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Social Interaction Assisted Resource Sharing Scheme for Device-to-Device Communication Towards Green Internet of Things

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ABSTRACT Recently, to reduce the increasing energy consumption along with the explosive growth of smart terminals and network data in Internet of Things (IoT), green IoT is attracting more and more attention from both academia and industry. Towards green IoT, this paper devotes attention to Device-to-Device (D2D) communication and social network which are two essential components in green IoT and first reviews the latest developments about them. Further, this paper proposes a social interaction assisted resource sharing scheme for D2D communication, to improve the utilization of spectrum resources in green IoT. Specifically, the proposed scheme abstracts the D2D communication system into social layer and physical layer, by combining social network with D2D communication. Extensive simulations with real social interaction data are conducted and they show that the proposed scheme can achieve improvements in terms of the transmission success rate for green IoT.

INDEX TERMS Green IoT, D2D communication, social network, resource sharing.

I. INTRODUCTION

In recent times, various smart terminals and massive network data are explosively growing in Internet of Things (IoT), which leads to that the energy consumption in IoT is increasing quickly. To this end, green IoT [1]–[3] with the focus on reducing energy consumption in IoT is attracting more and more attention from both academia and industry. With the continuous development of IoT around the world, an unprecedented number of IoT devices are bound to consume a lot of energy. It is expected that by 2020, IoT devices will become the leading energy consumers in the field of information and communication technology [4]. It has also been estimated that the global energy consumption of IoT edge devices will approach 46TWh by 2025, which is equal to Portugal's entire annual electricity consumption in the year of 2015 [5]. As people recognize the depletion of brown energy on our planet and the harmful effects of carbon emissions in surrounding environment, it is hopeful and necessary to use resource sharing to reduce energy consumption of IoT devices in accordance with the needs of global environmental friendliness and sustainable development in modern society.

In order to relief the above problems and further improve the utilization efficiency of transmission energy, technical solutions for efficient consumption have been widely explored. Researchers have proposed many methods, hoping to promote resource sharing between various heterogeneous wireless networks. The basic idea of these methods is to increase the chance of sharing spectrum in an effective way, and to promote the coexistence of multiple wireless communication systems in a certain frequency band. In recent years, with the increasing demand for IoT devices, Device-to-Device (D2D) communication technology [6]–[8] that allows

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terminal devices to directly multiplex cellular network spectrum will greatly improve the utilization of spectrum and network capacity. The D2D communication originally proposed in cellular networks has become a new paradigm for enhancing network performance. At the same time, the emergence of new applications such as content distribution and location-aware advertising has introduced new user cases for D2D communication under cellular network. Preliminary research shows that D2D communication has the advantages of improving transmission energy consumption efficiency and reducing communication delay. Academia, industry and standardization bodies are studying the feasibility of D2D communication in LTE.

As a result of the fusion of ubiquitous mobile communications and fast-growing online social networks, mobile social networks are infiltrating people's daily lives. With the explosive growth of online social networks, more and more people on major social media networks are actively participating in online social interactions, and the social relationships between them have also been widely expanded and significantly enhanced. Social relations are becoming a new and important aspect of the design of communication systems. Besides, with the emergence of online and mobile social networking companies, such as Facebook and Twitter, more and more real-world data and traces of human social interaction are being generated. It enables researchers and engineers to observe, analyze and factor social factors into engineering system design in an unprecedented way. The author in [9] uses social structures such as communities to design efficient data forwarding and routing algorithms in tolerable networks, while in [10], social intermediateness and centrality are used as forwarding indicators. Besides, [11] proposes a prediction method based on social interaction indicators to identify the best information carrier for content publishing and subscription. Simultaneously, the authors in [12] use social influences to design effective data distribution mechanisms for mobile networks. However, there is a common assumption in these work that all users are always willing to provide services such as data forwarding and relay, which might not be realistic for some applications.

