Social Trusted D2D Seed Node Cluster Generation Strategy

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Abstract. In this paper, we propose a Device-to-Device (D2D) seed node cluster generation strategy based on coalitional game in social trusted D2D communication system. First, in the premise that the D2D seed node not harm the interests of other nodes and the cooperative power cost considered, a simple distributed algorithm is adopted to form independent and disjoint coalitions to maximize the throughput of the seed node cluster. Then the social trusted framework is introduced to make the segmentation of coalitions effectively meet the requirements of social security. The simulation results show that compared with the node cluster of the traditional cellular network and non-coalitional game, the system throughput of which is maintained at a higher level with social security ensured as well.

Keywords: D2D communication · Coalitional game · Social trusted · Throughput · Node cluster

1 Introduction

With the explosive growth of mobile data traffic, the load of base stations and spectrum resources are nearly saturated. The advantages of D2D communication in data offloading and distribution are making it the mainstream and center of the next generation mobile network, although D2D initially exists as a technical support option for public security services. In the process of D2D providing a variety of in-cell applications and services, it is obviously unfeasible that the simple direct connection on the basis of existing research considering only physical factors without any social awareness toward trust. Therefore, the method combining D2D communication with social awareness emerges and becomes a hot topic in D2D research.

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In this paper, we focus on promoting the whole throughput and safety coefficient of the social trusted D2D seed node cluster. The major contents of this paper are summarized as follows:

1. Applying the concept of coalitional game into the architecture of system model, proposing a new social aware D2D communication model.
2. Dividing the social relationships into five categories which corresponding five different kinds of social trust coefficient. Social trust classification will help selecting the seed node to join the cluster and enhancing the security of it.
3. Considering the system throughput and social trust coefficient of the seed nodes, the concept of safety throughput is proposed.

The remainder of this paper is organized as follows. In Sect. 2, the related work is briefly described. Section 3 introduces the proposed multi-nodes cooperation model and social relationship model under the framework of coalitional game. In Sect. 4, we present seed node cluster generation algorithm. Section 5 gives performance analysis of proposed algorithm and Sect. 6 draws conclusion of this paper.

2 Related Work

2.1 Social Awareness in D2D Communication

A D2D relay nodes set allocation strategy is presented in [1] based on D2D communication interruption probability and social parameters, which reduces the outage probability, optimizes the system throughput and solves the optimal power allocation for D2D users (DUEs) equipment and D2D relay equipment problems as well. On this basis, a D2D relay communication interference coordination algorithm introducing social relations is proposed in [2], in which relay node selection using the key characteristics of social relations can significantly improve the security and the connection success rate of D2D communication and reduce the cost of the relay detection. In [3], it is pointed that user distribution density and communication distance are important factors affecting the social perception of D2D communication. D2D node data distribution has the social attribute too [4]. By analyzing the interest difference within social users, the author proposes a logic structure detection method based on user interest difference. Accordingly, [5] considers the small scale cluster with DUEs sharing similar interests to optimize cell resource allocation. [6] designs a D2D node set prediction mechanism based on the social interest, in which data sharing is based on DUE cluster sharing similar interest. Considering the mobility of DUES and different interests, the author proposes a distributed mobile embedded social aware caching scheme to cache the shared content in the partitioned form. [7] ensures the size of the DUE set but ignores the influence of social relationships. Due to the mobility and inclination of social networks, DUE always inevitably has social relationship with a specific D2D node and exchanges a large amount of information.

Fig. 1. System model

2.2 Security Challenges in Social-Aware D2D Communication

[8] and [9] use historical social relationships of DUES to group users and explore the probability of the user joining a node cluster. In the field of mobile communications, the combination of social network parameters for directional data transmission can significantly increase the efficiency of wireless communications and user intimacy. Introducing social networks into D2D communication has great potential in solving D2D communication technology problems, improving the effectiveness of the system and designing a new communication system [10–14].

3 Social Trusted Multiple Seed Nodes Cooperation Model

The emergence of D2D communication has subverted the traditional mobile network architecture. D2D communication simplifies the network topology between users and base stations and increases the topology among D2D users. A part of the user nodes share work of data offloading and distribution from the base station. The other users obtain the base station resources by establishing D2D connections with these nodes, which are the so-called seed nodes in this paper.

