

A Relay Selection Algorithm Based on User Trust Degree for D2D Communications

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A Relay Selection Algorithm Based on User Trust Degree for D2D Communications

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Abstract. The emergence of 5G has promoted the rapid development of the Internet of Things(IOT), the dramatic increasing of mobile equipment has led to the increasing shortage of spectrum resources, D2D(Device-to-Device) communication technology is widely concerned for its ability to improve the utilization of spectrum resources. In order to expand the communication scope, relay nodes are introduced into D2D communications, as the third party of D2D relay communication, the quality of relay nodes directly affects the quality of communication process. In order to make more users willing to participate in relay communication, social relationship is introduced into D2D relay communication, However, as an explicit relationship between people, the function of social relationship in D2D communication is limited by the mobility of users and the variability of communication scenarios. In order to find a more reliable relay node and upgrade the connection success rate of D2D relay communication, implicit social relationship between the users need to be mined. Aiming at that, user trust degree (UTD) is established in this paper. By combining the explicit relationship which is called the social connectivity degree with the implicit social relationship called the interest similarity degree, and considering the user's movement, a relay selection algorithm is presented to help sender find a relay node with a deeper user trust, which can increase the user's willingness to participate in D2D relay communication and upgrade the success rate of communication connection, so this algorithm can ensure the security of the relay node and can improve the throughput performance. Simulation results show that this algorithm can increase the success rate of connection, improve the overall throughput of the system and improve the user's communication experience.

Keywords: D2D communication, Relay selection, Social connectivity degree, Interest similarity degree, User trust degree.

1 Introduction

Modern communication technology is at the stage of rapid development, the appearance of 5G makes the connection between people and people, people and things, and things and things more closely, as an important part of 5G communication technology, D2D communication technology can improve the data processing capability of mobile network and can improve the speed of data transmission [1]. D2D communication allows

the user to communicate directly by multiplexing the spectrum resources of a cellular user. Introducing D2D communication into cellular network can reduce communication delay, improve spectrum efficiency and improve user experience. However, communication distance limits the application scope of D2D communication. Adding relay nodes in D2D communication can expand its application scope and improve the success rate of connection establishment [2-4]. Due to the introduction of relay nodes, D2D communication changes from one-hop communication to multi-hop communication, but the reliability of the relay node directly affects the success rate of communication connection, in order to enhance the communication security and ensure that the communication process can be established normally, some researchers quantify social relationship between people to find a relay node which has a stronger willingness to participate in D2D relay communication. [5-10].

In recent years, there have been numerous studies on D2D relay selection based on social relationship. Literature [11] proposed a D2D relay selection algorithm under fog community, considered relay selection under different social environments, which improved the transmission success rate and reduced the transmission delay. Similarly, literature [12] comprehensively considered several communication conditions, through capability assessment and social relationship assessment, an algorithm based on Bayesian probability formula has been proposed to help sender make final trust point decision.

Literature [13] proposed a coalitional game-theoretic framework, and leverage two key social phenomena to promote efficient cooperation among devices, the proposed mechanism can achieve significant performance gain. Literature [14] proposed an innovative social-aware energy-efficient relay selection mechanism that considered the hidden social ties among mobile users to ensure that more users are willing to participate in the cooperative communications, which achieved a significant performance gain.

In most of the studies above, some social attributes are introduced to improve the quality of relay nodes, such as social relationship assessment and social ties, these methods quantified the social relationship between users and enhanced the efficiency of finding relay nodes. However, these studies only considered some specific social attributes in a single scenario and ignored the fact that the selected relay node may not be the best relay node for D2D users. It is obvious that social attributes are helpful to find reliable relay nodes, the relay nodes found through social relationship are more likely to interact with the sender, so the connection establishment success rate of D2D relay communication is higher, but people are constantly moving, a user in a single day will arrive in many different location, the social relationship change quickly, those who only consider one single social relationship are difficult to ensure the connection success rate and can not guarantee the security of communication, for example, when a user takes convenient transportation like subway, he may be in a weak social relationship scenario for a short time, at this time, as an explicit relationship between people, considering social relationship alone cannot adapt to the complexity of communication scenario and it's hard to find a suitable relay node to establish the relay connection, when the sender is in a weak social relationship scenario, D2D communication will

encounter the cold start problem and it may be difficult to find a relay node and establish a relay communication in a short time.

Based on the above questions, we take into account the real life scenario, first, we consider the mobility limitation of the relay node, introducing the explicit social relationship—social connectivity degree to quantify the social relationships between the sender and the relay node, then we consider that people are often connected because they have certain common interests, and we introduce an attribute called the interest similarity degree, and divided it into long-term interest and short-term interest to exploit the hidden social connections between the sender and the relay node, hence, we can find the deep connection between the sender and the relay node, , finally, the utility function of UTD is formed by combining the social connectivity degree and the interest similarity degree. This algorithm is more suitable for real scenarios and can solve the cold start problem, therefore can ensure the throughput performance of communication process and upgrade the connection success rate of D2D relay communication.

The rest of this paper is organized as follows. The section II introduces the system model, the relay selection algorithm based on UTD combined with the user mobility is proposed in section III, the performance analysis is shown in section IV. the simulation results and the analysis of UTD algorithm performance are given in section V, Finally, the conclusion is given in Section VI.

2 System model

In the D2D communication system, when the channel condition is not good so that the single-hop communication cannot be carried out or the communication distance is too far to establish the normal single-hop communication, multi-hop D2D communication can be used to complete the communication process, one or more relay nodes need to be selected at this time. The D2D relay selection system model is shown in Fig.1.

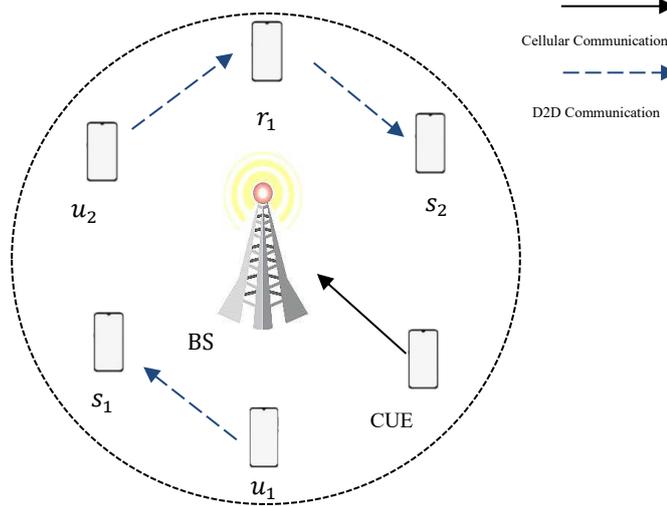


Fig. 1 System model

D2D communication modes mainly include the D2D direct communication and the D2D relay communication, where black solid line represents cellular communication mode and blue dotted line represents D2D communication mode. At this moment, cellular communication and D2D communication are simultaneously carried out, so the D2D receiver will receive the same frequency interference from other cellular transmitters, interference analysis will be described in Section IV. When the distance between the sender u_i and the relay node n is too far or the channel condition is insufficient to support this direct D2D communication, the sender can choose the D2D relay communication to increase the number of communication hops and meet the communication quality. Several D2D users can reuse one cellular user's spectrum, but in order to control the D2D user's interference to the cellular user, we should fully consider the number of D2D users who reuse the spectrum resources of the cellular user and evaluate the channel condition, ensuring that D2D relay communication should be carried out without affecting the normal communication of the cellular user.

3 A Relay Selection Algorithm Based on UTD

To enhance the success rate of D2D communication connection, and to improve the data transmission rate, this paper propose two social relationship factor called the social connectivity degree and the interest similarity degree, and considering the user mobility, to build the utility function of UTD between user, finally we propose a relay selection algorithm based on UTD, which will help sender to find a relay node to forward data in a higher transmission rate, and make sure that the connection is established successfully and guarantee the safety of the communication process.