D2D communication shares the spectrum with cellular networks, and increases the capacity of network by using D2D communication between device users. D2D communication can reduce load of evolved Node B (eNB) and end-to-end transmission delay, while device users can directly transmit data without intervention of eNB. However, in the process of sharing spectrum resources with cellular networks, due to D2D's unique spectrum multiplex communication mode, it will inevitably introduce additional interference to original cellular users in the network. If there is no effective resource allocation and interference management means, the problem of system performance degradation caused by these interferences will largely limit the application of D2D communication. Besides, D2D communication also faces many other challenges, such as user device discovery and routing. Optimized routing discovery involves finding the best path for end-to-end D2D communication by considering network and device constraints, and routing management is a process of finding the best alternative path when a link on an earlier established route fails. Moreover, user devices under inband D2D communication need to reuse uplink and downlink resources in the same cell. Consequently, it is important to design a D2D mechanism in such a way that D2D device users do not interrupt cellular service. Although the characteristics of D2D interference have not been well understood, it is imperative to resolve interference management through power and resource allocation scheme.

Therefore, in this work, for the purpose of further improve the utilization of transmission energy and solve the problems of interference coordination between D2D communication and cellular network, we propose a social interaction assisted resource sharing scheme. The main contributions of this paper could be summarized as the following three aspects.

- Firstly, the proposed scheme combines social network with D2D communication, and abstracts the actual communication system into social layer and physical layer. Specifically, social layer mainly completes the ranking recommendation for corresponding D2D device users according to the user's social activities, and physical layer makes a comprehensive selection based on the recommendation order and transmission rate requirements of cellular network users.
- Additionally, the proposed approach in this paper combines real user social interaction rating behavior, other than simulation data, for experimental analysis, which has more reference value for specific practical applications. Meanwhile, through the constraints in the proposed method, D2D user devices could be effectively selected, and the number of available D2D link combinations based on proposed format could be increased, while the performance is relatively stable.
- Furthermore, to cope with N-P hard problem caused by sending multiple requests during D2D user device pairing process, the proposed scheme relaxes and approximates the issue, which effectively reduces computational complexity and provides possibility for engineering applications in reality.

The rest part of this paper is organized as follows. Section II briefly reviews the recent developments about D2D communication and social network. Section III proposes a social interaction assisted resource sharing scheme for D2D communication underlaying cellular network. In Section IV, numerical experiments are made and the performance of proposed approach is analyzed. Finally, Section V concludes this paper.

II. RECENT DEVELOPMENTS ABOUT D2D COMMUNICATION AND SOCIAL NETWORK

To cope with the growing demand for local network services from increasing data, D2D communication has been continuously developed, making it possible for mobile users

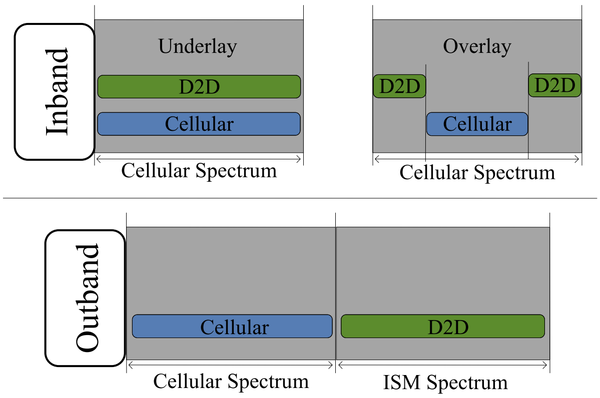

FIGURE 1. **D2D communication in various scenarios.**

to communicate directly at short distance without going through higher levels of control. D2D communication could reduce the consumption of transmission energy effectively, while providing greater throughput and higher data rates, as well as lower latency. At the same time, in addition to the above advantages, D2D communication also faces many technical problems, including device discovery and routing, spectrum resource allocation, interference coordination and management. In recent years, mobile social network has been gradually penetrated into every aspect of people's daily lives. Therefore, it is considered to combine the characteristics of social network with D2D communication headed for further improvement of energy efficiency under cellular network.

A. RECENT WORK ABOUT D2D COMMUNICATION

D2D communication is a kind of technology that allows terminals to communicate directly by reusing cellular resources, which could be applied to mobile cellular networks to improve resource utilization and network capacity. Besides, D2D communication will become an inherent part of IoT. It will also enable the effective use of network resources. When user device is out of coverage, if the central base station fails or becomes inaccessible, remote devices can use D2D communication to implement short-range peer-to-peer connections, so that they could relay data to each other. Meanwhile, D2D communication is expected to deploy in IoT to reduce the transmission energy consumption between eNB and terminal users. Some practical scenarios of D2D communication are providing service continuity when user devices exceed the coverage of core network, which reduce the load of eNB and increase the capacity of network at the same time. Different scenarios of D2D communication are shown in Fig. 1.

