

Social Activeness Based Relay Selection: A Game Theoretic Approach

Jagadeesha RB and Jang-Ping Sheu
Department of Computer Science
National Tsing Hua University, Hsinchu, 30013, Taiwan
jagadeesha.rb@gmail.com, sheujp@cs.nthu.edu.tw

Abstract- D2D cooperative communication is one of the essential requirements of the next generation networks. As human beings carry D2D devices, their emotions also play a prime role in cooperative data exchange. Several earlier works have discussed the various social factors; none has considered the significance of multiple social networks a user can have contact with. In this paper, we leverage the social contacts of a user with various social networks to decide the next hop relay. We take into account the total friends and their contact duration of each social network to determine the relay that has the maximum potential to disperse the information. By considering these social aspects along with the physical parameters, we developed a utility function to model our problem as a relay selection game. We proved our game model as an exact potential game, which has Nash equilibrium. Simulation results show that the proposed method has better throughput when compared to the conventional methods.

Keywords- Cooperative communications, social networks, game theory, Nash equilibrium.

I. INTRODUCTION

Due to the explosive growth of handheld smart devices like smartphones and tablets, it is projected that by 2018 the mobile generated traffic will reach 120 Exabyte of data per month [1]. Besides, the upcoming 5G technology will introduce many proximity services, and device-to-device (D2D) communications will be the most prominent among them. In a D2D scenario, usually the human beings will carry the handheld devices through which they will share information among each other through licensed or unlicensed spectrum [2]. In support of this, we observe that in the current trend several social networking Apps promote mobile users to circulate more data into the network. However, normally these users will be hesitant to communicate with strangers. As a result, well-established social relationships mandate the cooperative D2D communications. In this kind of cooperation based communication, some users act as relays to those have good social ties and channel characteristics with them to assist in forwarding the data [3][4].

While considering the social and physical factors, both play an equally important role in deciding the user selection for cooperative communications. Thus, it is a very challenging task to determine the most reliable user device as a relay when we target to maximize the amount of information being dispersed. Few authors have discussed social trust, reciprocity, contact frequency, secrecy level, etc., into account while deciding the relay user to maximize the throughput [5]-[8].

Due to the advent of many social networking Apps, it is common to find real life friends who are related socially via multiple of these networking Apps like Facebook, Wechat, and Line. However, from our intuition, though there are several Apps, all these Apps are different regarding the number of subscribers, user activity, popularity, user interface, etc. As a result, a user will become more interested in joining a network by considering all these factors. In such a situation, to disseminate the information like an advertisement or video

broadcast to a large crowd will be influenced by all these factors mentioned before, which motivated this study.

In this paper, we consider the physical and social characteristics of D2D nodes and find the best relay in the surrounding to maximize the information dispersion or throughput by cooperative communications. Mainly, we consider a realistic scenario of a socially active user having contacts with multiple social networks of different size to investigate their role while choosing the next hop relay for information dispersion. We develop a utility function by combining physical and social attributes that consider interference, congestion, and social activeness. So, we model this problem as a non-cooperative game to determine the most appropriate user to act as a relay, that is socially active and physically less interfering and less congested to improve the amount of dispersion. The main contribution of our work are as follows: our work is the first to consider the diversity of the social network links and our game model is an exact potential game that converges in finite steps. The simulation results show that the throughput and utility of our model is comparatively better than the traditional methods.

We have organized the rest of the paper in the following way. In section II we cite some of the most relevant related works, and in section III we describe our system model. In section IV we detail our algorithm and game model. We discuss the results in section V, and finally, we conclude our paper in section VI.

II. RELATED WORK

Several papers have discussed the different social aspects while considering the D2D communications like resource management, next hop relay selection, traffic offloading, delay, communication cost and throughput maximization, etc. We mainly cite some work that has considered the social influence on D2D communications and relay selection.