3.1 User Mobility

Mobile terminals are carried by people, who move constantly, and their position are in constant change, if the distance between the relay node and the sender is too far, the transmission rate of communication may cannot be guaranteed. In order to ensure the communication quality is within the lowest acceptable range, we consider the limited communication range of D2D communication, the concept of user mobility is introduced in this paper, the user is regarded as a node that is constantly moving, its moving distance is limited to an acceptable minimum communication distance to ensure the minimum data transmission rate, then we can obtain the relay node set after the user mobility screening.

According to Literature [15], In a circle with the maximum communication distance as the radius, the sender is at the central point $(0,0)$, relay node is located at (x_r, y_r) , d_{ur} denotes the distance between the sender and relay node, as shown in Eq.(1)

$$d_{ur} = \sqrt{x_r^2 + y_r^2} \quad (1)$$

Similarly, d_{rs} denotes the distance between the relay node and the receiver which can be calculated by Eq.(2).

$$d_{rs} = \sqrt{(x_r - x_d)^2 + (y_r - y_d)^2} \quad (2)$$

Using R denotes the threshold of movement distance limitation, the communication distance should be satisfy $d_{ur} < R$ and $d_{rs} < R$.

Using t denotes the communication time, v denotes the movement speed of the relay user, the motion angle is a random value θ . After time t , the relay node is located at $(x_r + t \cdot v \cdot \cos \theta, y_r + t \cdot v \cdot \sin \theta)$, we use d'_{ur} denotes the distance between the relay user and the D2D sender.

$$d'_{ur} = \sqrt{(x_r + t \cdot v \cdot \cos \theta)^2 + (y_r + t \cdot v \cdot \sin \theta)^2} \quad (3)$$

Similarly, d'_{rs} denotes the distance between the relay user and the D2D receiver.

$$d'_{rs} = \sqrt{(x_r + t \cdot v \cdot \cos \theta - x_d)^2 + (y_r + t \cdot v \cdot \sin \theta - y_d)^2} \quad (4)$$

Relay user that satisfy $d'_{ur} < R$ and $d'_{rs} < R$ are put into candidate set G1.

So far, all users in the candidate set G1 can satisfy the requirement of the minimum communication distance. However, many of the nodes in the current candidate set are strange nodes, they are less willing to participate in relay communication, those relay nodes are rational, it is bound to consider their own profits, if choose these nodes as the relay node, the connection success rate will be lower and may cannot guarantee the transmission rate. So in the next step, we introduce the social connectivity degree and the interest similarity degree, by combining these two factors, we build the utility function of UTD, then we propose an algorithm based on UTD to find the relay node which has certain social relations with the sender, the relay node found by this algorithm have a strong social trust with the sender, hence, UTD algorithm can improve the success rate of connection establishment, and improve the throughput performance.

3.2 Social Connectivity Degree

Since the smart phones penetrating into all aspects of life, people can communicate anytime and anywhere and forming the mobile social networks, which especially show the characteristics of "social" and "interaction". The social relationship between people is always having the feature of stability, periodicity and regularity. A large amount of social information can be utilized in D2D relay selection algorithm, which is conducive to finding the better relay node.

D2D communication in mobile networks is different from other wireless networks because mobile devices are carried by people, a mobile user has full control over his device, it is the user, not the device, that decides whether to participate in D2D cooperative communication. In other wireless networks, such as sensor networks or mesh networks, it is assumed that the device is willing to help each other to forward the data, by contrast, the relay node in D2D communication is a person with an independent mind, so it is important to understand whether he is willing to participate in D2D relay communication.

Assuming that there are N relay nodes around sender u_i who needs D2D relay communication, and form a set $R = \{r_1, r_2, \dots, r_N\}$, r_i ($i \in (1, N)$) denotes the relay node, and the D2D receiver is s_i . An undirected weighted graph is $G = (V, \omega)$, which represents the social relationship model between the sender u_i and the relay node r_i . At the same time, vertex set is $V = \{u_i, r_1, r_2, \dots, r_N\}$, the side set is

$\omega = \{(u_i, n) : \delta = 1, n \in u_i\}$. As shown in Fig.2, when the sender u_i want to establish the D2D relay communication, considering the social connectivity degree and interest similarity degree in social networks, and considering the user's mobility limitation in mobile networks, then find the best rely node.

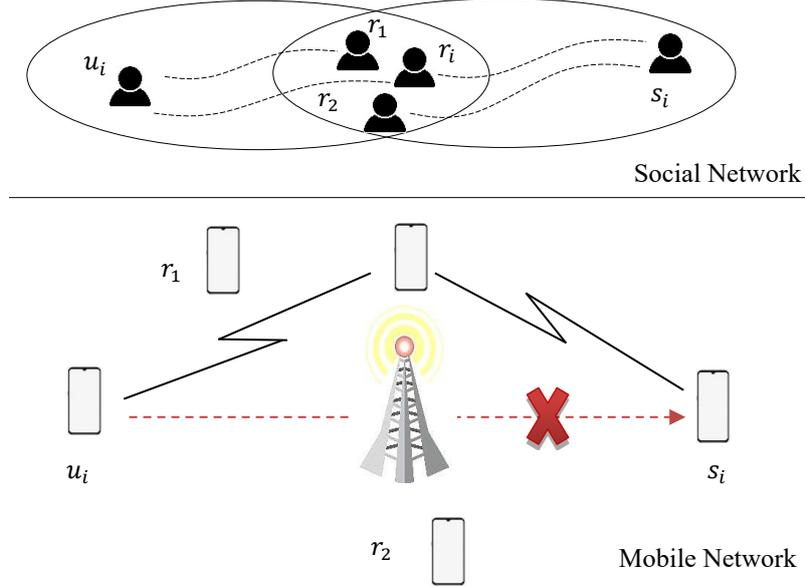


Fig. 2 D2D Relay communication

When the communication distance is beyond the maximum communication distance or the channel conditions is so poor that we can't establish connection, introducing relay communication is helpful to improve the system throughput and the success rate of connection establishment, for the sender u_i , most of the relay nodes in its communication range are strangers, and those relay nodes are rational, so before they make a decision, they will consider their equipment privacy security and battery remaining capacity and reluctant to join relay communications process, which results in a low success rate of connection establishment. To solve this problem, we consider the social relationship between users and hope to find a relay node which have a certain relationship with the sender, due to the interactive characteristics of the social network, those relay nodes are often more willing to participate in relay communications, so the success rate of connection establishment and system throughput can be effectively improved. We present a factor called social connectivity degree $Trust_{u_i, n}$ ($Trust_{u_i, n} \in [0, 1]$) which is used to represent the strength of social relationship between the sender u_i and the relay node n . Firstly, social connectivity degree is defined based on WeChat communication data or mobile phone communication data. In this paper, social connectivity degree between people is quantified from two perspectives, which are the contact factor and the interaction factor.

In reality, a person who often contacts with sender u_i may be a sales person or an e-commerce person, although this kind of people often contact with this user, they do not have a relatively stable social relationship with the sender, in order to avoid the inclusion of such people in the candidate set G1, we define the contact time t_c , which is used to ensure that there is indeed a close social relationship between the two users, In the observation time ρ , if contact time t_c is larger than the minimum contact time t_{min} , we assume that there is social relationship between two users, and use $\mu_{u_i r_i}(t)=1$ represents the sender u_i and the relay node n are communicating. $\mu_{u_i r_i}(t)=0$ represents the sender u_i and the relay node n are not establish the communication process.