In academia, [13] analyzes various types of communication with respect to the routing characteristics of D2D communication. It mainly includes probabilistic algorithms, bioinspired algorithms, hierarchical algorithms and context-aware algorithms. The stochastic/probabilistic algorithms are mainly optimized for specific objects. They are designed to formulate routing probabilities, which optimize a set of network resources, such as energy consumption and link metrics. The basic methods of such optimization include real-time optimization and prior optimization, with the intention of adapting to flexible and changeable wireless network scenario. Generally, a lot of routing algorithms will be based on the aforementioned random probability theory, rather than a deterministic method. Therefore, the random routing algorithm is probably more suitable for the uncertainty of device movement in D2D communication. Examples of biological heuristics include cluster-based algorithms, such as ant colony optimization, while swarm intelligence is collective behavior based on observing decentralized and self-organizing systems. The hierarchical algorithm could be tree-based or cluster-based, how to choose cluster head is the main problem of this kind of algorithm. A lot of algorithms have been proposed in the literature about cluster head selection, but these algorithms generate extra delay and complexity, which probably are not suitable for D2D communication. For D2D communication, context-aware routing algorithm could obtain context-related information of devices in network, and based on these information, select a D2D device for data forwarding and transmission. These algorithms support the characteristics of D2D communication, and can opportunistically utilize network resources for cognitive and seamless communication in real time.

By using the concepts of game theory and autonomous learning machine, the performance of the Bayesian joint game in D2D communication is evaluated in [14]. Most of the existing solutions assume that the player only has a certain fixed learning rate, so that the optimal solution will be obtained at some points. In the proposed scheme, according to the newly defined utility function, each player has variable learning rates, and they determine their transmission behavior through competitive learning, this method makes the game process quickly reach the Nash equilibrium. Besides, each player gets feedback of its own transmission behavior within a unit time interval from the surrounding environment.

Generally speaking, due to mutual interference, there is a basic balance between D2D communication and traditional network interruption performance. Reference [15] introduces a new interference-aware routing algorithm for emergency transmission in urban environments. For different traditional network interruption restrictions and the distance between end-to-end in D2D communication, the solution recommends different D2D routing strategies. The influence of different user densities and building material characteristics on the feasibility of D2D communication is also considered.

For the sake of same objective, [16] points out one scheme that combines D2D communication with cognitive radio (CR), that is CRD2D. By means of the integration of D2D and CR technology, a socially conscious big data application routing framework is proposed, which uses the regularity of node mobility and spectrum mobility to improve the performance of data transfer. It also solves the open research problem of big data routing.

Jedari *et al.* [17] proposes a malicious-forwarding-behavior-aware D2D link selection mechanism to reduce the impact of malicious attacks on data forwarding, and then based on the correlation between user's forwarding activities, the user behavior is analyzed, while the malicious user is identified through the Elman neural network. As a result, malicious users are detected and the best D2D link is selected.

Jameel *et al.* [18] has mentioned secure routing approach in D2D communications with decode-and-forward relaying. Specifically, for a certain path, derive the strict expression of secure connection probability within two scenarios of colluding and noncolluding eavesdroppers. Firstly, according to actual scenario application, the above strict definition is relaxed to obtain its approximate expression. After that, according to the approximate expression of secure connection probability, classical Bellman-Ford algorithm is used to find the path with the highest security connection probability through identification and adopt it as a safe path. The validity of the proposed method is verified by experimental simulation, the experimental results show that the performance of above mentioned secure routing algorithm is similar to the ergodic search method.

Hu *et al.* [19] focuses on the design of secure D2D transmission, firstly, consider the scenario of a single antenna under the premise of adopting randomize-and-forward relay strategy, and then derive the secure outage probability expression in the case of two-hop transmission. After that, under the constraint of probability of confidentiality interruption, the problem of maximum confidentiality rate is raised. Afterward, based on the above analysis, a more general multi-antenna scenario is introduced. The experimental results show that the proper use of relay transmission can improve the confidentiality throughput and expand the security coverage.

