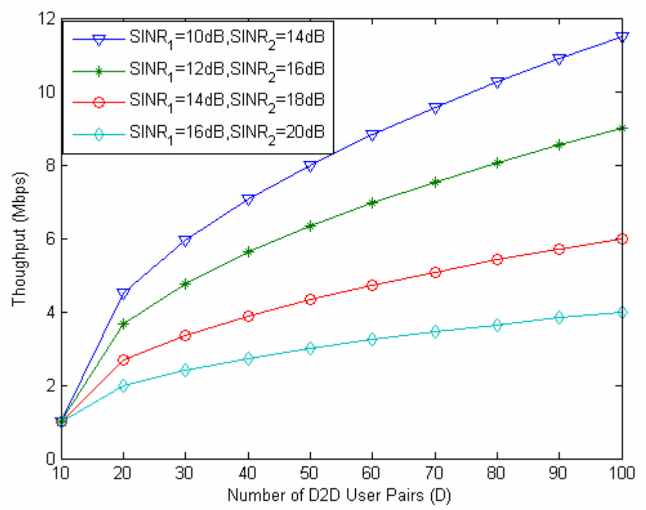

Figure 4. Relationship between throughput and SINR threshold

Relay-assisted D2D communication can increase network coverage and improve system throughput. Figure 5 shows the variation of system throughput with the number of idle users under different communication schemes. When the user selects the cellular mode for communication, there is no need to select a relay node, therefore, the number of idle users has no effect on system throughput. The random selection algorithm, the reference algorithm based on region divisioning maximization throughput in the reference [14] and the proposed algorithm need to be relayed to participate in cooperative communication. The more idle users, the more optimal relays that can be selected, the higher the probability of relay-assisted D2D communication, the greater the network coverage. So the throughput of the system will increase with the increase of the number of idle users. The Random Selection algorithm does not have a relay selection criterion, the quality of the selected relay user is not uniform, and can not meet the communication requirements, so the throughput under this scheme is the smallest; The Reference algorithm only considers the geographical location factor when selecting the relay, the selected relay may not be able to assist the D2D communication, so the relay-assisted D2D communication quality is poor; Proposed algorithm considers the geographical location and residual energy of idle users when selecting relay, the selected relay is suitable for practical applications, and D2D communication coverage is large. In addition, we can see from the Figure 5, as the number of idle users increases, the difference in system throughput becomes more apparent. This is because when the number of idle users is small, the candidate relay node has less reserve, the condition limit cannot select more relay nodes, when the number of idle users is large, the number of optimal relays selected from the candidate relay users is increased.

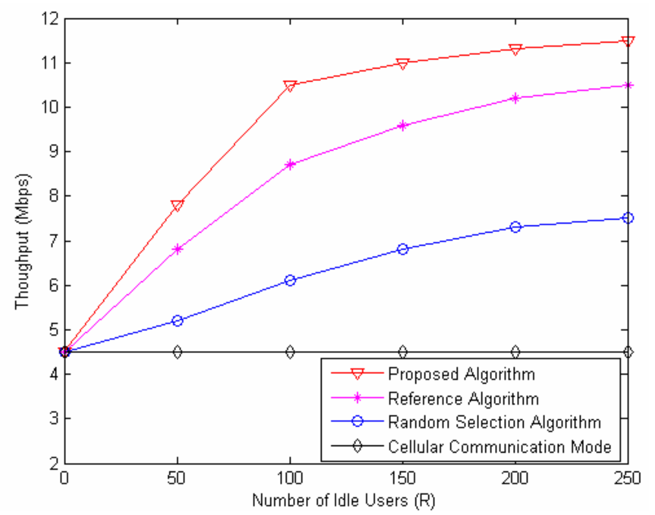

Figure 5. Relationship between throughput and number of idle users

Figure 6 shows the relationship between the system throughput and the threshold of the idle user's residual energy. When the user communicates by cellular mode, there is no relay selection process, so the system throughput does not change with the residual energy threshold. The relay selection criteria of the Random Selection algorithm and the Reference algorithm do not involve residual energy, so the residual energy threshold has no effect on system throughput. In the Proposed algorithm, as the residual energy threshold is larger, fewer users can be selected as candidate relays, the possibility of assisting D2D communication is reduced, and the network coverage is reduced, therefore, the throughput curve is gradually declined.