The average communication times $T_{u_i r_i}$ is defined as:

$$T_{u_i r_i} = \frac{\int_0^{\rho} \mu_{u_i r_i}(t) dt}{L_{u_i r_i}} \quad (5)$$

$L_{u_i r_i}$ denotes the number of contacts between the sender u_i and the relay node n during the observation time ρ . Thus, the contact factor $U_{u_i r_i}$ can be written:

$$U_{u_i r_i} = \exp\left(-\frac{(T_{u_i r_i})^2}{2\sigma_1^2}\right) \quad (6)$$

Where σ_1 denotes the scale parameter of the contact time between the sender u_i and the relay node n , which can be set according to the actual situation. The contact factor reflects the intimacy degree between two users.

Second, we consider the interaction factor between people, assuming that the sender u_i and the relay node n have some common friends, they will have certain social relationship, the interactive factors reflect the depth of the relationship between the two users. Therefore, we define the common friends number proportion between the sender u_i and the relay node n , $F_{u_i r_i}$ is defined in Eq.(7).

$$F_{u_i r_i} = \frac{|f_{u_i} \cap f_{r_i}|}{|f_{u_i} \cup f_{r_i}|} \quad (7)$$

Where f_{u_i} denotes the friend collection of the sender u_i and f_{r_i} denotes the friend collection of relay node n .

To sum up, by combining the contact factor and interaction factor, a relay node that are closely related with the sender in the time domain and the space domain can be found. Thus, the equation of the social connectivity degree $Trust_{u_i r_i}$ as shown in Eq.(8):

$$Trust_{u_i r_i} = \beta_1 U_{u_i r_i} + (1 - \beta_1) F_{u_i r_i} \quad (8)$$

Where β_1 ($\beta_1 \in [0,1]$) is the weight parameter which can be adjusted according to different communication scenarios. For example, in real life, the social events of modern people feature shortness and dispersion. Those friends we often contact may not have many common friends with us, but they still have deep relationship with us, such

as couples, new friends, etc. At this time, we can set $\beta_1 = 1$ to find the user who has the deepest contact as the relay node. If there are no close friends within the current communication range, we set $\beta_1 = 0$ to find the relay node in the old social circle which has the most common friends with the sender as the relay node, it can still ensure that the relay node we found has a strong social relationship with the sender. In addition, if the relationship between the relay user and the sender is not clear, two factors can be considered comprehensively, and we can set $\beta_1 = 0.5$.

3.3 Interest similarity degree

As an explicit relationship between users, social relationship is helpful to find relay users in certain situations such as cluster network, but social relationship alone is not enough to deal with the change of the dynamic and complex scenarios. When the sender is in a strange environment, the sender u_i may not be able to find a relay user who has a social relationship with him, in order to solve the cold boot problem, this paper proposes the interest similarity degree and divides it into long-term interest similarity and short-term interest similarity, then, use it to mine the implicit social relationship. The interest similarity degree helps the sender to find a reliable relay node in communication scenarios with weak social relationship. In real life, those with similar interests tend to be more interested in what is being transmitted to each other, and are more willing to participate in relay communications, hence, it can upgrade the connection success rate and ensure the safety of the communication process.

Assuming $R = [c_{uil}]_{m \times n}$ represents a signing matrix of the interested point l of the user u_i , where m denotes the number of users, n denotes the number of interested points, the value in matrix c_{uil} denotes the number of the sign of the D2D sender u_i in the interest point l , which is used to indicate the users' interest similarity degree level of the interested point l , if $c_{uil} = 0$, the user has no interest similarity with the sender in interest point l .

First, for all interest points, we calculate the average frequency of the sign of the D2D sender u_i , which is shown in Eq.(9)

$$\overline{c_{u_i,l}} = \frac{\sum_{l=1}^n c_{u_i,l}}{n_{u_i}} \quad (9)$$

Where n_{u_i} represents the total number of interested points that user u_i has checked in. Use the user's average sign-in number $\overline{c_{u_i,l}}$ to build the Boolean matrix $R' = [c'_{uil}]_{m \times n}$, where $c'_{uil} \in [0,1]$.

$$c'_{uil} = \begin{cases} 1, & \text{if } c_{uil} > \overline{c_{u_i,l}} \\ 0, & \text{otherwise} \end{cases} \quad (10)$$

Hence, the asymmetric user influence matrix $W = [w_{uin}]_{m \times m}$, where w_{u_i,r_i} represents the influence factor from u_i to the relay node r_i . The equation of w_{u_i,r_i} is defined by Eq.(11):

$$w_{u_i r_i} = \frac{\sum_{l=1}^n c'_{u_{il}} \times c'_{r_{il}}}{\sum_{l=1}^n c'_{r_{il}}} \quad (11)$$

If the impact value $w_{u_i r_i}$ between the sender u_i and the relay node n is larger than the average impact value \bar{w} , then the interest similarity $LI_{u_i r_i} = 1$, indicating that the sender u_i have an impact on the relay node n ; Otherwise, $LI_{u_i r_i} = 0$, which means that the sender u_i doesn't affect the relay node n . \bar{w} and $LI_{u_i r_i}$ can be denoted as follows:

$$\bar{w} = \frac{\sum_{u_i=1}^m \sum_{r_i=1}^m w_{u_i r_i}}{\sum_{u_i=1}^m \sum_{r_i=1}^m \gamma(w_{u_i r_i})} \quad (12)$$

$$LI_{u_i r_i} = \begin{cases} 1, & \text{if } w_{u_i r_i} > \bar{w} \\ 0, & \text{otherwise} \end{cases} \quad (13)$$

Where $\gamma(x)$ is the indicator function, when $x > 0$, $\gamma(x) = 1$, otherwise $\gamma(x) = 0$.

Short-term interest also affects user similarity, this paper introduces three parameters which based on the analysis of interaction of mobile social network information similarity in content to define short-term interest between users, including release information similarity, user comment information similarity and user forward information similarity. Finally, sum three parameters and build the short-term interest equation.

First, assuming the release information subject sets of the sender u_i and the relay node n are $T_i = \{t_1, t_2, \dots, t_{m2}\}$ and $T_j = \{t_1, t_2, \dots, t_{n2}\}$ respectively, then the release information similarity between the sender u_i and the relay node n can be denoted as follows:

$$SI_{u_i r_i}^p = \sum_{t_i \in T_i} \sum_{t_j \in T_j} \exp(-dis(t_i, t_j)) \quad (14)$$

This paper use edit distance $dis(t_i, t_j)$ to measure the user's comment information similarity, which can not only calculate the similarity degree between string, but also can evaluate the similarity degree of natural language, when the comment of the sender u_i and the relay node n are more similar, the short-term interest similarity is larger.

Second, the comment content similarity between and the relay node n is shown in Eq.(15).

$$SI_{u_i r_i}^c = 1 - \frac{dis_c(u_i r_i)}{\max(length_c(u_i), length_c(r_i))} \quad (15)$$

Where the $dis_c(u_i r_i)$ represents the edit distance between the sender u_i and the relay node n , while the length of the comment of the sender u_i and the relay node n are $length_c(u_i)$ and $length_c(r_i)$ respectively.

Similarly, the forward content similarity is also measured by editing distance, then the forward content similarity between the sender u_i and the relay node n can be denoted:

$$SI_{u_i r_i}^b = 1 - \frac{dis_b(u_i r_i)}{\max(length_b(u_i), length_b(r_i))} \quad (16)$$

Where the $dis_b(u_i r_i)$ represents the edit distance between the sender u_i and the relay node n , and the length of the forward content of the sender u_i and the relay node n are $length_b(u_i)$ and $length_b(r_i)$ respectively.

