Social-aware Content Uploading for Cooperative Device-to-Device Communications

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To support the social-aware content uploading for users (clients) with a poor uplink channel quality in cellular networks, we propose a cooperative device-to-device (D2D) communication scheme. Under this scheme, mobile clients are able to communicate directly and the ones with social relationship form a multi-hop D2D chain, the head of which is in charge of transmitting the desired content to the base station (BS). A promising feature of this scheme is to stimulate effective cooperation among all clients by making use of social-aware relationship. To establish the D2D chain in this scheme, we first employ coalitional game to divide all clients with social relationship into multi-chains, and then propose a coalition formation algorithm to select the optimal chain according to the cost of content uploading such as energy and time. Finally, simulation results are presented to verify the efficiency of our proposed scheme in terms of the total content uploading time and energy consumption.

***Index Terms*—Content uploading, social relationship, device-to-device communication, coalition game.**

I. INTRODUCTION

A majority of handheld devices, such as smartphones and tablets, can efficiently capture, store, process and transmit multimedia content in digital format. Hence, more and more multimedia contents are uploaded to the BS through such devices in live fashion via the wireless upload channels [1]. Consider some important application scenarios in public safety and disaster recovery places, where some multimedia contents (e.g., photos or videos of the points of interest) need to be gathered and uploaded to a control center or the BS timely and reliably. The mobile devices in cellular network are perhaps the best way to carry out the task of content uploading [2].

Recently, extensive researches have been devoted to content uploading in cellular networks, for example, [3-5], where [3] investigated the buffer space management of data delivery, and [4-5] studied secure routing of data delivery with selfish jammer and incentive jamming, respectively. However, most of them focused on mobile devices with no collaboration. Such operation remains quite challenging to achieve separately content uploading for each user. If the user equipment (UE) suffers from a poor uplink channel quality, it is difficult to upload a high-quality video flow to the BS timely and reliably. Furthermore, as content uploading in some applications is time-sensitive, content uploading may be required to be performed within a specified time frame. Therefore, a reliable data uploading scheme is required.

The challenge in the considered scenario that we tackle in this article is to enable (D2D) cooperation such that they can form a multi-hop D2D chain [6-7] to upload content, where the UE with a poor uplink channel quality can use another UE with a high uplink channel quality as a relay, and the head of the chain is in charge of uploading all contents received from the other UEs to the BS. The multi-hop D2D communication has became a efficiency solution compared to the non-cooperative one. Nevertheless, there is a critical issue to solve: how to stimulate clients to cooperate with each other.

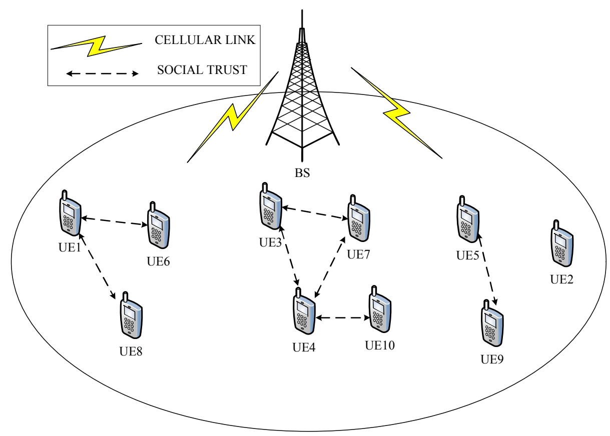

Fig. 1: An illustration of the social-aware content uploading system.

To address the above question, we propose a social-aware content uploading scheme based on cooperative D2D communication. This is a fundamental difference from a typical D2D cooperation problem [8], where the notable feature is to stimulate cooperation among clients via utilizing social networks [9], which is a mutual social relationship observed among family members, friends and colleagues. The main contributions of this paper can be summarized as follows:

- We extend the works of cooperative D2D content uploading to the more real social network scenario, where the devices carried by human beings have diverse cooperative behaviors due to the knowledge of human social relationships. This work covers the pervious works on cooperative D2D content uploading with full trust and no trust as the special cases.
- We model multi-hop D2D chains based on social relation-