In [3], social tie based cooperation between the user has been analysed to select the next hop relay. The authors identified two factors namely social trust and social reciprocity among the users to decide the best relay in a one-hop network. The social tie helps to find a relay that offers the best social link, and in the case of social reciprocity, the users help mutually. An optimal stopping approach based relay selection has been proposed in [4]. Here the authors have used the strength of social ties between the users to decide the mode of transmission (relay, direct) in a two-hop network. The transmission signal is proportional to the social trust; so, the users with high trust can offer higher throughput.

A couple of papers have investigated the location, privacy, security issues with the aid of social tie [7][9][10]. In [7] the authors have considered the degree of trust between the users to derive the optimal power required to relay the message secretly. Based on the degree of trust, the information and jamming signal are transmitted with suitable power directly to the destination and via a relay. The relay node with trust degree can only decode the message, not the eavesdropper. In [9] the frequency of social

meetings and number of common members between the groups are used as parameters to model the data transmission between the members of different social groups in a D2D environment. The proposed GROUPS-NET algorithm assigns edge probabilities based on the said parameters to forward the message between the group members in a centralized way. The influence of social and physical position has been investigated, in [11]. The mobile terminals (MTs) act as relays to send the data to a destination at a distance of one-hop from them by the cooperative communications. Here the strength of the social trust between the MTs encourages to relay the data.

In another category of works [13][14] community-based resource allocation has been discussed for the D2D scenario, where the users with common social interest and physical proximity are classified as a community. The authors used coalition game model to handle the resource allocation efficiently.

However, none of the above-mentioned works have considered the social activeness like the popularity of the social networks, their group size, the number of social networks with which user has interaction, etc. In our proposed work, we try to include these factors while determining the system performance.

III. SYSTEM MODEL

A. D2D Networking Scenario

Our D2D communication scenario has divided into social and physical layers among the users who wish to share information like video, Apps, photos to a large number of users at relatively lower transmission cost. In the social layer, the users have social tie by different social networks, and in the physical layer, they may have wireless link and interference with various other users in the surrounding.

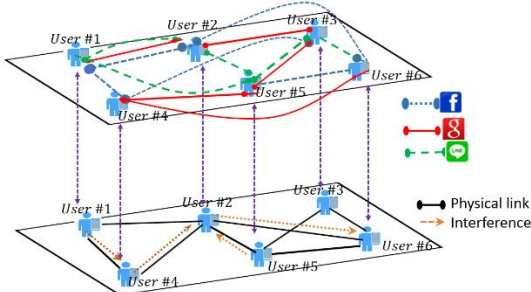


Figure 1. Social and physical layer of a D2D network.

As shown in Fig. 1, the top layer is the social layer. Here users have social connectivity through Facebook, Line, Google+, etc. The bottom layer in Fig. 1 is the physical layer, where users have the physical links (bold lines) through which they communicate, and interference links (dotted lines) due to different transmission power. We explain the parameters of social and physical layers in more detail in sub-section B and C respectively.

B. D2D Social network

It is common that a user may have the social tie with another user by multiple social networks like Facebook, Twitter, Line, etc., as shown in Fig. 2. (a). However, each of these networks has its popularity, size, the category of subscribers, etc. We exploit these features to design the social network scenario.

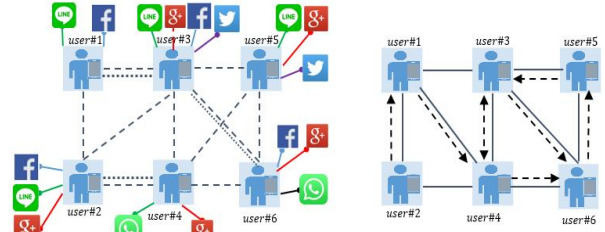


Figure 2(a) Social network scenario. (b) Physical and interference links between the users.