Hence, the total short-term interest factor $sim_{u_i r_i}^{total}$ is:

$$SI_{u_i r_i}^{total} = \frac{SI_{u_i r_i}^p + SI_{u_i r_i}^c + SI_{u_i r_i}^b}{3} \quad (17)$$

In summary, the user interest similarity degree $Interest_{u_i r_i}$ can be obtained by combining the long-term interest similarity and short-term interest similarity:

$$Interest_{u_i r_i} = \beta_2 LI_{u_i r_i} + (1 - \beta_2) SI_{u_i r_i}^{total} \quad (18)$$

Where β_2 ($\beta_2 \in [0, 1]$) is the weight, which can be adjusted according to different communication scenarios. In the actual communication process, user doesn't necessarily comment or forward certain things. Therefore, when the network information of users cannot be obtained, we assume that the location where users go is the point they are interested in. At this time, we set $\beta_2 = 1$. Second, if the user does not open the location service but we can obtain the user's network information, we set $\beta_2 = 0$ to analyze the user's interest from the content, comment and forward information. Finally, if the user's location information and network information can be obtained both, we set $\beta_2 = 0.5$ to comprehensively analyze the user's interest similarity. Finally, we are able to find the relay node which has the greatest interest similarity degree to the sender

3.4 The Utility Function UTD

Combined with the social connectivity degree and the interest similarity degree between users, this paper defines UTD as an indicator to measure the similarity between the sender u_i and the relay node n . The higher trust degree between sender and relay node, the larger possibility of establishing communication and the higher throughput performance. The utility function $UTD_{u_i r_i}$ of the UTD can be denoted in Eq.(19).

$$UTD_{u_i r_i} = \beta_3 Trust_{u_i r_i} + (1 - \beta_3) Interest_{u_i r_i} \quad (19)$$

Where β_3 ($\beta_3 \in [0, 1]$) is the weight, which can be adjusted according to different communication scenarios. As a parameter that can directly evaluate interpersonal relationship, social relationship should be placed in the first place. Therefore, in the scenario with clear social relationship, we set $\beta_3 = 1$ to find the node with the deepest social contact with the sender. If sender in a situation where the social relationship is not clear, we can comprehensively consider the two factors, and set $\beta_3 = 0.5$, besides, if sender is in a strange place, there is basically no node having social relationship with

the sender, so we set $\beta_3 = 0$ to find the explicit relationship between users and find the node which have the greatest interest similarity with sender to establish relay communication.

So far, we introduced the social connectivity degree and interest similarity degree to measure the UTD, and constructed the utility function of UTD, after the user mobility screening, we get the candidate set G1, then we set UTD threshold value, this paper set it as 0.3, and get the candidate set G2. The specific value can be adjusted according to the actual communication scenario, if there are many selectable nodes in the G2 candidate set and most relay nodes have strong social relationship with the sender, we can increase the threshold value of the utility function and reduce the number of nodes to find a relay node with larger UTD, relay node found in this way will have a higher willingness to participate in the relay communication. Hence, this algorithm can improve the success rate of the communication connection and can improve overall system throughput.

4. Performance analysis

Assuming that there is no interference between D2D users, the specific situation is shown in Fig.2, dotted line represents the interference from other CUE sender, the solid line represents two users are communicating.

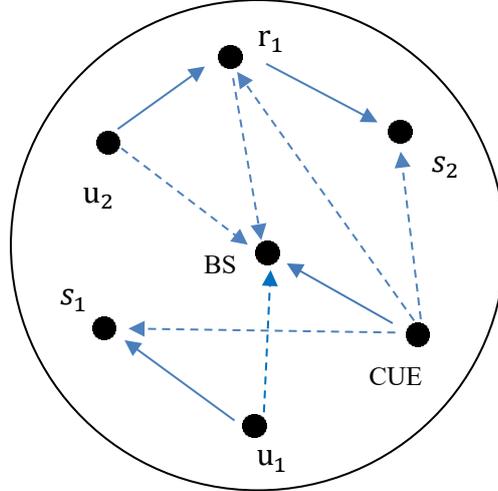


Fig. 3 Interference between cellular users and D2D users

The path loss from the sender u_i and the relay node r is defined as:

$$PL_{u_i r} = PL_0 \cdot d_{u_i r}^\alpha \quad (20)$$

PL_0 is the reference path loss of near distance communication, $PL_0 = 40 \log_{10}(d_0) + 7.8 - 18 \log_{10}(h_{BS} - 1) - 18 \log_{10}(h_{UT} - 1) + 2 \log_{10}(f_c)$, $d_0 = 10m$ is the reference range, $h_{BS} = 20m$ is the height of base station, $h_{UT} = 1.5m$ is the

height of terminal device, $f_c = 2GHZ$ is the carrier frequency. d_{u,r_i} is the distance between the sender u_i and the relay node n , and α denotes the path loss coefficient. When a D2D single hop communication is going on, the Signal to Noise Ratio (SINR) from the sender u_i to the receiver s_i is shown in Eq.(21).

$$\varphi_{u_i s_i} = \frac{P_{u_i s_i} \cdot d_{u_i s_i}^{-\alpha}}{(I_C + n_0) \cdot PL_0} \quad (21)$$

Where $P_{u_i s_i}$ denotes the sending power from the sender u_i to the receiver s_i , $d_{u_i s_i}$ is the distance from the sender u_i to the receiver s_i , I_C is the same-frequency interference of the cell user in the same channel, and n_0 is Gaussian white noise. When the channel bandwidth is W , the data transmission rate of the sender u_i in D2D direct communication is shown in Eq.(22).

$$R_{u_i s_i} = W \log_2(1 + \varphi_{u_i s_i}) \quad (22)$$

When user choose D2D relay communication, decoding and forwarding (DF) mechanism is adopted. When the sender u_i sends a relay request, real-time information of the nearby relay node is obtained through base station BS, which contains the social connectivity degree and interest similarity degree of this relay node, the SINR on the link of the relay node n can be expressed as:

$$\varphi_{u_i r_i} = \frac{P_{u_i r_i} \cdot d_{u_i r_i}^{-\alpha}}{(I_C + n_0) \cdot PL_0} \quad (23)$$

Similarly, the SINR on the link of the relay node s_i can be expressed as:

$$\varphi_{r_i s_i} = \frac{P_{r_i s_i} \cdot d_{r_i s_i}^{-\alpha}}{(I_C + n_0) \cdot PL_0} \quad (24)$$

Where relay $P_{u_i r_i}$ and $P_{r_i s_i}$ are the transmitting power of the relay node u_i and the sender n respectively, $d_{u_i r_i}$ denotes the distance between the sender u_i and the relay node n , $d_{r_i s_i}$ denotes the distance between the relay node n and the receiver s_i .

According to the characteristic of relay communication, the system capacity is determined by the minimum throughput of all hops, and the data transmission rate of D2D relay communication is obtained as follows:

$$R_{total} = W \min \{ \log_2(1 + \varphi_{u_i r_i}), \log_2(1 + \varphi_{u_i s_i} + \varphi_{r_i s_i}) \} \quad (25)$$

Hence, the optimal performance and detection time should be considered comprehensively. Assuming that the D2D user's communication time is T , the time cost of detecting a relay node is set for a fixed value τ , the effective throughput X_n when detecting the n th relay node can be denoted by:

$$X_n = \frac{R_{total}(T - n\tau)}{T} \quad (26)$$

where $n\tau$ denotes the total time cost needed to detect a total of n relay nodes, $T - n\tau$ denotes the effective communication time of D2D users, hence the effective throughput of the system can be denoted as follows:

$$Y_e = \max(X_n) \quad (27)$$

Set Y_{\min} denotes the minimum throughput threshold, If the system's effective throughput Y_e is larger than the minimum throughput threshold Y_{\min} , It indicates that D2D communication has been successfully established. Assuming that the total number of probes is N_p , the number of successful probes is N_s , then, the success rate of connection can be denoted as follow:

$$R = \frac{N_s}{N_p} \quad (28)$$

5 Simulation result

5.1 System parameters

Assuming that all users are randomly distributed within the coverage range of a macro cell, considering the interference between cellular users and D2D users, the bandwidth is assigned to the relay user by the base station according to the UTD and the specific indexes are set according to actual situation in reality. The main parameters of simulation are listed in Table 1.