3.1 Throughput Payoff of the Coalition

We consider a single cell D2D communication model as shown in Fig. 1 with D2D seed nodes and a base station (BS). Each seed node is regarded as the transmitter while BS is regarded as a receiver. All seed nodes in the cell are defined as $N = \{1, ..., T\}$, where $S \subseteq N$ is a coalition containing N users. In TDMA transmission network, it is assumed that time is divided into equally slots. In this way, in non-cooperative scenario, a seed node takes up one time slot, which means T numbers of seed nodes need T time slots to transmit data.

This can be defined as node-level information transmission. While in cooperative scenario, seed nodes compose different disjoint coalitions, each of which can be regarded as a virtual MIMO device. All the seed nodes of a coalition take up a time slot to carry out a transmission. T times of node-level information transmission are carried out. Due to the mobility and the time-variability of the trust coefficient of the seed nodes, the current coalition segmentation is no longer optimal any more, so the next distributed autonomous coalition segmentation is needed. It is assumed that the transmission service arrival of each seed node obeys the same independent Poisson distribution. According to ergodicity, each coalition can be dispatched and the probability of being dispatched is roughly the same as the ratio of the number of users in the coalition and the number of the total users in the system.

Based on the above assumption, the virtual system formed by a coalition S with size $|S| \times T$ can be modeled as:

$$r_S = G_S + H_S z_S \tag{1}$$

where $z_S = [z_1, ..., z_{|S|}]^T$ is the transmit signal vector of each symbol period in coalition S. Each element in z_S represents the signal sent by each seed node in the coalition S. The signal vector received by the BS receiver in each symbol period is expressed as $r_S = [r_1, ..., r_{|S|}]^T$, in which each element is a signal received by BS. $G_S = [G_1, ..., G_{|S|}]^T$ is the independent and identically distributed additive complex Gauss white noise vector of BS receiver.

According to information theory, for Gauss channel, the best distribution of the transmitting signal is also the Gauss signal. It is reasonable to make the element of z_S independent and identically distributed Gauss variable with zero mean value. The covariance matrix of the transmitting signal z_S is:

$$Q_S = E\left[z_S \cdot {z_S}^{\dagger}\right] \tag{2}$$

where ${z_S}^{\dagger}$ is the conjugate transposed matrix of z_S. For a cooperative coalition S, we consider the path loss model between the seed node and the base station in n slots. The fast fading channel matrix ${H_S}^n$ of $T \times |S|$ is adopted where each element represents the channel fading coefficient from the seed node to BS receiver int n slots:

$$ {h_i}^n = e^{j{\phi_i}^n} \sqrt{\kappa / {d_i}^{n\alpha}} \tag{3}$$

where α is a path fading index and κ is a path fading constant. ${\phi_i}^n$ and ${d_n}^i$ are the signal phase and distance from the seed node i to the base station receiver in n numbers of time slots respectively.

Since we consider a TDMA system, it can be defined that a fixed transmitting power limitation for each time slot, i.e., regardless of the number of seed nodes in a coalition, the total transmit power is limited to:

$$P_S = tr(Q_S) = tr(E[z_S \cdot {z_S}^{\dagger}]) \tag{4}$$

where $tr(\cdot)$ represents the trace of a matrix which can be obtained by summing the diagonal elements of the matrix. The average power limit is applied to all the seed nodes transmitting end of the active coalition set at the time slot. In the non-cooperative scenario, the power limitation above is the same as the power limitation of the active seed nodes in each slot. In fact, due to ergodicity, for each time slot, the long-time power limitation is the same as what of each time slot for each seed node. In this system, only one coalition is allowed to transmit in a time slot, which meas transmitting data will not be interfered by other coalition. Thus, the capacity of the virtual coalition set in one time slot with power limitation is:

$$\begin{aligned} &C_S = \max_{Q_S} I(z_S; r_S) = \max \log\left(\det\left(I_T + H_S \cdot Q_S \cdot {H_S}^{\dagger}\right)\right) \\ &s.t.\ tr[Q_S] \leq P_S. \end{aligned} \tag{5}$$

Finally, according to the water-filling power allocation of each seed node in the coalition, the transmission speed of the seed node j of the coalition S in n time slots can be defined as:

$$C_j = \log\left(1 + \frac{{P_j}^n {\lambda_j}^n}{\sigma^2}\right) \tag{6}$$

In order to form the aforementioned coalition and benefit from the tradeoff between throughput and security, the social trust coefficient of each seed node is evaluated next.