He *et al.* [20] analyzes two transmission schemes, that is, amplified forwarding and decoded forwarding in D2D network, and corresponding closed-form expressions for secrecy outage probability (SOP) and connection outage probability (COP) for single-hop links. According to the above scenario of a single-hop link, the SOP and COP expressions of the end-to-end link path are further derived and used as performance evaluation indicators of path security and communication quality. By comprehensively considering the SOP and COP, an index to measure the pros and cons of path selection is obtained, and then a flexible path selection algorithm is proposed, which can help us choose the appropriate communication link according to different security and communication quality requirements.

Wang *et al.* [21] proposes an adaptive jamming receiver operating in a switched FD/HD mode for a D2D link in random networks. Subject to the secrecy outage probability constraint, the approach optimizes the transceiver parameters to maximize the secrecy throughput. Under the assumption that the position distribution of eavesdroppers obeys the uniform Poisson point process, in order to confuse these collusion eavesdroppers, each relay works in a full duplex state. In order to solve the problem of secure routing, an approximate expression of secure connection probability is given, and it is applied to the improved Bellman-Ford routing algorithm.

Jameel *et al.* [22] introduces a kind of workflow of trust-aware secure routing mechanism, firstly, the degree of trust of the sensor node is calculated according to the daily behavior of the sensor node; then, the degree of trust of the path is calculated from it, and a trust calculation model is established to obtain the optimal path from the source node to the destination node.

To summarize, recent work about D2D communication usually focuses on routing algorithms and summarize the issue as optimization problem. Due to the N-P hard problem caused by sending multiple requests during D2D user devices pairing process, the current methods might face computational complexity problems, while the proposed scheme in this work relaxes and approximates the issue to reduce computational complexity and provide possibility for engineering applications in reality.

B. RECENT WORK ABOUT SOCIAL NETWORK

Social network is becoming a new and important aspect in communication system design, with the emergence of mobile social networking companies, more and more real-world data and traces of human social interaction are being generated. This enables researchers to observe, analyze social factors and incorporate them into the design of engineering systems in an unprecedented way.

From the literature, Ahmed *et al.* [23] proposes a framework based on social trust and social reciprocity to promote efficient cooperation between cooperative D2D communication devices, the problem of relay selection is reduced to the joint game between social trust and social reciprocity. By designing a network-assisted relay selection mechanism, the solution of joint game scheme is implemented. The relay selection mechanism is not affected by group bias, individual allocation, authenticity and computing efficiency.

Jameel *et al.* [24] introduces the peer discovery techniques in D2D communication from two aspects, that is ad-hoc approach and network-controlled approach. Establish a new paradigm for peer discovery in D2D communication underlaying cellular systems, and based on the framework, a social-aware ad-hoc peer discovery scheme is proposed. Specifically, according to social community and centralities information, mobile users could be divided into different groups. Subsequently, determine the optimal detection rate for each group by sending beacons at constant intervals.

Wu *et al.* [25] employs social similarity aware D2D user equipment to network relay helps to improve system capacity. Then, propose a two-stage D2D selection scheme. Specifically, a joint algorithm exploiting the intuitionistic fuzzy analytic hierarchy process and the entropy weight generation method is designed for stage one. In stage two, with the constructed decision weights, the multi objective binary integer linear programming could be transformed to a simpler binary integer linear programming problem and thus be solved distributively through an efficient message passing method.

Wu *et al.* [26] employs the weighted directed graph theory to model the two-sided physical-social-aware preferences which optimally match potential providers to demanders of contents. Then, analyze the physical-social-aware matching problem. Finally, a distributed algorithm based on the Dinkelbach iteration and deferred acceptance approaches is developed.

Wang and Wang [27] proposes a cooperative secure transmission strategy to enhance the network secrecy performance. Specifically, by constructing the social-aware utility functions for active D2D links as well as inactive devices, it can formulate the optimization problem aiming at maximizing the overall network sum utility. Consequently, develop the social relationship weighted matching algorithm.

Jameel *et al.* [15] introduces an optimal jammer selection method in D2D communication to maximize the confidentiality probability under the consideration of social trust characteristics and power allocation. Since the secret rate maximization problem is non-convex regardless of channel state information model, therefore, the use of a heuristic genetic algorithm for faster optimization will reduce the performance loss.

Ahmed *et al.* [28] investigates the problem of physical-layer secure transmission jointly with resource allocation in D2D communications based on social trust. The issue incorporates mutual interference and proposes different transmission modes for a secrecy-ensured resource allocation-based overlapping coalition formation scheme with transferable utility to obtain a final stable partition.