Let \mathcal{L}_{ij}^w represent the link weight between a link l_{ij} , where l_{ij} is the link between the nodes i and j ; and the term $w(1 \leq w \leq \mathbb{N}_i^j)$ represent the index of the total number of social networks between the link l_{ij} . The higher the value of \mathcal{L}_{ij}^w indicates higher social activeness between any nodes i and j . Let \mathbb{N}_i^j represent the number of networks by which node i and j are socially connected. (Example: user #1 and user #3 have $\mathbb{N}_i^j = 2$ as there are two social links connecting them as shown in Fig. 2. (a)). Let X^j be the number of socially connected networks to the potential destination relay j ($1 \leq x \leq X$). The term \mathcal{F}_x^j is the number of friends in social network x for j . The NW_x is the network weight of the social network x ($0 < NW_x \leq 1$) and $C_{f_j}^x$ is the contact duration of a user (friend) f ($1 \leq f \leq \mathcal{F}_x^j$) of network x connected to relay j determined over a total monitoring time of T_m . In Fig. 2. (a), for user #3 the value of $X^j = 4$, as it has four social networks connected.

C. D2D Physical network

For a D2D communication, physical proximity is an essential factor. In our system model, we distributed the N users at different locations, and they can have any topology. We assume each user i ($1 \leq i \leq N$) can have different transmission power P_i^T . As a result, users may have different transmission range and interference with neighbours. Let IW_i be the interference weight of node i with which it interferes the transmission of the nearby nodes ($0 < IW_i \leq 1$). In Fig. 2. (b), the discrete arrows show the direction of interference between the users and the bold lines show the communication links. It is not necessary that the presence of communication link between two nodes to have interference among them. We denote BW_{ij} as the bandwidth of link $l_{i,j}$. Let $load_{ij}$ represent the data sent by node i towards node j when we consider the link $l_{i,j}$.

Using this knowledge we derive the utility equations in the next section as defined by (1) - (5).

D. Problem formulation

We consider a D2D scenario with N nodes communicate physically and when nodes communicate on the same channel simultaneously, they interfere each other's transmissions. In Fig. 2. (b), the bold lines represent the communication links and discrete lines show the interference links. As an instance, *user#1* has communication link with *user#2*, *user#3*, and, *user#4*. However, *user#1* is interfered by *user#2* and in turn *user#1* interferes *user#4*. Thus, the overall received power by a node depends on the transmission power of the source node and effective interference by the interfering nodes

in the surrounding as given by (1). Here R_{ij} is the received power at node j when node i transmits with a power P_i^T and the summation represents the resultant interference by N^j which is a set of interfering nodes (excluding node i) surrounding the node j .

$$R_{ij} = \max\left(0, P_i^T - (P_i^T * \sum_{k \neq i, k \in N^j} IW_k)\right) \quad (1)$$

The value of R_{ij} is valid for $(P_i^T * \sum_{k \neq i, k \in N^j} IW_k) < P_i^T$, else 0.

Based on this, we determine the *physical gain* PG_{ij} of a node i when it communicates with node j . In equation (2), the numerator value represents the achieved total data rate based on the Shannon's theorem. The term in the denominator $\sum load_{kj}$ is the total data load received by node j from a set of nodes N_d^j that have a physical link to j and send data to node j . This is the measure of congestion, as more nodes send data to node j , the node gets congested faster.

$$PG_{ij} = \frac{\log_2(1 + R_{ij})BW_{ij}}{\sum_{k \neq i, k \in N_d^j} load_{kj}} \quad (2)$$

Now, based on the discussions in subsection B, we consider how the social tie between the users can be used to determine the social gain SG_{ij} that will influence the selection of user as a relay as shown in (3).

$$SG_{ij} = \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^w \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} (NW_x * C_{fj}^x) \quad (3)$$

In (3) the first summation represents the link weight of the social links between node i and potential relay j , over the total possible links N_i^j . The second summation represents the number of networks connected to potential relay j , and the third summation represents the number of friends f in each network x connected to j . As a result, the product term indicates the social activeness of the friends of the potential relay. It is better to choose a relay with higher social activity as it has more potential to disperse the data.