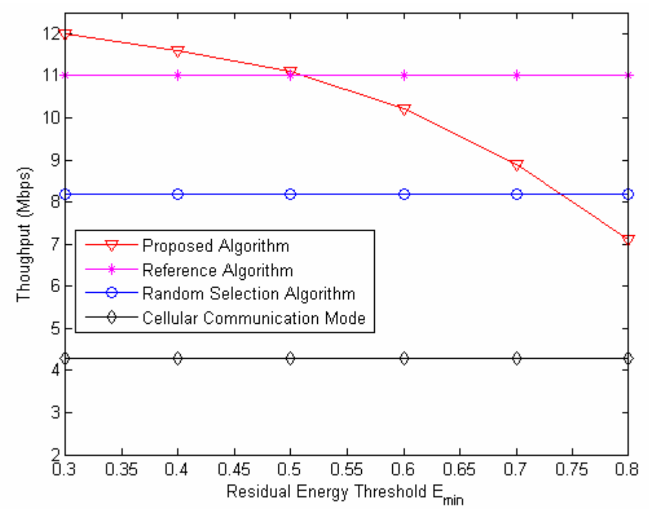

Figure 6. Relationship between throughput and residual energy threshold

As shown in Figure 7, the relationship between the d_{TR} and the system throughput is shown, d_{TR} is the distance between D2D TX and D2D RX. When d_{TR} is small, the system throughput of the Proposed algorithm is close to Direct communication, which is significantly better than the Reference algorithm, this is because when d_{TR} is small, the optimal communication mode is D2D direct communication. As d_{TR} gradually increases, D2D users can only achieve direct communication by increasing the transmit power, while causing greater interference to cellular users, system performance is reduced, and system throughput is declining. In addition, when d_{TR} is large, D2D users tend to choose relay-assisted communication, at this time, the advantages of relay-assisted D2D communication are fully embodied. When there are more candidate links c which can be reused by the D2D user, the system throughput is correspondingly higher, because the optimal reusing link is easily selected from more candidate links.

5 Conclusion

This paper proposes a two-stage relay selection algorithm for joint mode selection and resource allocation, aiming at the problem that D2D users cannot communicate directly because of poor channel quality in practical applications. Firstly, the algorithm determines whether D2D users need relay-assisted communication, then selecting candidate relay users based on the location and residual energy of idle users to reduce the range of candidate relay users, and then weighting the geographical location and residual energy of candidate relay users to select the optimal relay users intelligently, finally, based on the first-level sealed quotation auction mechanism, the optimal

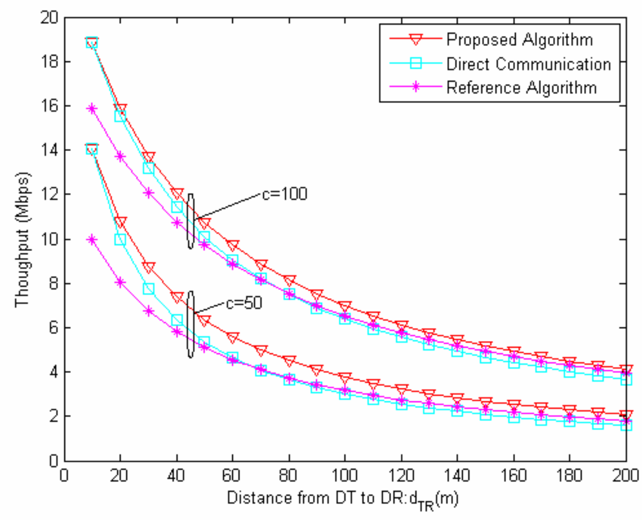

Figure 7. Relationship between throughput and d_{TR}

spectrum resource reused by the two-hop communication link is determined.

The algorithm proposes communication mode selection to minimize the waste of resource to improve spectrum utilization; Then, based on the practical application scenario, considering the willingness and the ability of idle users to assist D2D communication, the candidate relay users with strong willingness are selected to improve the quality of users communication, and eliminating candidate relay users who are unable to assist communication caused by factors such as insufficient power, which effectively reduces the competition among candidate relay users and the probability of network outages. In addition, the first-level sealed quotation auction mechanism can effectively solve the problem of multiple communication links simultaneously selecting the same spectrum resource. The simulation results show that the algorithm has better performance and can effectively improve the system throughput.

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Appendix

1. Computational Complexity Analysis

Suppose that it is necessary to allocate spectrum resources to N relay-assisted D2D communication links, then 2N communication links need spectrum resources to achieve communication, the data rate of each communication link is R, and M cellular users can choose. The traditional spectrum resource allocation method, for any communication link, selecting a cellular user to share its spectrum resource and ensure the user's communication quality, the complexity of this process is $O(MR)$. After each communication link obtains spectrum resource, it is necessary to determine which cellular user to maximize system throughput. The complexity of this selection process is $O(M\log(M))$. To allocate cellular users to all communication links, at least 2N allocations are required, and the complexity of 2N times becomes $O(2NM\log(M))$. So the overall complexity of the spectrum resource allocation process is $O(2NMR + 2NM\log(M))$. However, the resource allocation algorithm proposed in this paper only needs to directly calculate the J, and each cellular user only needs to calculate it once, so the calculation complexity is $O(M)$.

2. The Derivation of Formula (18)

$$\because \gamma_r = \frac{P_{d_t} H_{d_t r}}{P_{c_T} H_{c_T r} + N}$$

$$\therefore I_1 = \frac{P_{d_t} H_{d_t r}}{\gamma_r} - N$$

And the price is the reciprocal of interference.

$$\therefore J_1 = \frac{\gamma_r}{P_{d_t} H_{d_t r} - N\gamma_r}$$

Similarly

$$\because \gamma_{d_r} = \frac{P_r H_{rd_r}}{P_{c_R} H_{c_R d_r} + N}$$

$$\therefore I_2 = \frac{P_r H_{rd_r}}{\gamma_{d_r}} - N$$

$$\therefore J_2 = \frac{\gamma_{d_r}}{P_r H_{rd_r} - N\gamma_{d_r}}$$