To incorporate the social behavior of D2D nodes, Chun *et al.* [29] considers the decision to relay using the donation game based on social comparison, characterize the probability of cooperation in an evolutionary context and then evaluate the network performance of relay-assisted D2D communications. It shows that practical scenarios achieve lower transmission capacity and higher outage probability than before.

Wang *et al.* [30] proposes an attack detection mechanism in D2D link selection. Firstly, by analyzing the relationships and forwarding behaviors of users, behavioral attributes of D2D users can be identified. According to the contact history, contact states including contact depth and contact width are estimated to accurately perceive the relationship between users. Furthermore, the intimate degrees of user relationships are analyzed under different scenarios for the behavior detection.

Ometov *et al.* [31] studies aspects of social trust associations over proximity-based direct communications technology, with a primary focus on developing a comprehensive proof-of-concept implementation. It indicates that its recently developed prototype delivers rich functionality for dynamic management of security functions in proximate devices, whenever a new device joins a secure group of users or an existing one leaves it. To characterize the behavior of implemented demonstrator, they evaluate its practical performance in terms of computation and transmission delays from the user perspective actually.

TABLE 1. Summary of symbols.

Symbol	Notation
i	User i
j	Resource sharing item
t	Rating time
N	Request sending number
λ	Parameter set of Poisson distribution
$P_{ro-hold}$	Holding probability
P_{ijt}	Probability for user i to hold item j at time t
P_{fN}	Error probability of N users
ε	Threshold value of error probability
δ	Threshold value of D2D link transmission rate
σ_N^2	AWGN channel variance
h_{ij}	Small-scale fading coefficients
P_s^c	Transmit power from cellular user to D2D receiver
P_t^d	Path loss of D2D signal link
T^c	Maximum achievable link rate of D2D pair
$\overline{T_D}$	Transmission success rate
$o(\cdot)$	Time complexity function

To summarize, recent work about social network focuses on social aware assisted relay selection, and formulate corresponding secure transmission strategy to enhance network capacity and safety. These approaches attempt to quantify users relationship through some abstract parameters, while might limit users autonomy in reality to some extent. Nevertheless, the proposed scheme in this work only makes ranking recommendation in social layer, and the number of available link combinations could be increased.

III. SOCIAL INTERACTION ASSISTED RESOURCE SHARING SCHEME

In this section, we first give the system model, and then formulate the optimization problem. For ease of reference, important symbols are summarized in Table 1.

A. SYSTEM MODEL

With the development of communication technology, the wireless communication system will develop towards the direction of network convergence. Its purpose is to comprehensively utilize multiple wireless access technologies and multiple wireless communication methods to improve spectrum utilization and network capacity. D2D communication is one of the hotspot technologies. It allows several mobile devices in the cellular network to communicate directly

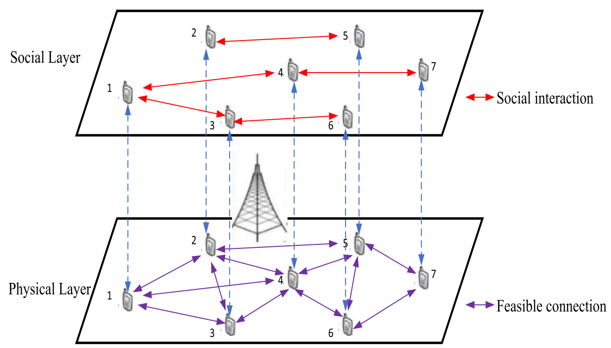

FIGURE 2. Social interaction assisted D2D communication.

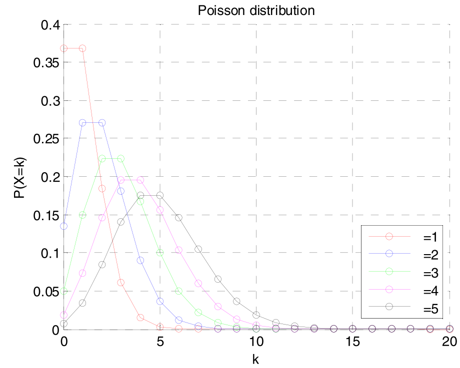

FIGURE 3. Poisson distribution map with different λ values.

with each other. The key technology is how to solve the interference coordination between D2D communication and the cellular network system.