3.2 User Social Relationship Model

In the analysis of social networks, this paper considers the social relationships between DUEs and the social relationships between D2D devices. The social relationships are divided into the following two categories and five types with trust coefficient set for each of them.

User Social Relationship. First, this paper defines a human social relationship (HSR) to indicate the willingness of each D2D node to exchange data with other nodes. This parameter is determined by the degree of familiarity and trust and the frequency of data exchange between D2D node users and the frequency of data exchange. Another type of user social relationship is the market value relationship (MPR). This parameter is determined by the expected benefits that can be obtained by two nodes performing D2D communication. In other words, the establishment of D2D communication guided by this factor is due to the high common interest between the two nodes.

Device Social Relationship. In this type of social relationship, there are not many users actively intervening existing. Instead, D2D device owners and D2D device manufacturers set up rules for trust evaluation. For example, there are co-location device relationship (C-LDR) and co-work device relationship (C-WDR). The former indicates that the two devices that will establish D2D communication have once shared a specific location information (e.g., the family relationship of human society), the latter means that two D2D devices once exchanged resources (e.g., the cooperation between human society) in a D2D communication. Finally, we define an ownership device relationship (ODR) for two D2D devices that belong to the same user. The various relationships and their trust coefficient are shown in Table 1.

Table 1. Social relationship

Social relationship	Relation type	Relation description	Trust coefficient
HSR	User social relationship	Familiarity between D2D nodes	[0, 1]
MRP	User social relationship	Expected benefits that can be obtained by two nodes performing D2D communication	0.2
C-LDR	Device social relationship	Devices sharing a specific location information	0.8
C-WDR	Device social relationship	Devices sharing public experience	0.6
ODR	Device social relationship	Devices that belong to the same user	1

According to the above-mentioned social relationship model, We can describe the social relationship of D2D seed nodes as:

$$r_j = r_i = p_{i,j} \cdot s_{i,j} \tag{7}$$

Where $s_{i,j} \in [0, 1]$ represents the social relationship between a D2D communication pair. $p_{i,j}$ is a bisection function. If user i and user j are close to each other, $p_{i,j}$ takes 1; otherwise, it takes 0.

$s_{i,j}$ in the above parameters is decided by the social relationship between users and the social relationship between devices in the previous statement:

$$s_{i,j} = \alpha \cdot H_{i,j} + (1 - \alpha) \cdot D_{i,j} \tag{8}$$

Where $H_{i,j}$ is determined by the social relationships between users in Table 1. Apparently, the HSR and MPR in previous belong to $H_{i,j}$. While C-LDR, C-WDR and ODR belong to $D_{i,j}$ categories. When a D2D communication pair has multiple relationships of the same type (e.g, there is a user social relationship and a market value relationship at the same time), we select an item with the highest coefficient of trust as $H_{i,j}$. It is because closer social relationships will provide securer D2D connections and improve the performance of D2D connections in this way. In addition, we also set a weighting parameter α to dynamically adjust the proportion of user social relationship and device social relationship between the D2D communication pairs according to a specific application scenario. The extreme case where *alpha* is equal to 1 or 0 indicates that there is only user social relationship or only device social relationship between the D2D communication pairs. A more thorough analysis of all possible communication scenarios is beyond the scope of this article. Therefore, if there is no explicit designation, the default value of *alpha* is 0.5. i.e., we consider the importance of user social relationship and device social relationship to be the same.

Considering the actual throughput and social trust coefficient of seed nodes, we can get the safety throughput of each seed node in one time slot:

$$T_j = C_j \cdot r_{i,j} \tag{9}$$

where C_j defined in (6) represents the transmission speed and r_j defined in (7) represents the social trust coefficient of seed node j respectively.

4 Social Trusted Seed Node Cluster Generation Algorithm Based on Coalitional Game

The generation problem of D2D seed node cluster is modeled as a utility non-transferable coalitional game. The proposed game model can characterize the trade-off between improving system throughput and ensuring node security. By analyzing the formation process and the structure of the coalition, all the seed nodes in the cluster are guaranteed to have higher transmission speed and social trust coefficient.