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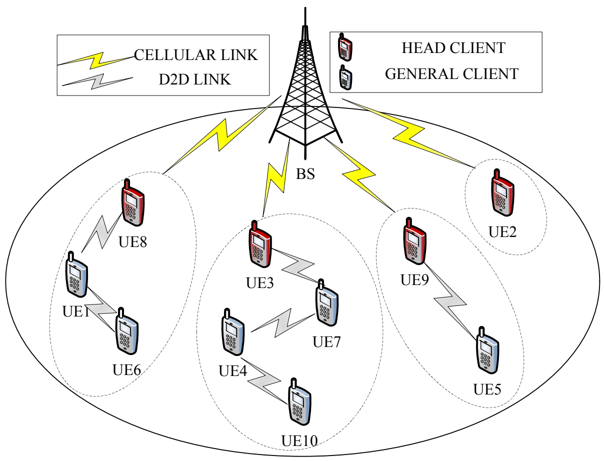

Fig. 2: Multi-hop D2D chains based on the physical and social relationship.

TABLE I: DESCRIPTIONS OF IMPORTANT SYMBOLS

Symbol	Description
$N = \{1, 2, 3, ..., n\}$	A set of mobile clients, n is the total number of clients
B_i	Social trust database with client i
P_i	Physical cooperative database with client i
$K = \{S_1, S_2, ..., S_k\}$	A partition, S_i represents the chain i, k is the number of the total chains
$C(S_i)$	A set cost function for every chain $S_i \subseteq N$
$t_j = b_j / r_j$	A file content b_j, data rate r_j the relationship of content uploading time required t_j for client j
$T(S_i)$	The total content uploading time for the chain S_i
$\Phi = \{N_1, N_2, N_3, ..., N_n\}$	The set of cooperation strategies, which contains physical social database for all clients
$\Omega = \{N, \Phi, C, \succ_i\}$	A coalitional game,the set of players N,the set of cooperation strategiesΦ,the cost function $C(S)$, the preference order $\succ_i$

ship as a coalition game, and design a coalition formation algorithm to obtain the optimal chain formation.
- We evaluate the efficiency of our proposed scheme on the total content uploading time.

The remainder of this paper is organized as follows: Section II introduces system model and our proposed content uploading scheme. Section III describes the problems of chain formation as a coalition game and presents a coalition formation algorithm to obtain the optimal chain formation in terms of the content uploading time. Section IV presents the numerical results. Finally, conclusions are given in Section V.

II. SYSTEM MODEL

We consider a single cell consisting of one BS and a set of mobile clients $N = \{1, 2, 3, ..., n\}$, where n is the number of clients. We assume the devices are allocated orthogonal frequency resources by the BS according to Maximum Throughput (MT) policy, in which the BS collects the uplink Channel Quality Indicators (CQIs) of the devices, and then distributes the radio resources to these devices in an ascending order of their uplink CQIs [10]. Hence, there exists no mutual interference between devices. As shown in Fig. 1, such a system can naturally be classified into two models: the physical model and the social model.

A. Physical Model

When any two devices are within mutual communication range, the corresponding D2D cooperation can be established. Taking such physical constraint into account, we introduce the cooperative graph G to describe cooperative relationships among the devices, and then obtain cooperative database P_i for a device i, which contains all cooperative candidates for device i.

To obtain physical cooperative database, we perform the ad hoc peer discovery before D2D communication, where each device $i \in N$ periodically broadcasts a randomized probing beacon to the devices within its D2D communication range. Once the other devices receive the probing beacon, it will send a feedback message to device i. The peer discovery mechanism has been widely adopted by D2D group formation of previous works.

B. Social Model

The underlying rationale of using social network is that handheld devices are carried by human beings and the social behaviors of human can be utilized to provide effective and trustworthy assistance for D2D communication [11]. Hence, each device can obtain its own social trust relationship through a privacy preserving manner and such an operation can be done before content uploading. In Fig. 1, UE5 is willing to help UE9 (or vice versa) without any relay when they are friends.