From the above discussion, we define the utility function that combines physical and social aspects of the network. An important aspect to notice is that when we determine the utility of a link l_{ij} the link must have both social and physical connectivity to choose a potential relay. Let U_{ij} be the utility of the link l_{ij} as shown in (4).

$$U_{ij} = \alpha * SG_{ij} + (1 - \alpha) PG_{ij} \quad (4)$$

It is the sum of social and physical gains as both these parameters are dimensionless. We set the value of α (non-negative constant) based on the significance of PG_{ij} and SG_{ij} . Therefore, we expand the utility as in (5).

$$U_{ij} = \alpha * \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^w \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} NW_x * C_{fj}^x + (1 - \alpha) * \frac{\log_2(1 + R_{ij})BW_{ij}}{\sum_{k \neq i, k \in N_d^j} load_{kj}} \quad (5)$$

IV. PROPOSED GAME MODEL

We consider that the data each node wish to send is independent. Thus, each node has to determine by itself the best next hop relay by a non-cooperative game. In our game theory model of peer relay selection, each node i is a *player* that wish to choose a potential relay to maximize the data dissemination. Let us define the parameters of our game now. The *strategy* s_i of node i consists of selecting the destination relay, $j \neq i$ while S_{-i} be the strategy of all other players. And (s_i') be the

change of strategy done by node i . The term N is the set of total nodes in the network. *Utility* $U_i(s_i)$ is associated with node i when it selects the strategy s_i . The higher the utility is, the higher will be the efficiency of transmission to a potential relay j as it has more potential to disperse the data. The utility function U_{ij} , when node i choose a strategy as s_i to select potential relay j as already defined in (5) is a dimensionless quantity. For a utility function to have good convergence properties, we have to ensure that the utility function U_{ij} possess certain mathematical properties. In such a case, we can determine the relay that offers best data dissemination in finite steps.

A. Proof of Nash Equilibrium.

Definition: *Nash Equilibrium (NE):* First of all, in a game a strategy profile s^* is called as NE, if and only if, for each player i and any strategy s_i in the strategy space the following relation should satisfy:

$$u_i(s^*) \geq u_i(s_i, S_{-i}^*) \quad (6)$$

Here, the term on the left-hand side $u_i(s^*)$ represents the utility of choosing the equilibrium strategy s^* by node i which is profitable than the utility of choosing any strategy s_i . The term S_{-i}^* represents the set of strategies of all other nodes at equilibrium as shown on the right-hand side.

Two *properties of potential game*: (1) NE exists in each *exact potential game*. (2) if we limit only one node that can change its relay at a time, we can converge to NE. For a potential function Φ to be an *exact potential function*, the condition in (7) has to be satisfied, where we try to maximize the utility of a node *in general* as follows.

$$U_i(s_i, S_{-i}) - U_i(s_i', S_{-i}) = \Phi(s_i, S_{-i}) - \Phi(s_i', S_{-i}) \quad (7)$$

The $U_i(s_i, S_{-i})$ represents the utility of node i while choosing the strategy s_i irrespective of the other user's strategy S_{-i} . The term $U_i(s_i', S_{-i})$ represents the utility of node i after change of strategy to s_i' . Similarly, the terms on the RHS represents the potential function difference. We define the potential function as in (8), which represents the overall utility of all the N nodes.

$$\Phi(S) = \sum_{i=1}^N \left\{ \alpha * \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^w \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} NW_x * C_{fj}^x + (1 - \alpha) * \frac{\log_2(1 + R_{ij})BW_{ij}}{\sum_{k \neq i, k \in N_d^j} load_{kj}} \right\} \quad (8)$$

We can further expand this as the sum of utility for a single node i and remaining nodes $N \neq i$. And the difference between the potential function before and after the change of strategy s_i to s_i' be as follows:

$$\begin{aligned} & \alpha * \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^w \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} NW_x * C_{fj}^x + (1 - \alpha) * \frac{\log_2(1 + R_{ij})BW_{ij}}{\sum_{k \neq i, k \in N_d^j} load_{kj}} + \\ & \sum_{k \neq i, k \in N} \left\{ \alpha * \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^w \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} NW_x * C_{fj}^x + (1 - \alpha) * \frac{\log_2(1 + R_{ij})BW_{ij}}{\sum_{k \neq i, k \in N_d^j} load_{kj}} \right\} - \\ & \alpha * \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^w \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} NW'_x * C_{fj}^x + (1 - \alpha) * \frac{\log_2(1 + R'_{ij})BW'_{ij}}{\sum_{k \neq i, k \in N_d^j} load'_{kj}} - \\ & \sum_{k \neq i, k \in N} \left\{ \alpha * \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^w \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} NW_x * C_{fj}^x + (1 - \alpha) * \frac{\log_2(1 + R_{ij})BW_{ij}}{\sum_{k \neq i, k \in N_d^j} load_{kj}} \right\} \quad (9) \end{aligned}$$

In (9) first and the second term represents the utility before the change of strategy by node i and remaining nodes. Similarly, rest of the two terms represents the utility after the change of strategy.