Research shows that the existing spectrum utilization rate is low, especially the ISM (Industrial Scientific Medical) unlicensed frequency band, which has stimulated the research of cognitive radio technology and made it possible for cognitive users to use the cellular network spectrum. Nevertheless, cellular network operators have reservations about sharing their licensed spectrum with other systems. Therefore, a D2D communication technology is proposed, which will enable cellular network operators to share their licensed spectrum. D2D communication shares the use of spectrum with cellular networks, and increases the capacity of the network by using D2D communication between users. D2D communication can reduce the load of eNB and end-to-end transmission delay. Users can directly transmit data without the intervention of eNB. However, in the process of sharing spectrum resources with a cellular network, due to D2D's unique spectrum multiplex communication method, it will inevitably introduce additional interference to the original cellular users in the network. Without effective resource allocation and interference management methods, the problem of system performance degradation caused by interference will largely limit the application of D2D technology in future communication scenarios. To this end, a spectrum sharing scheme based on social relationship assistance is proposed, as shown in Fig. 2.

As illustrated in Fig. 2, D2D resource sharing communications with assistance of social interaction can be projected onto two layers: the social layer and the physical layer. In the social layer, different devices have different contact relationships based on social interactions among the devices' users. In the physical layer, different devices have different feasible connection relationships subject to physical transmission constraints. In addition, according to different physical transmission constraints, there are various connections between different devices. Combining the characteristics of social network with D2D communication system can not only effectively improve the performance of D2D communication system, but also improve the personal experience of device users. Besides, it is assumed that D2D communication exists in the scenario where just one cellular user covers, that is, each D2D communication is independent and does not affect each other. At the same time, for a period of time when the item is shared between different device users, it is assumed that one D2D pair can form a D2D link when it meets the constraints of specific success rate and transmission speed.

B. SOCIAL LAYER

At first, we assume that the higher of rating score item j got, the larger holding probability $P_{ro-hold}$ it will be have, for the reason that device users may keep the item j if he/she likes it. That is also to say, the device users will make a higher rating score if he/she likes the item j. Moreover, we also consider that the probability of holding item j will change with time went on and assume it follows the exponential distribution as a whole, which can be illustrated as

$$P_{ijt} = P_{ijt_0} \cdot e^{-\beta(t-t_0)} \tag{1}$$

where P_{ijt} means the probability for user i to hold item j at time t, while t_0 strands for the initial rating time for user i rate item j. Specifically, for a specific user, its relationship can follow the Poisson distribution, which could be expressed as

$$P_{ijt_0} = P(r_0, \lambda) = P(X = r_0) = e^{-\lambda} \cdot \frac{\lambda^{r_0}}{r_0!} \tag{2}$$

For different λ values in Poisson distribution, the Poisson distribution curve could be shown in Fig. 3.

As shown in Fig. 3, as the λ value increases, the curve moves to the right as a whole. At the same time, for different λ values of Poisson distribution curves, it obtains extreme values at the point of λ. Furthermore, we make the rank of social users according to item j's holding probability $P_{ro-hold}$ to make recommendation for user i in the seek of nearby content sharing Device j. Besides, we assume that a D2D device user sends a request to a neighboring device user each time, and when it is rejected, it turns to the next neighboring device user to send a request. Among them, the order of sending requests depends on social layer recommendation rank, and the maximum number of sending requests is recorded as $R_{\max} \in [1, N]$. In addition, the success rate constraint can be

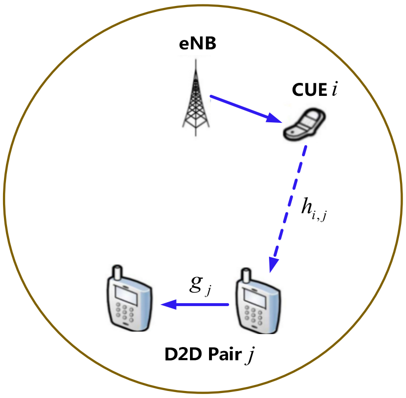

FIGURE 4. D2D communication underlaying cellular network.

illustrated as

$$P_{fN} = \frac{(1-P_{ro-hold1})\cdot(1-P_{ro-hold2})\cdots}{(1-P_{ro-holdN})} \leq \varepsilon \quad (3)$$

where P_{fN} represents error probability of Nusers, while the threshold value ε can be set according to specific application scenarios. Equation (3) shows that with the increase in the number of sending requests, the error rate should be controlled within a certain range to ensure the accuracy of content transmission. At the same time, the data transmission rate of cellular network user equipment during normal communication also should be guaranteed.