Specifically, utility non-transferable coalitional game can be defined as $(\mathcal{N}, \mathcal{V}, \mathcal{S})$, in which $\mathcal{N}$ is the set of all game participants with all seed node included. $\mathcal{S} = \{S_1, ...S_k, ...S_K\}$is called a coalition structure and its constituent element $S_k (1 < k < K)$ s a coalition that satisfies $\forall k' \neq k$, $S'_k \bigcap S_k = \varnothing$ and $\bigcup_{k=1}^{K} S_k = \mathcal{N}$. ν is the eigenfunction of coalitional game, which is obtained based on the safety throughput of seed nodes. Since it is a utility non-transferable coalitional game, $\nu(S_k)$ is the set of all $|S_k|$-dimensional utility vectors that S_k can guarantee, which gives each coalition $S_k \subseteq \mathcal{N}$ a subset $\nu(S_k) \subseteq \mathbb{R}^{|S_k|}$:

$$\nu(S_k) = \{\phi(S_k) | \phi(S_k) = (\phi_i(S_k))_{i \in S_k}\} \tag{10}$$

where $\phi(S_k)$ is a vector and the elements in $\phi(S_k)$ represent the safety throughput of participant i in coalition S_k:

$$\phi(S_k) = T_i, i \in S_k, S_k \in \mathcal{S} \tag{11}$$

where T_i is defined in (9). Then we can define the utility function of each coalition $\mathcal{S} \subseteq \mathcal{N}$:

$$\nu_S^n = |\mathcal{S}| T_S^n \tag{12}$$

The aim of this paper is to increase the security throughput as much as possible. As water-filling power considered as the cost of coalition, there will be coalitions with strong desire to deviate from the major coalition and break it into independent and disjoint minor ones. Thus, the major coalition is not always the best coalition structure. With the basic concept of coalitional game described in the previous sections, we can design a self-organizing coalitional game algorithm in D2D communication networks, which is based on the simple principle of merger and separation and allows an improved segmentation $\prod_N$ as follows:

Principle of Merger. For any coalition set $\{S_1, ..., S_j\}$, as long as the condition $\{U_{j-1}^l\} \triangleright \{S_1, ..., S_l\}$ is satisfied, the coalition set is merged, i.e. $\{S_1, ..., S_l\} \rightarrow \{U_{j=1}^l S_j\}$, where each S_i represents a coalition.

Principle of Separation. For any coalition $U_{j=1}^l S_j$, as long as the condition $\{S_1, ..., S_l\} \triangleright \{U_{j=1}^l S_j\}$ is satisfied, the coalition set is separated, i.e. $\{U_{j-1}^l\} \rightarrow \{S_1, ..., S_l\}$, where each S_i represents a coalition.

In short, if merger (or separating) produces a $\triangleright$based priority set, multiple coalitions will merge or separate. The article [14] shows that any iteration of merger or separation will terminate. So it is feasible to design a coalitional game algorithm by merger and separating. In the seed node cooperation coalitional game, it is very attractive to use Pareto criterion as a comparison relation of the merger-separation principle. Under the effect of the Pareto criterion, at least one seed node can increase its personal payoff with this merger only if it does not reduce the payoff of other seed nodes. The coalition will merge. Similarly, at least one seed node in the coalition can directly increase its personal payoff by this separation only when it does not harm the payoff of other seed nodes. Therefore, a merger or separation decision depends on the fact that all seed nodes must benefit from this merger or separation. As a result, any merger (separation) form can be reached when it allows at least one seed nodes to increase payoff and all related users guarantee their payoff meanwhile. The algorithm we propose is summarized as follows:

Algorithm 1. Social trusted seed node cluster generation algorithm

Initialization: $\prod_N \leftarrow \{1, 2, .., N\}, C_i \leftarrow 0, H_i^0, \alpha \leftarrow 0.5, n \leftarrow 1 \forall i$
repeat
1) Each seed node selects a potential coalition partner meeting the requirements $r_j > 0$
2) Calculate node transmission speed by formula (6)
3) Calculate the social trust coefficient of each seed node by formula (7)
4) Each node joins a coalition that guarantees maximum security throughput by formula (9) and (11)
until Convergence to a stable and optimal coalition segmentation

Theorem 1. *Iterative operations based on Merger-Separation (M-S) criterion will be terminated.*

Proof. Proposition 1 guarantees that social trusted seed node cluster generation algorithm can converge. In addition, the complexity of algorithm is closely related to the number of M-S operations. There are a total number of $N - 1$ attempts in the merger operation. Considering the worst scenario, i.e., to traverse all the coalitions in the coalition structure and achieve separation operations, the number of operations required is Baer number. Stability is one of the most important concepts for a coalition game because that of the segmentation means that no combination of the participants can improve the payoff by separating. The stability of the coalition structure obtained by the proposed game model is analyzed below.