We limit *only one node* i to change its strategy at a time. As a result, the summation terms $\sum_{k \neq i, k \in N}$ will cancel in (9). This can be simplified as in (10).

$$\begin{aligned} \emptyset(s_i, S_{-i}) - \emptyset(s'_i, S_{-i}) = & \alpha * \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^w \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} NW_x * C_{fj}^x + (1 - \alpha) * \frac{\log_2(1+R_{ij})BW_{ij}}{\sum_{k \neq i, k \in N_d} \text{load}_{kj}'} \\ & \alpha * \sum_{w=1}^{N_i^j} \mathcal{L}_{ij}^{w'} \sum_{x=1}^{X^j} \sum_{f=1}^{F_x^j} NW'_x * C_{fj}^{x'} + (1 - \alpha) * \frac{\log_2(1+R'_{ij})BW'_{ij}}{\sum_{k \neq i, k \in N_d} \text{load}'_{kj}} \end{aligned} \quad (10)$$

Therefore, $\emptyset(s_i, S_{-i}) - \emptyset(s'_i, S_{-i}) = U_i(s_i, S_{-i}) - U_i(s'_i, S_{-i})$ which indicates the proposed game of peer relay selection is an *exact potential game*. Hence, it converges to NE.

B. Relay selection algorithm.

In this subsection, we describe our algorithm for relay selection by each of the users. Initially, each user based on its device id sequentially computes the utility towards other nodes and chooses the node with maximum utility as the potential relay. Once a user chooses the relay, it announces its selection to other nodes, and the remaining users update their utility towards that relay by re-computing the utility. If the utility value of a node towards a relay becomes more than the previous round's choice, the node chooses the current relay with maximum utility. Otherwise, their strategy remains the same. In this way, after few rounds when no node can deviate from their chosen relays of maximum utility, the algorithm terminates. This state is the Nash equilibrium, where nodes do not deviate from their strategy.

Let us consider a brief example. Assume that user A has surrounded by nodes B , C and D . Now, node A wishes to choose either C or D to choose as the next hop relay. Let A transmit with power $P_A^T = 100$ and B interfere with $IW_B = 0.3$. As a result, the effective received power at node C due to A is $(100 - 0.3 * 100) = 70$. Now if A chooses to transmit to node D , let B and C interfere D with $IW_B = 0.2, IW_C = 0.4$. Thus, overall received power at D due to A will be $(100 - (0.2 + 0.4) * 100) = 40$. This forms the physical gain. In this example, we have considered the load, bandwidth, data of all the links as equal for simplicity.

Assume that A and C are connected by Facebook, then link weight between A and C \mathcal{L}_{AC}^1 be 0.5. Let C has 5 Facebook friends (\mathcal{F}_1^C) with average contact frequency (C_{fC}^1) of 10. In addition, $NW_1 = 0.5$ for Facebook. Thus social gain from A to C will become $(0.5 * (0.5 * 5 * 10)) = 12.5$. Similarly, assume that A and D are connected by two links (Facebook and Line), so $\mathcal{L}_{AD}^1 = 0.5$ and $\mathcal{L}_{AD}^2 = 0.2$. Now, if node D has 4 Facebook friends (\mathcal{F}_1^D) with avg. contact frequency of 10; 2 line friends (\mathcal{F}_2^D) with contact frequency of 10. In addition, $NW_2 = 0.2$ for Line. Thus, the social gain from A to D becomes $(0.5 + 0.2) * (0.5 * 4 * 10 + 0.2 * 2 * 10) = 16.8$. By assuming $\alpha = 0.5$ and combining the physical and social gains, $U_{AC} = (35 + 6.25)$ and $U_{AD} = (20 + 8.4)$. Therefore, A chooses node C as its potential relay due to its higher value. Note that, whenever A chooses C , the other nodes that have already connected to C will update the value of interference, load in their utility computation.