However, not any clients with social trust relationship can help with each other. Hence, in the first step of D2D chain formation, each client i broadcasts a request to find its candidate helpers with social trust relationship who can help client i to upload content. Through a matching and feedback process, each client i can build its own social trust database B_i, which contains candidate helpers [12]. As depicted in Fig. 1, UE4 has social trust with only UE3, UE7 and UE10. If UEi has no candidate helper, we set its social trust database as $B_i = \emptyset$.

With the assistance of physical model and social model, all clients have obtained the physical-social database as $\Phi = \{N_1, N_2, N_3, ..., N_n\}$. Then, the devices cooperate to construct multi-hop D2D chains for data uploading [13]. as illustrated in Fig. 2. In particular, the head of each chain is in charge of receiving all generated contents from the entire chain and uploading them to the BS.

III. CHAIN FORMATION BASED ON COALITIONAL GAME

In this section, we address how to stimulate clients to form the optimal partition underling physical social database, such that the total uploading time can be reduced. By employing the coalition game [14], we construct the uploading time as cost function of the coalition game. Then, with the help of the cost function, we model the chain formation based on physical-social database as a coalition game. Finally, we design a coalition formation algorithm to obtain the optimal chain formation based on the cost of the total uploading time.

A. Coalition Cost Construction

As shown in table I, we define a collection of chains as a set $K = \{S_1, S_2, ..., S_k | S_i \subseteq N, S_1 \cup S_2 \cup ... \cup S_k = N, i = 1, 2, ..., k\}$, where k is the number of the total chains and K also refers to as a partition. Meanwhile, we define $C(S_i)$ as a cost function for every chain $S_i \subseteq N$, which is measured as the total content uploading time required for all clients in chain S_i.

We assume that each UE j has a file data b_j to be transmitted into the BS through a data rate r_j over its cellular link, and thus the content uploading time required t_j should satisfy the relationship: $t_j = b_j/r_j$. Let us consider a partition $K = \{S_1, S_2, ..., S_k\}$. For the sake of simplicity, we first compute the uploading time $T(S_i)$ for chain S_i in collection K, which contains m-hop paths with $j = m$ being the head and $j = 1$ being the first UE in this path.

When the first UE in chain S_i begin to transmit content, it can occupy the channel for a time $t_1 = b_1/r_1$ to forward its data b_1 to the second UE with data rate r_1 over the D2D link. Meanwhile, the second UE with data rate r_2 sends its own data b_2 and the data b_1 received from the previous UE, so the occupied time for the second UE is $t_2 = b_1/r_2 + b_2/r_2$. This procedure repeats until the last UE m in the chain S_i, which is the head UE of the chain and is in charge of transmit its generated data b_m and data from the other UEs in the chain S_i to the BS with a data rate r_m. The expression of the channel occupation time t_m is depicted as follows:

$$t_m = b_1/r_m + b_2/r_m + b_3/r_m + ... + b_m/r_m \quad (1)$$

Since all UEs in the chain can transmit content by a multi-hop D2D chain, and the content uploading time from all clients in the chain S_i is closely related with the head UE. The total uploading time $T(S_i)$ will be determined by the consumption time of the head UE in the chain:

$$T(S_i) = t_m = b_1/r_m + b_2/r_m + b_3/r_m + ... + b_m/r_m \quad (2)$$

By repeating the same operation for the other chains in the partition K, we obtain the uploading time for different chains respectively and they are depicted as $T(S_1)$, $T(S_2)$, $T(S_3)$,..., $T(S_k)$. So the total uploading time for the partition K is the summation of the uploading time for all chains [15].

B. Coalitional Game Formulation

Based on the cost function introduced above, we formulate all cooperative clients to form multi-hop chains based on physical-social database as the coalitional game [16]. The coalitional game $\Omega = \{N, \Phi, C, \succ_i\}$ as follows:

- the set of players N.
- the set of cooperation strategies $\Phi = \{N_1, N_2, N_3, ..., N_n\}$ for all players.
- the cost function $C(S)$ for each coalition S, which refers to the total uploading time for all clients in the coalition S.

Algorithm 1 Coalition Formation Algorithm for D2D Communications

Input:
A set of mobile clients $N = \{1, 2, 3, ..., n\}$, the physical-social database $\Phi = \{N_1, N_2, N_3, ..., N_n\}$, the initial partition $K^{ini} = \{S_1, S_2, S_3, ..., S_k\}$ and the flag value F for each client.