Theorem 2. *The coalition structure S obtained by social trusted seed node cluster generation algorithm is stable.*

Proof. It is pointed out in [14] that the coalition structure is stable only if it is the result of the iteration of the M-S criterion. The social trusted seed node cluster generation algorithm is based on the M-S iteration process, so it can directly use the above theorem to verify the correctness. Conversely, if the proposed algorithm cannot be terminated, the final coalition structure cannot be formed. Proposition proved.

5 Simulations

5.1 Simulation Scenario and Parameters

In this section we verify the effectiveness of the proposed algorithm. Considering a single-cell scenario with simplified interference. The cell radius is 500 m, the maximum D2D communication distance is 50 m, the base station transmit power is 46 dBm, the seed node transmit power is 23 dBm and the number of users is [10, 100]. The remaining parameters are shown in Table 2.

Table 2. Core simulation parameters

Parameters	Value
Maximum D2D range	30 m
Cell radius	100 m
Base station transmit power	46 dBm
User transmit power	23 dBm
D2D link establishment time	1 s
Node movement model	Levy flight
Amount of users	[10, 100]
$H_{i,j}$	[0, 1]
$D_{i,j}$	[0.6, 0.8, 1]

5.2 Simulation Results and Analysis

In the communication scenario, the communication entities (seed nodes and non-seed nodes) are subject to the free movement of Levi's flight. The discovery of the D2D device and the establishment of the D2D connection are completed by the base station using the appropriate network protocol. Data transmission between the D2D nodes Out-of-band is completed out-of-band (e.g. Wi-Fi and LTE parallel). In order to verify the efficiency of the strategy, the following scenarios are used as a comparison:

Cellular Solution. Connect using only traditional cellular links.

Simple D2D Connection. Two D2D devices covered by cellular are connected in the shortest distance with base station acting as a security assessment.

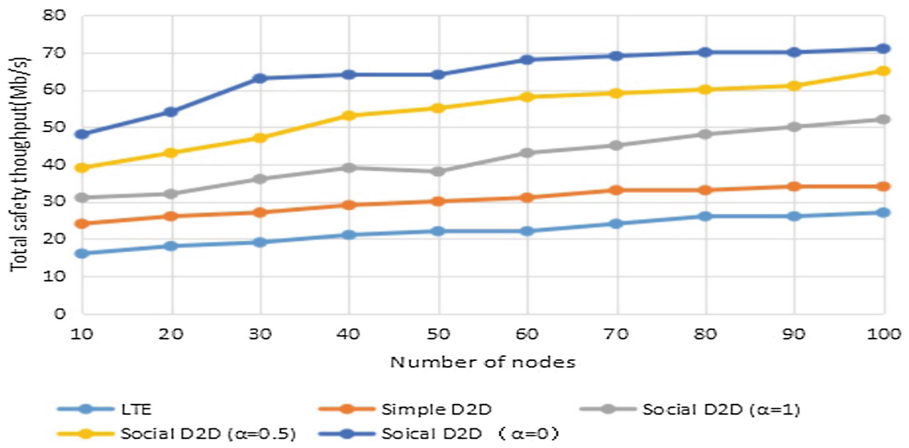

Fig. 2. Impact of social relationships on system throughput

Social Trusted D2D Connection. A D2D node cluster is established based on the method in previous of this paper. The cellular coverage of the seed node is guaranteed while the cellular coverage of other non-seed nodes is not. The security assessment is self-assessed by the D2D linker. In order to evaluate the impact of social relationships between users and social relationships of devices, α will be taken as 0, 0.5, 1 for comparison.

Figure 2 shows the relationship between the total safety throughput and the total number of D2D seed nodes in the cell. As is shown, the total safety throughput of social trusted D2D connections is always better than the cellular solution and the simple D2D direct connection within the range of the number of users. Specifically, when α is equal to 0 (i.e. consider social relationships of devices). The result shows that the social trust coefficient between devices higher, the safety throughput of the system will greatly improve.