Table 1. Simulation parameters

| | |
|--------------------------------|------------|
| Radius of neighborhood | 500m |
| White noise | -174dBm/Hz |
| System bandwidth | 2GHz |
| SNR threshold of base station | 20dB |
| SNR threshold of D2D receiver | 30dB |
| SNR threshold of relay users | 30dB |
| Sends power of macro cell user | 40dBm |
| Sends power of D2D user | 40dBm |
| Path loss factor | 4 |
| UTD threshold | 0.3 |

5.2 Pseudocode

A Relay Selection Algorithm Based on UTD

- 1: Set basic communication parameters
 - 2: If the relay node n is still in the communication range after moving in time t
 - Get the candidate set G1
 - end
 - 3: Set the weights β_1 , β_2 to get the social connectivity degree and interest similarity degree
 - 4: Set the weight β_3 to get the utility function of user similarity degree
 - 5: Set UTD threshold
-

```

Get the candidate set G2
6:Rset the user trust threshold, reduce the number of nodes, find the optimal relay
node
end

```

5.3 Analysis of simulation results

This part will illustrate the performance of the UTD algorithm, and we demonstrate the simulation results based on MATLAB software. By comparing the UTD relay selection algorithm with the single social relationship algorithm, it is proved that the throughput and the connection success rate of the UTD algorithm are relatively excellent. The main performance indexes include the system throughput, the success rate of communication connection establishment, the CDF of throughput and connection setup time, and the influence of weights on throughput.

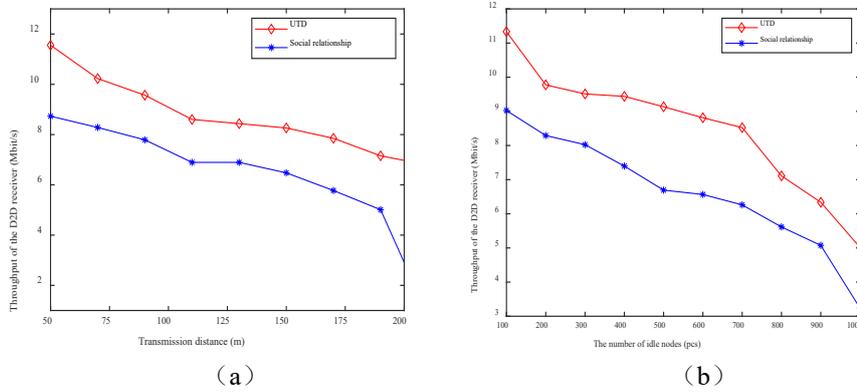


Fig. 4 Throughput of the D2D receiver

Fig.4 shows the change of throughput of the D2D receiver. Part (a) shows the throughput of the D2D receiver with the communication distance between 50m and 100m, With the increase of distance, the performance of the UTD algorithm proposed in this paper is better than the single social relationship algorithm, because the UTD algorithm takes into account the implicit social relationship between people—the interest similarity degree, which can help the D2D sender to find more reliable relay nodes within the same distance range, they are willing to participate in relay communications and more willing to help the sender to complete the data transmission, so result in a higher transmission rate. part (b) shows the change of throughput of D2D receiver with the number of relay nodes between 100 to 1000, the social circle of the sender is in a limited range, we can see that with the increase of the number of relay nodes, the number of strange nodes will increase, and the total number of interest point will also increase, therefore, the difficulty of the node search will be increased too, leading to a decreasing trend of throughput, it can be seen from the figure that the performance of the UTD algorithm proposed in this paper is better than the single social relationship algorithm, this is because the nodes found by the UTD algorithm have deeper social trust degree, therefore, the relay node will try its best to provide the D2D receiver with higher transmission rates.

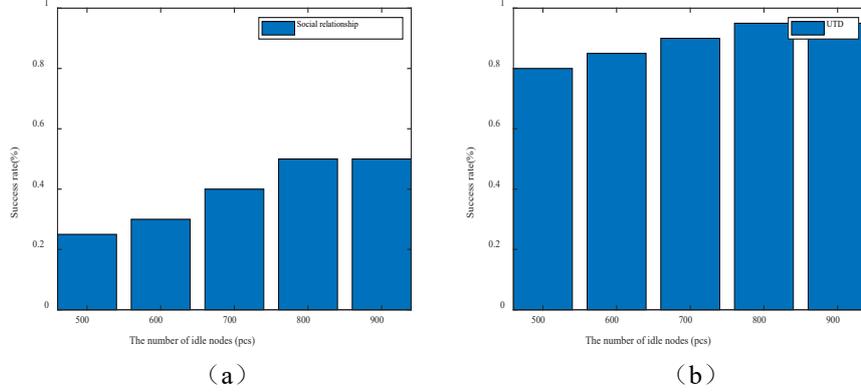


Fig. 5 Connection success rate in different number of idle nodes

Fig. 5 shows the success rate of D2D communication connection establishment under different number of relay nodes. It can be seen that the connection success rate of the UTD algorithm is greater than the single social relationship algorithm in the number of relay nodes from 500 to 900. This is because the UTD algorithm can find more reliable relay nodes and these nodes are more likely to ensure the efficiency of communication process, by mining social trust and common interests among users, the UTD algorithm ensures the stability of relay nodes and upgrades the connection success rate.

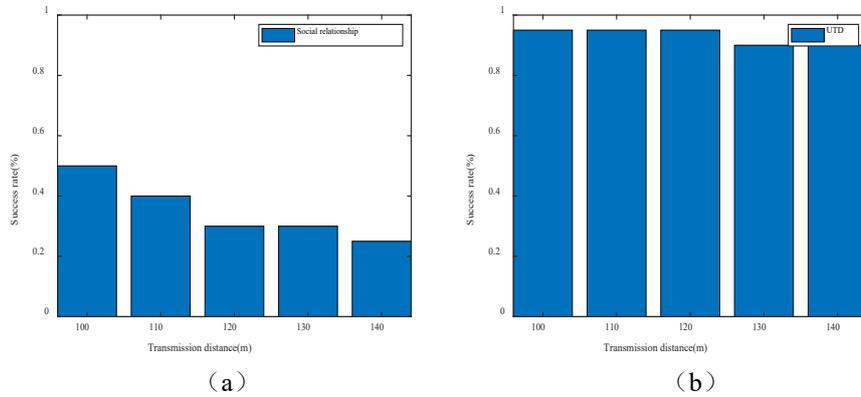


Fig. 6 Connection success rate in different transmission distance

Similarly, Fig. 6 shows the success rate of the D2D communication connection establishment under different transmission distance, the success rate of both the UTD algorithm and the single social relationship algorithm decreases with the increase of communication distance, compared to a single social relationship between algorithm, the algorithm of the UTD in transmission distance from 100 to 140 meters can keep a high success rate of connection establishment, this is because by mining the implicit social relationship between the user, the UTD algorithm can expand the social circle of the sender and can find more nodes within the same communication distance that can successfully establish the relay communication.

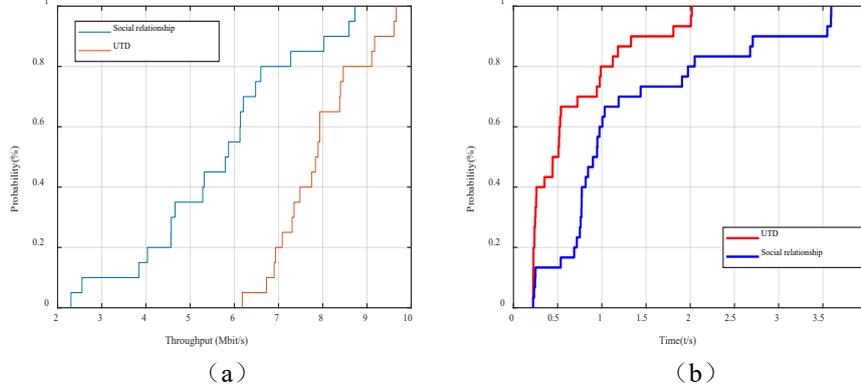


Fig. 7 CDF curves

Fig. 7 shows two CDF graphs, in which the part (a) is the CDF curve for throughput, part (b) is the CDF curve of detection time, we can see that the performance of the UTD algorithm is better than the single social relationship algorithm, it has higher throughput and lower connection setup time, this is because the relay node found by UTD algorithm has a strong social trust with the sender, and this node has strong relay willingness and high security, hence the connection setup time and throughput performance are more outstanding.