C. PHYSICAL LAYER

The problem of spectrum sharing between D2D device users and cellular network users is a hot topic in D2D communication research, while the key step is how to set up a D2D communication link. Specifically, we consider a physical layer communication link establishment strategy based on D2D user equipment underlaying cellular network, as shown in Fig. 4.

For the sake of different scenarios in reality, D2D communications may go through diverse channels which directly influence the transmission success rate. Therefore, we assume additive white Gaussian noise on each channel with variance σ_N^2. Moreover, we assume the communications have fixed transmit power and path loss where devices has low mobility, that is, the devices will keep still until file transmission finished. Due to the pairing between D2D user equipment, the mathematical complexity of the communication link establishment problem is $_o(N \cdot M)$, which is an N-P hard problem. In fact, in order to simplify this N-P hard problem, it can be approximated after being relaxed, that is, converted into a transmission rate limitation issue between cellular user and D2D pair, which can be illustrated as

$$T^c = \log_2(1 + \frac{P_s^c \cdot h_{cb}}{P_t^d \cdot h_{ij} + \sigma_N^2}) \geq \delta \quad (4)$$

where T^cmeans the maximum achievable link rate of D2D pair, while the threshold value δ can be set according to specific application scenarios. Besides, h_{cb} and h_{ij} denote the small-scale fading coefficients of corresponding links. Meanwhile, P_s^c and P_t^d are the product of transmit power and path loss of D2D signal link and interference link from cellular user to D2D receiver, respectively. Equation (4) shows that when the D2D link is used for resource sharing, the transmission rate of cellular users in this range should not be significantly affected, that is, the transmission rate of cellular users should be guaranteed to be above a certain threshold.

D. OVERALL SHARING PROPOSAL

For resource sharing in D2D communication underlaying cellular network, first, Device i finds its nearby possible Devices N in the physical layer; and then, with social layer's assistance, these N Devices will be ranked according to comprehensive judgment of holding probability that they cleave to the item j and transmission success rate. For a specific combination of $D_1, D_2, \cdots, D_N$, its transmission success rate can be expressed as

$$\begin{aligned} &P_{ro-hold1}\cdot T_1 + (1-P_{ro-hold1})P_{ro-hold2}\cdot T_2 + \ldots \\ \overline{T_D} = &+ (1-P_{ro-hold1})(1-P_{ro-hold2})\cdots \\ &\times(1-P_{ro-holdN-1})P_{ro-holdN}\cdot T_N \end{aligned} \quad (5)$$

while

$$T^d = \log_2(1 + \frac{P_j^d \cdot g_j}{P_i^c \cdot h_{ij} + \sigma_N^2}) \quad (6)$$

In this paper, we assume that a D2D pair may establish a D2D link for resource sharing only if the item j's content can be successfully delivered. The performance of item j sharing can be characterized with the overall consideration of success rate and transmission speed in the item resource sharing duration.

IV. EVALUATION AND ANALYSIS

In this section, the performance of the proposed social interaction assisted resource sharing scheme will be analyzed through experiments. In the research, the physical layer assumes that D2D user equipments are randomly placed in a circular area with a $20m$ radius, and the transmission power is set $P_s^c = 1000dBm$, $\varepsilon = 0.58$, $\delta = 4.1$, while others take the unit values. At the same time, the social layer will combine real social interaction rating data [32] for experiments. According to the social interaction assisted resource sharing scheme (SLA, Social Layer Assistance), Fig. 5 shows the corresponding relationship between item and transmission success rate for a certain fixed number of requests. Among them, NSLA (No Social Layer Assistance) is an approach that is selected only based on physical distance without the assistance of social relationships, while the comparison scheme [33] LAP (Link Admission Policy) assumes that a D2D pair may be configured for a