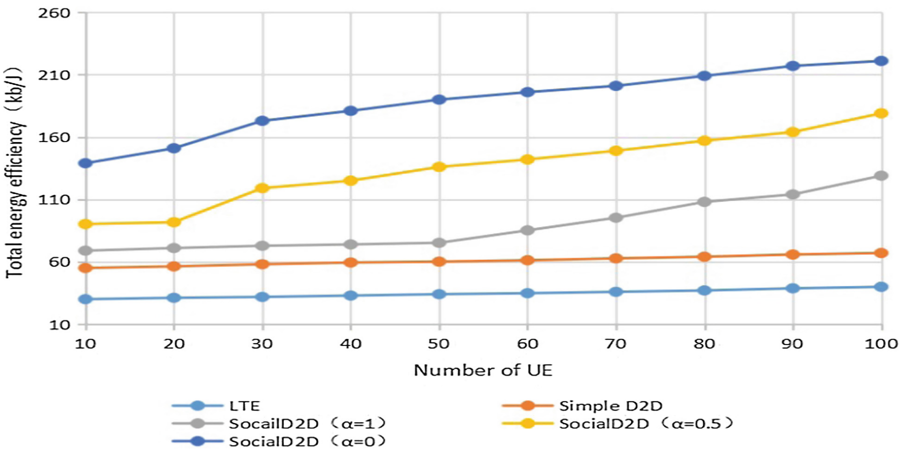

Fig. 3. Impact of social relationships on total energy efficiency of the system

Figure 3 shows the relationship between energy efficiency of D2D communication in a cell and the total number of D2D seed nodes. It can be seen that the energy efficiency of social trusted D2D connection the is obviously better than the cellular solution and the simple D2D direct connection. In particular, when α is equal to 0 (i.e., consider only the device social relationships), the energy efficiency of the system will be greatly improved. It is because D2D communication pairs sharing a device social relationship are usually closer in space.

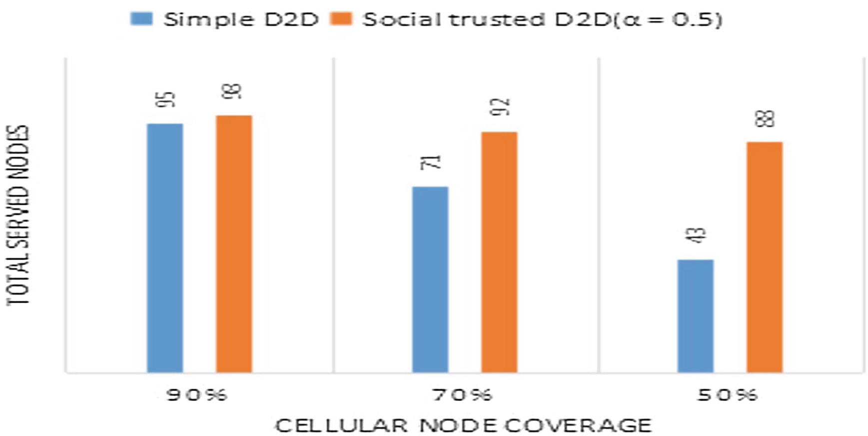

Fig. 4. Impact of social relationships on number of served nodes in the system

Further, in the right subplot of Fig. 4 we report on the proportion of users served with a simple D2D link or a social trusted D2D cluster. As we learn from this plot, when the available cellular coverage area is particularly small, in the case of the simple D2D solution the number of users that establish a D2D connection is low. This is due to the fact that under-coverage users reside in proximity to the BS and thus receive higher channel quality compared to that on the D2D link. As a consequence, a higher number of users may be served through the infrastructure links with the BS. On the contrary, the percentage of users served via D2D connections is three times higher for the proposed social trusted D2D solution. The explanation of this result lies in our solution being able to also provide connectivity to those users who are outside the cellular coverage (i.e., within D2D clusters). Note that this important outcome is achieved due to the operation of our social-based secure cluster formation scheme.

6 Conclusions

In this paper, we combine social relationships with D2D communication and adopt the method of coalitional game to propose a D2D seed node cluster generation algorithm toward social trust. This paper introduces two models, multiple seed node cooperation model and user relationship model. Based on this, this paper proposes the concept of security throughput, which maximizes throughput of seed node clusters on the premise of security. Simulation results proves the effect of our solution.

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