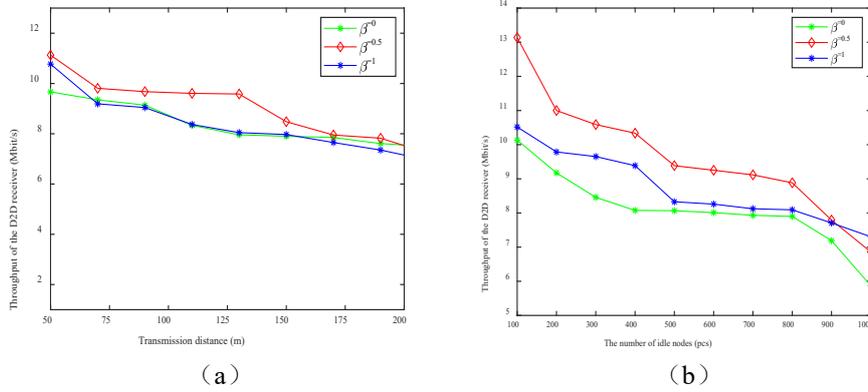


Fig. 8 The influence of β in throughput

Fig. 8 shows the influence of parameter β on system throughput under different number of relay nodes and different communication distance. In this paper, we set three different Values of β , $\beta=0$, $\beta=0.5$, and $\beta=1$. When $\beta=0$, it means that we only consider the social connectivity degree between the user and don't seek the interest similarity degree between users, thus get the green curve, when $\beta=1$, it means that we only consider the interest similarity degree between users, not considering the social connectivity degree between user and get the blue curve, when $\beta=0.5$, it means that we consider both the social connectivity degree and the interest similarity degree between users and get the red curve. It can be seen that when $\beta=0.5$, the performance of

the system is better, this is because when $\beta=0.5$, the UTD algorithm can comprehensive consider the explicit and the implicit social relationship between users, then find a relay node which has a deeper UTD between the sender, hence upgrade the security and quality of communication process.

6 Conclusion

In D2D relay communication, choosing the best stable relay user is an important way to improve the quality of D2D relay communication. The UTD algorithm combines the social connectivity degree and the interest similarity degree, and introduces the concept of the UTD, considering two aspects of relationship, which are the explicit relationship and the implicit relationship, so the UTD algorithm can adapt to the complex change of modern communication scenario. The UTD algorithm can quickly find the optimal relay user, reducing the detection time, and not only upgrade the connection success rate, but also improve the overall throughput of the system.

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Competing interests. The authors declare that they have no competing interests.

Availability of data and material. All data and material used during the study are available from the corresponding author by request.

Code availability. The code used in this article is custom code.

Authors' contributions. This algorithm was proposed by two authors. Haoran Liu performed the simulation work and wrote the paper. Xiaobin Li reviewed, revised and approved the final manuscript.