Output:
The optimal partition K^{fn} for all clients which can provide the lowest uploading time and energy.

1: obtain the client set $N' = \{1, 2, 3, ..., n\}$ based on an increasing order of uplink CQI;
2: **for** $S_w = S_1$ to S_k **do**
3:   **for** $i = w$ to n **do**
4:     set $F_i = 0$;
5:     **if** ($N_i = \emptyset$) **then**
6:       update S_w;
7:       $w = w + 1$;
8:       return line 2;
9:     **end if**
10:     **if** ($F_j = 1$) **then**
11:       $i = j$;
12:       return line 3;
13:     **else**
14:       $j = k$;
15:       return line 10;
16:     **end if**
17:   **end for**
18:   **if** ($i = n$) **then**
19:     return the optimal partition $K^{fn} = K^{ini} = \{S_1, S_2, S_3, ...S_k\}$.
20:   **end if**
21: **end for**

- the preference order $\succ_i$ is defined as $C(S) \succ_i C(S')$ if and only if $S \succ_i S'$ according to social trust database B_i. Meanwhile, the relationship $C(S) \succ_i C(S')$ should be satisfied:

$$C(S) \succ_i C(S') \Leftrightarrow T(S) \leq T(S') or E(S) \leq E(S') \quad (3)$$

Based on the coalitional game formulation, we propose a coalition formation algorithm to obtain the core solution, which is an optimal partition for all cooperative clients and can provide the lowest uploading time. The Algorithm 1 is given as follows.

1) By starting from an initial partition $K^{ini} = \{S_1, S_2, S_3, ..., S_k | S_i = \emptyset, k = n\}$ and the flag value $F_i = 1$, each client obtain the client set N' based on an increasing order of uplink CQI. The first client i in client set N' broadcasts BUSY message to all clients and set its flag $F_i = 0$. If client i has no any helper according to N_i, so the first chain S_1 has formed. Otherwise client i transmits message MESG to client j with the best channel quality based on N_i.
2) When client j receives the MESG, it first checks F_j value. If $F_j = 0$, client j sends REJ message to client i,

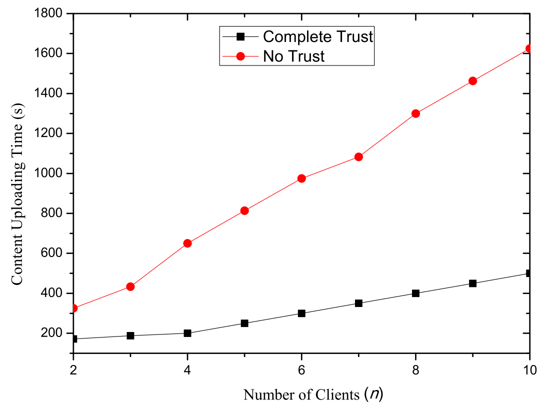

Fig. 3: Content uploading time versus client number with complete and no trust.

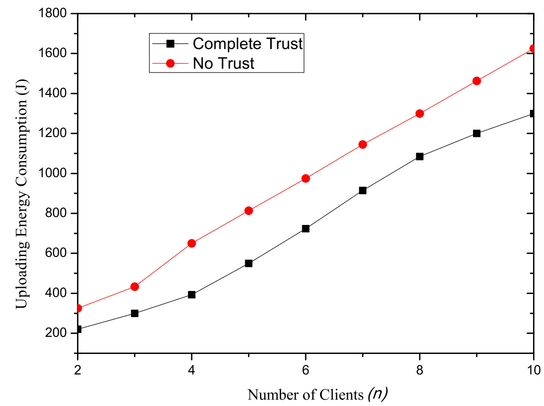

Fig. 4: Uploading energy consumption versus client number with complete and no trust.

then client i keep on sending message MESG to the next preferable client k. If $F_j = 1$, then client j transmits the MESG to its helper with the best channel quality based on N_j and sets its value $F_j = 0$. The process continues until there is a client m that has no any helper with the best channel quality according to N_m, so the first chain S_1 has formed and client m sets its flag $F_m = 0$.