V. SIMULATION RESULTS

In this section, we explain our simulation environment and experimental results. Firstly, our Matlab simulation setting consists of total 40 D2D users. We vary the physical and social connectivity between the users to vary the density of network. In one scenario, every user has physical and social links with every other user, and in another scenario, we allowed the users to freely choose their links. Each user may have up to four social networks and each network can have 1- 100 friends. We set the range of transmission power 20 - 40dBm. The interference weight range is set 0.2 - 0.9. The average contact duration is set 30 - 90 sec. We set the value of α as 0.25 to equalize the range of physical and social gains.

We compared our scheme with other 3 methods namely random relay selection, social based relay selection and physical based relay selection. In case of random selection method, nodes randomly choose a potential relay using both physical and social attributes. In case of physical method, nodes consider the interference and congestion of the physical channel and decide the best possible relay. In case of social method, nodes consider the contact frequency and network weight.

To determine the performance of our game model, first as shown in Fig. 4, we measure the average throughput by varying the number of users. As we vary the number of users from 5 to 40, in the proposed method the throughput steeply increases when we reach up to 20 nodes, later it gradually reduces. The main reason for this behavior is interference. Initially interference between the nodes are less until crossing 20 nodes. As the number of nodes increase, the throughput reduces gradually. In the random relay selection, as an user randomly chooses the relay, resulting in lower throughput. In social relay selection, nodes make decision of the relay based on the social parameters only. However, the performance is better than randomly choosing a relay node. In case of physical relay selection, nodes choose the relay purely based on physical parameters. We can see that the performance of the physical scheme is better than the social scheme as it is more aware of the physical links to reach a relay.

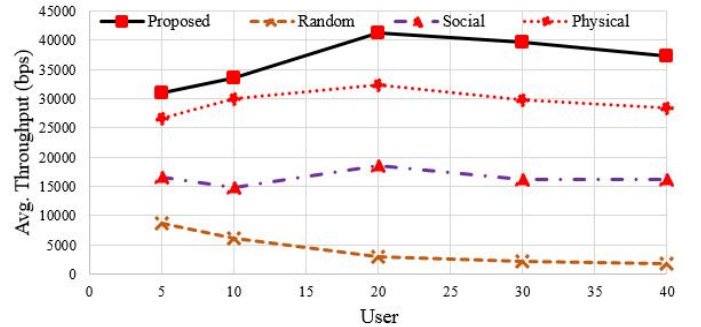


Figure 4. Throughput for varying number of users

In Fig. 5, we measure the average system utility by varying the contact frequency of the users in each network. We set the number of nodes $N = 40$ and vary the average contact frequency of users from 30 to 90 seconds. We can observe that as the contact frequency increases, the system utility also increase. It is due to more social interactions, which lead to better trust, to choose the same node as relay. However, in case of physical method, as it is aware of the physical links it chooses the best possible relays. The performance of social method is better than random method as it is aware of contact frequencies.

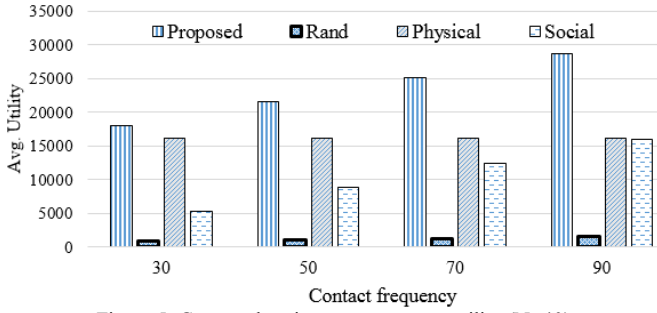


Figure 5. Contact duration versus system utility (N=40)

In Fig. 6, we vary the social density of the network by changing the social connections between the nodes. In high-density scenario (HD), every node has connectivity with every other node and in low-density scenario (LD) we maintain 50% connectivity between the nodes. When the number of nodes increase, in case of proposed HD scenario the throughput reduces gradually due to building interference. In LD case, initially the available number of social links are less, but as the number of nodes reaches to 20, throughput increases. However, due to increasing interference, throughput reduces later gradually. In case of random relay selection method, in HD case the throughput gradually reduces due to interference as the number of nodes increase; however, in case of LD the throughput remains almost low, as connectivity is low.