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Figures

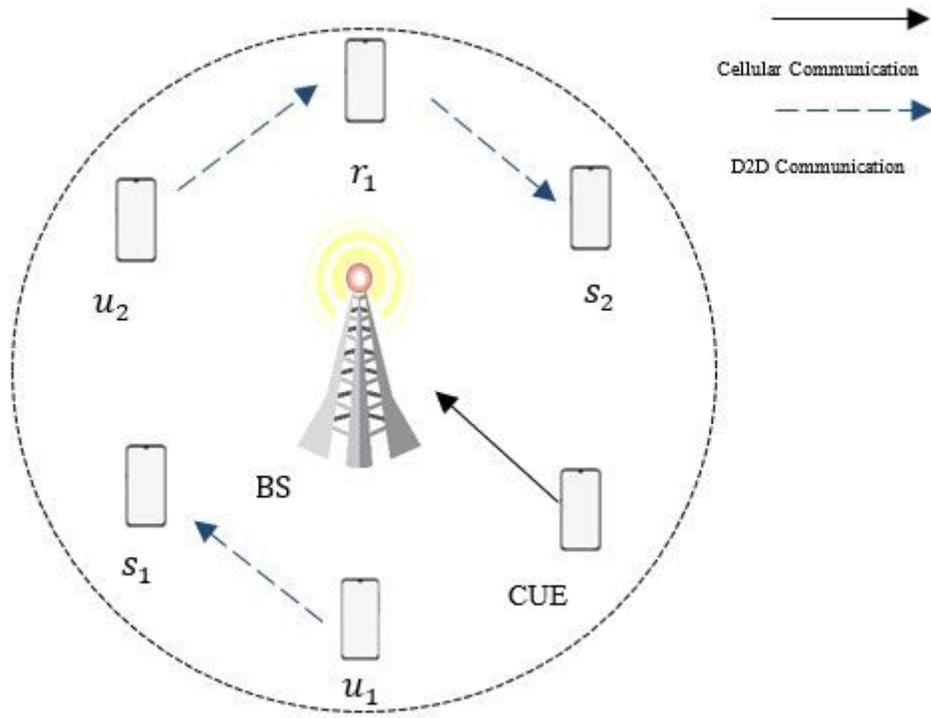


Figure 1

System model

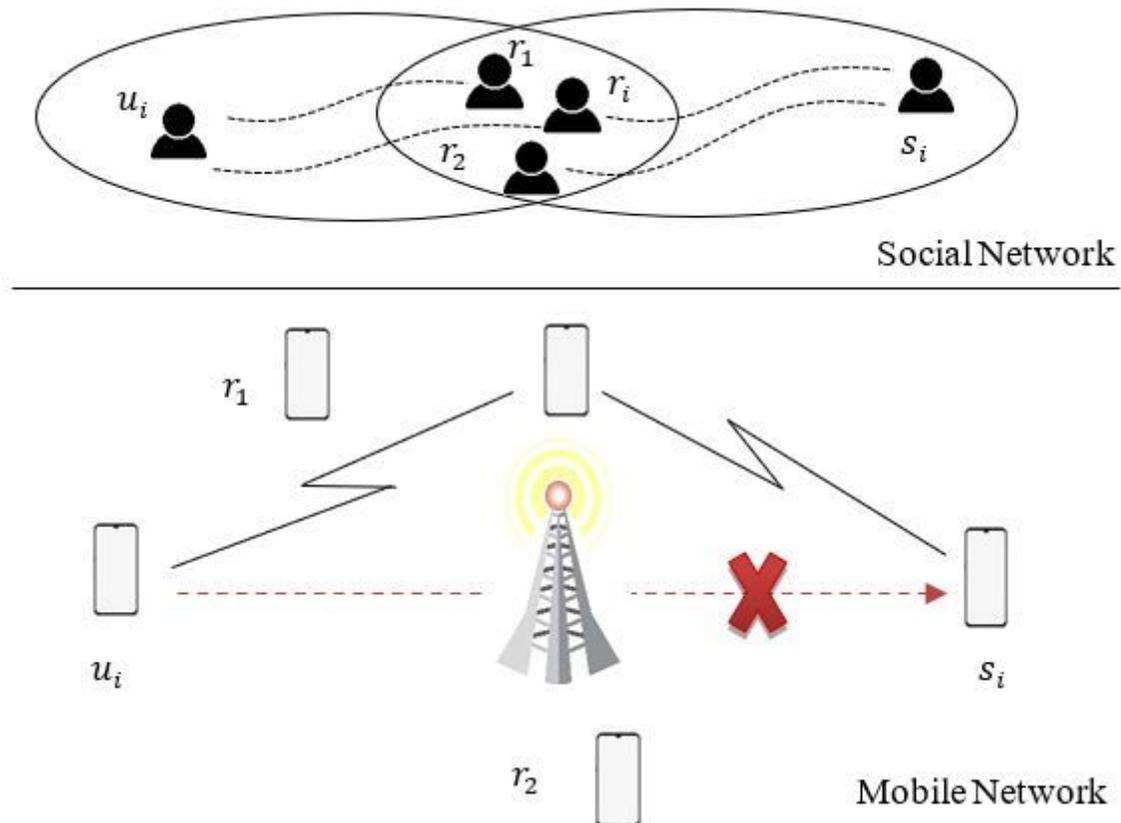


Figure 2

D2D Relay communication

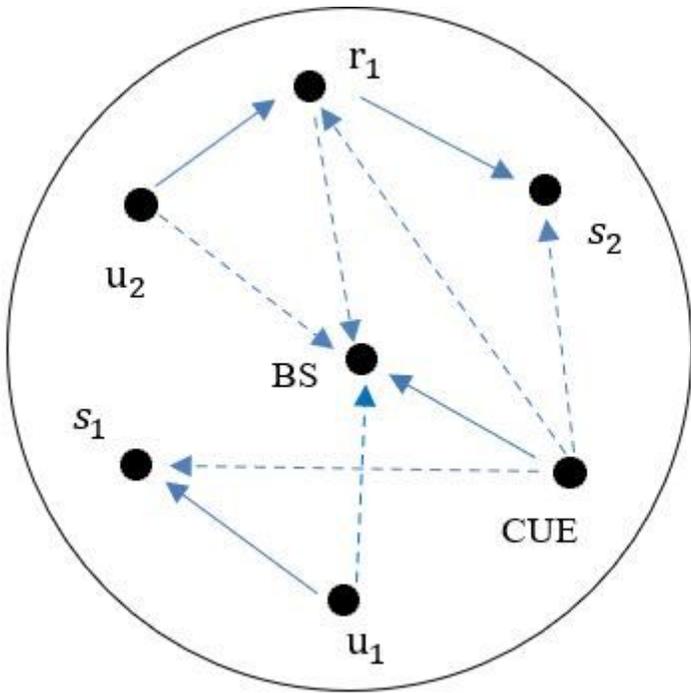


Figure 3

Interference between cellular users and D2D users

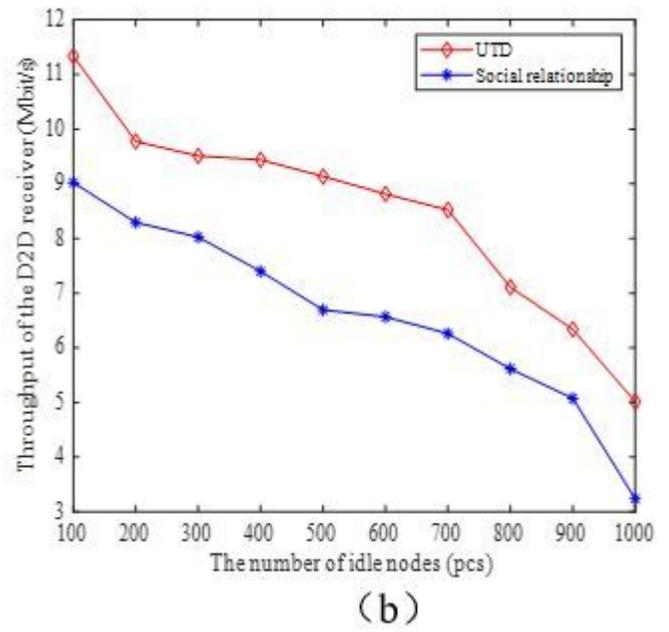
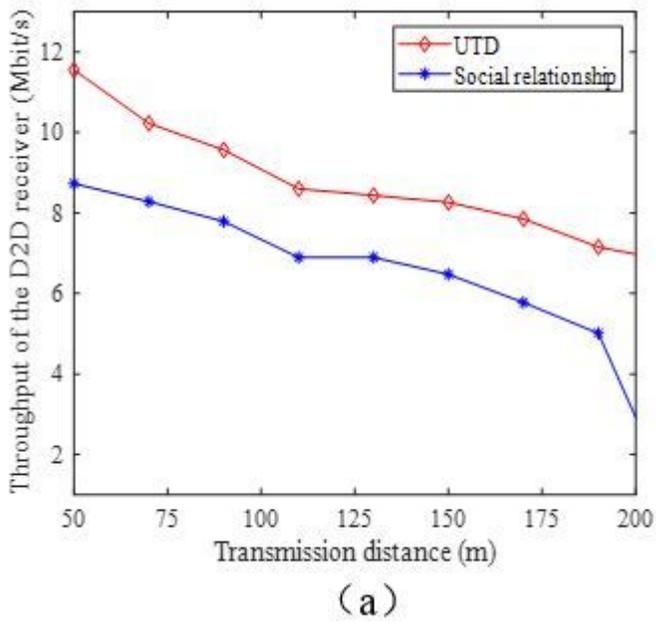
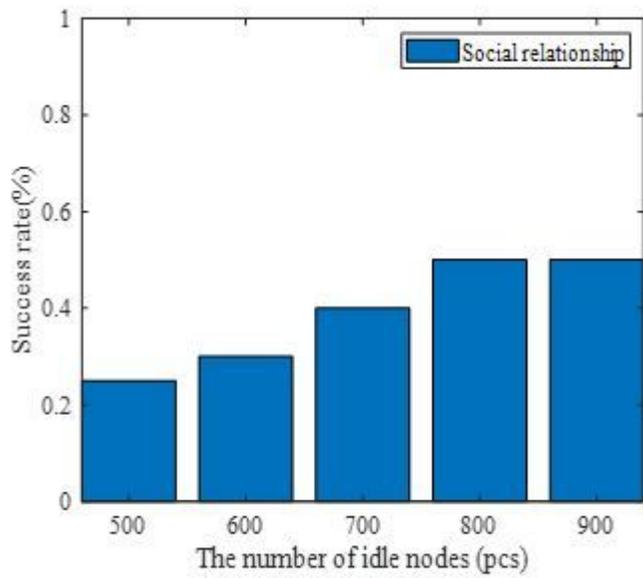
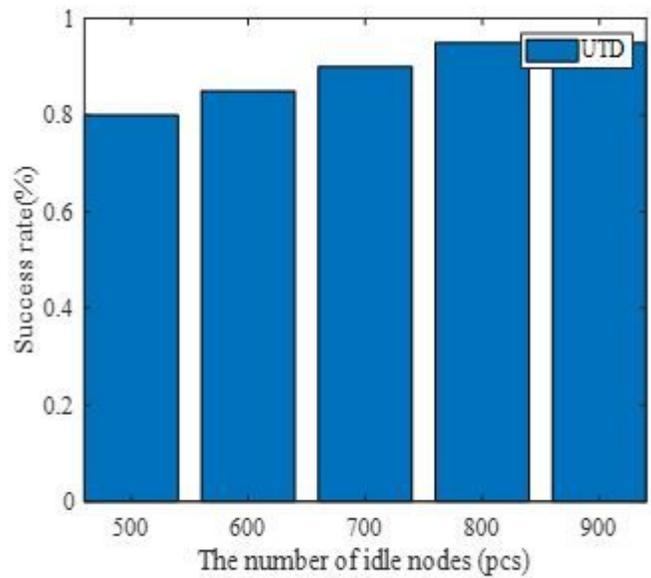