3) If the coalition S_1 contains all clients in the cell, the procedure is terminated. Otherwise all other clients with flags $F = 1$ will repeat the above steps until a new chain forms. Such a chain discovery procedure repeats until all clients¡¯ flags equal zero. Finally, an optimal partition K^{fn} for all clients will form.

We next consider the computational complexity of Algorithm 1. Although we cannot estimate the number of attempts in each iteration, we can consider the worst case for the partition, each client with no cooperation separately uploads its own content to the BS, so all clients can form n singleton chains. When the first chain forms, it needs to make n attempts. When the second chain forms, it also needs to make n attempts and so forth. Thus, the algorithm has a computational complexity of at most $O(n^2)$.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of social-aware content uploading scheme for cooperative D2D communications. We consider a round area with a radius of $r = 100$ meters, which ensures that all clients are within D2D communication ranges. The distance between the BS and the round center is $d = 500$ meters. So the effect of the distance for content uploading may be ignored. We set mobile clients $N = \{1, 2, 3, ..., n\}$, where n clients are uniformly distributed in the round area. The bitrates values $[3, 6, 10, 20]Mbps$ for all clients obey uniform distribution. Meanwhile, we assume uploading content for each client as $1000MB$.

We mainly consider three performance evaluation cases in the paper, namely: no trust, social (partial) trust and complete trust. In the first case, each client separately uploads its own content to the BS. The second case satisfies partial trust during all clients due to social relationship. In the third case, any two clients can cooperate with each other to form a singleton chain in entire cell.

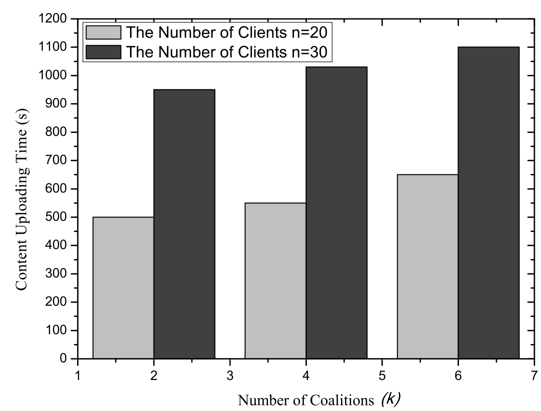

Fig. 5: Content uploading time with partial social trust.

Firstly, we evaluate the total uploading time with two trust conditions with a variable number of clients $(N = 2, ..., 10)$. As shown in Fig. 3, we observe that the total uploading time with complete trust outperforms no trust by up to four times. Due to the facts that the clients with poor channel use some clients with good channel to transmit content to the BS, so the total uploading time is greatly reduced. With the increase of client numbers, the disparity between both ones will become more and more obvious. Similar findings can be observed from Fig. 4, which compares the energy consumption on both trust relationships for different client number. As expected, the benefit of utilizing complete trust becomes more obvious when the number of clients increases.

Secondly, to better understand social trust on the total uploading time, we illustrate in Fig. 5 the influence of the number of coalitions on the total uploading time for different number of clients ($N = 20, 30$). As depicted in Fig. 5, we divide all clients into two, four or six coalitions to show the performance comparisons. As expected, the total uploading time required for client number $n = 20$ is far less than the one with $n = 30$. We also observe that the total uploading time increases slowly with coalition number rising. The main motivation for this trend is that clients with poor channel quality need more time to uploading content due to less cooperators.

V. Conclusion

This paper studies a social-trust content uploading for cooperative D2D communication. Our objective is to solve the problem of content uploading for some clients with a poor uplink channel quality. This scheme is obtained by stimulating effective cooperation between the clients with social trust relationship to form multi-hop D2D chain, and then the head of chain is responsible for uploading all the generated content to the BS. A constrained coalition game is introduced to construct all multi-hop D2D chains, and then a coalition formation algorithm is designed for obtaining the optimal chain formation. According to simulation results, we demonstrated the uploading time with complete trust outperforms no trust by up to four times, and then our proposed algorithm can reduce the total uploading time and energy consumption through establishing D2D cooperation.

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