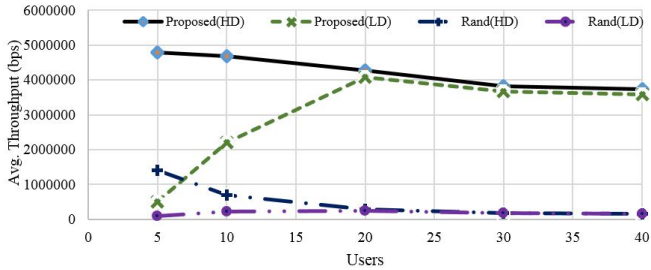


Figure 6. Throughput for social density variation.

In Fig. 7, we vary the interference factor as 0.4 and 0.7 to measure the throughput. We compare the performance with purely physical relay selection scheme. We can observe that in both the schemes as the interference weight increases the throughput reduces for different number of nodes. Nevertheless, in case of proposed scheme, the throughput is higher as it considers physical and social parameter to select the relay that offers the best throughput.

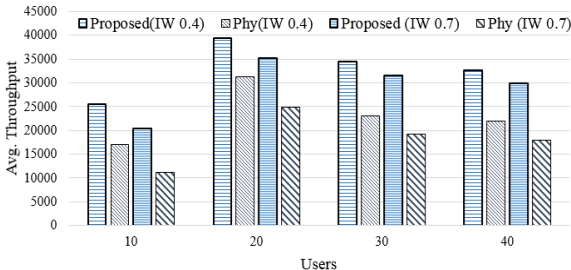


Figure 7. Avg. Throughput for varying interference weight

In Fig. 8, we investigate the effect of weight factor of different networks on system utility. Here, we consider 4 social networks with same number of friends in each network with contact frequency of 90 each to send the same data. In one scenario, we set network weights as 0.8, 0.6, 0.4, 0.2 for each network and vary the number of nodes. After 20 nodes, we observe a gradual reduction in the utility, as more nodes send data and cause congestion in this case. In another scenario, we maintain the network weight of each network as 0.5. We can observe that the utility value is lower than the former case. From, this we can conclude that, when we assign different weight to networks, nodes will be more decisive in choosing the best

possible relay, than in a case where all networks have the same weightage.

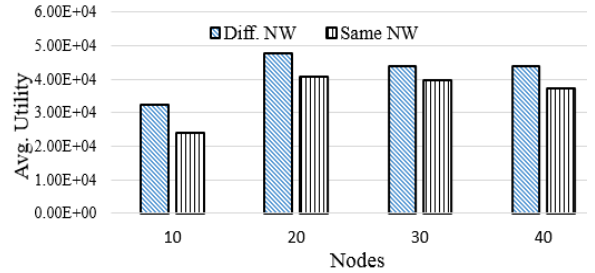


Figure 8. Avg. Utility for network weightage variation.

VI. CONCLUSION

In this paper, we proposed a game theoretic model for next hop relay selection for D2D nodes. Specifically, to maximize the information dispersion, we assumed each user might have social interaction with others via different social networks. We considered social parameters like type of network, link weight and contact durations in a scenario where nodes have interference and congestions. We observed that the network throughput depends on both physical and social parameters using which our utility function is formulated. Our proposed method of relay selection offers better throughput, utility than the traditional methods and has convergence property. From our results, we can infer that as each social network is different, it is more meaningful to assign them different weights to obtain higher throughput, than considering all networks as uniform. In our future work, we plan to study the effect of contact duration and user interests in case of dynamic community users.

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