Figure 4

Throughput of the D2D receiver



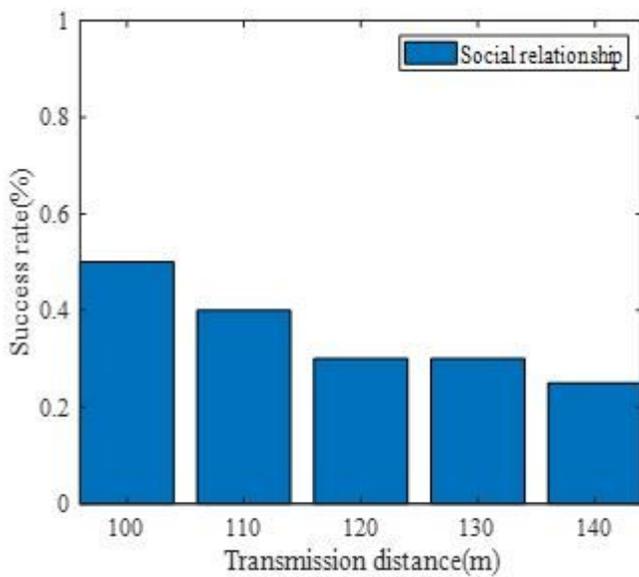
(a)



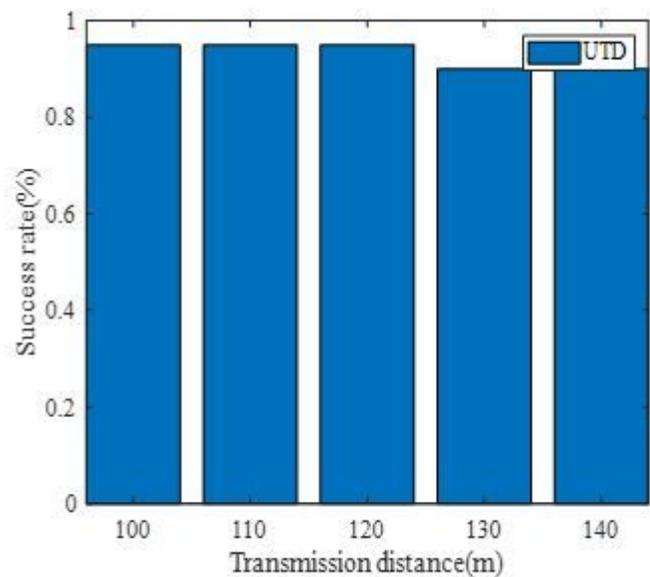
(b)

Figure 5

Connection success rate in different number of idle nodes



(a)



(b)

Figure 6

Connection success rate in different transmission distance

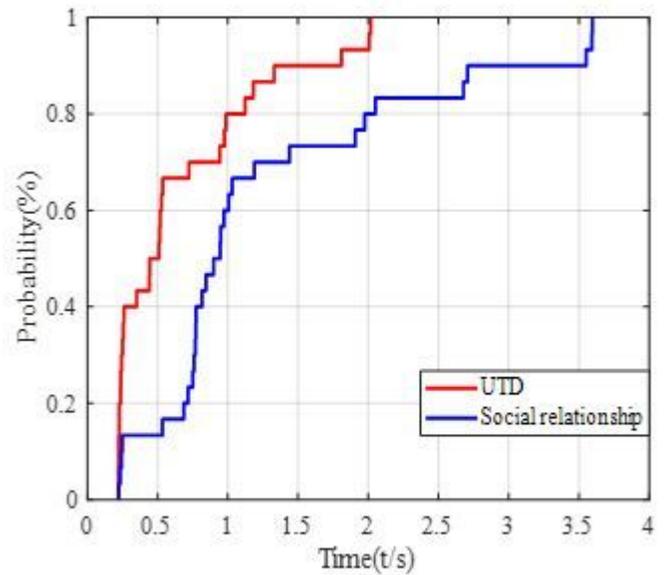
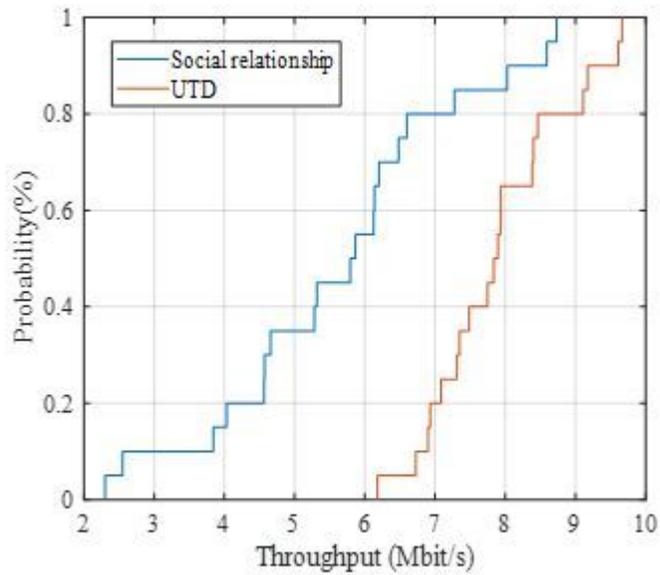


Figure 7

CDF curves

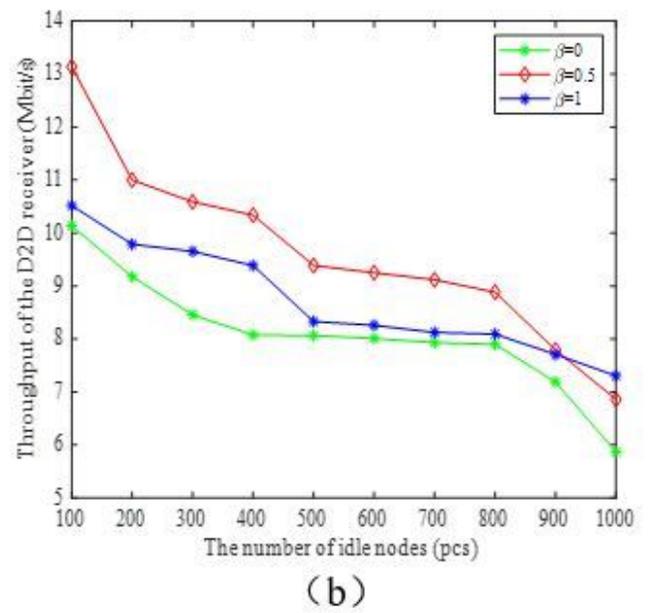
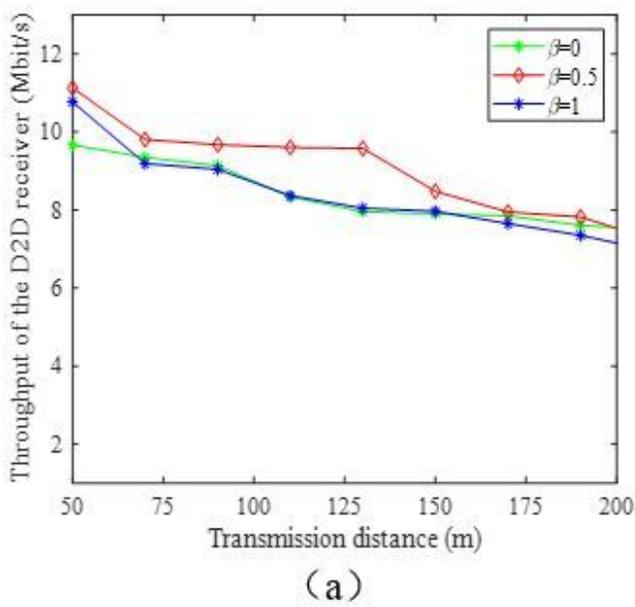


Figure 8

The influence of β in throughput