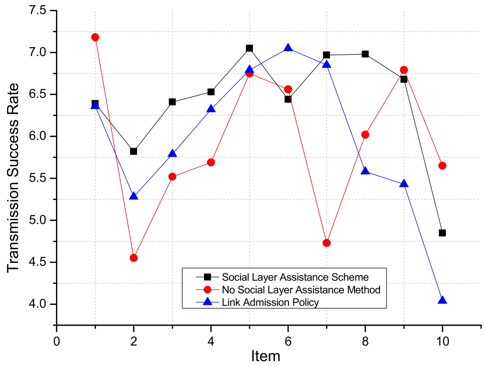

FIGURE 5. **Correspondence between item j and transmission success rate $\overline{T_D}$.**

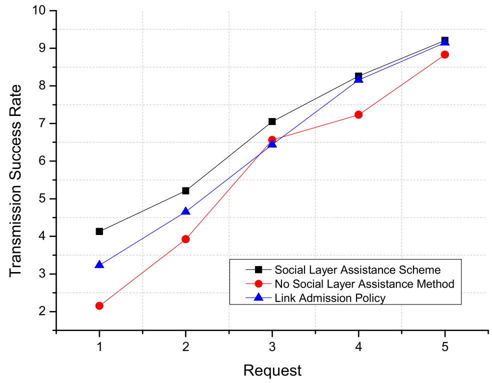

FIGURE 6. **Correspondence between request number R and transmission success rate $\overline{T_D}$.**

D2D link only if a necessary data block can be successfully delivered. At the same time, the interaction behavior characteristics of user devices are abstracted into contact duration and encounter frequency. Due to the mobility of user equipments, the time for D2D equipments able to maintain communication and perform effective data transmission is always within a certain range. Therefore, time-sensitive data files must be transmitted in one encounter, while time-sensitive data packets can be segmented and transmitted through multiple encounters. This method determines the transmission delay of the data block by considering duration of each contact and the frequency that two D2D user devices could be meet.

It could be seen from Fig. 5 that the proposed SLA scheme has an overall good generality for different pre-shared item $j$resource. Specifically, the transmission success rate has variable changes for different sharing items. Due to the close distance, sometimes NSLA scheme may have a larger transmission rate, but its robustness is poor. In addition, the transmission rate of the proposed scheme at item 8 and 9 is approximately 1.3 times that of comparative LAP approach. Above and beyond, compared with the comparison method LAP, the SLA approach has more options, that is, for different numbers of requests, the SLA scheme combined with social interaction assistance will get a variety of D2D combination for other device users to choose. In addition, compared with the other two proposals, the proposed scheme has a higher transmission success rate without increasing the complexity. In particular, in the case that the pre-shared item has been determined (e.g., $j = 163$), the correspondence between number of requests and transmission success rate is shown in Fig. 6.

In Fig. 6, for certain shared item resources, with the number of requests increases, transmission success rates of the three schemes all show an increasing trend. Compared with NSLA method, the overall performance of experimental LAP scheme is stable, but it fluctuates in individual cases (e.g., $R = 3$). Therefore, the proposed SLA scheme is more robust than the comparison method, and its transmission success rate is relatively high. The above experiments show that the performance of social interaction assisted resource sharing scheme (SLA) is significantly better than that of NSLA method, and when D2D device user sends multiple requests, the SLA scheme can provide multiple D2D device user combinations that meet the limitations. At the same time, it is more stable than LAP scheme, and can effectively improve the overall transmission success rate of the communication system. Moreover, the proposed scheme also gets some meaningful results in laboratory environment. For example, users of devices with a high rating for a specific movie are usually able to share it with other users who need it in the nearby.

V. CONCLUSION

In order to further improve the utilization of spectrum resources and address the problem of interference coordination between D2D communication and cellular networks for green IoT, this paper proposes a social interaction assisted resource sharing scheme. The approach combines social network with D2D communication, while abstracts the actual communication system into social layer and physical layer. Among them, social layer mainly completes the ranking recommendation for corresponding D2D device users according to the user's social activities, and the physical layer makes a comprehensive selection based on recommendation order and transmission rate requirements of the cellular network user.

Regarding the comparison, the SLA scheme proposed in this paper combines real user social data for experimental analysis, which has more reference value for specific practical applications. At the same time, through the constraints in SLA scheme, D2D user equipment can be effectively selected, and the number of available D2D communication link combinations based on this could be increased, while the performance is relatively stable. In addition, for the N-P hard problem caused by sending multiple requests during D2D user equipment pairing process, the proposed method relaxes and approximates it, which effectively reduces the computational complexity and provides the possibility for engineering applications.

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