Partner Selection for Cooperative Video Transmission in Social Networks

Tian Zeng
Chongqing Key Labs of Mobile Communications Technology,Chongqing University of Posts and Telecommunications,
Chongqing 400065, China
693832590@qq.com

Shaohui Sun
Datang Wireless Mobile Innovation Center, China Academy of Telecommunication Technology (CATT)
Beijing 100191, China
sunshaohui@catt.cn

Xiulan Yu
Chongqing Key Labs of Mobile Communications Technology,Chongqing University of Posts and Telecommunications
Chongqing 400065, China
yuxl@cqupt.edu.cn

Zufan Zhang
Chongqing Key Labs of Mobile Communications Technology,Chongqing University of Posts and Telecommunications
Chongqing 400065, China
zhangzf@cqupt.edu.cn

ABSTRACT

Aiming at the bad video quality which caused by the diversity of user's cooperation willingness and the limited transmission rate of multicast due to the worst channel quality of user, a model for cooperative D2D communications that combines social relationships and physical conditions between users is proposed. The corresponding D2D pairing for cooperative video transmission algorithm based on stable matching in this model is also given. Unicast throughput is derived by considering the social relationships and wireless propagation conditions. The preference information are generated by designing the utility function of cooperation, the users form a stable matching by dynamic negotiation. Simulation results demonstrate that D2D communications can be enhanced by considering social aspects, the performance of the proposed algorithm can be improved with higher throughput compared to the traditional cooperative scheme.

Keywords

Social network; D2D; cooperation; video; stable matching

1. INTRODUCTION

The future mobile communication technology needs to support mobile TV, video streaming, video surveillance and other individualized multimedia service. There are still many challenges that how to satisfy the quality of service (QoS) and quality of experience (QoE) for future mobile communication technology, especially in low latency, high reliable networks. Device-to-Device (D2D) communications has changed the operation mode of cellular network, D2D communications refers to a radio technology that enables user equipments (UEs) to communicate directly with each other. The adoption of D2D communications in cellular networks can deliver improved throughput, provide extended network coverage, enhance user energy efficiency and improve the quality of experience [1, 2].

At present, the video transmissions between network nodes can be categorized into multicast and unicast. Multicast means transferring information to a set of destination addresses, it can save server load. However, multicast can not provide personalized service to the user compared to unicast. Meanwhile, the transmission rate is limited to the worst channel quality of user, which leads to low rate and bad video quality [3]. Indeed, users acquire and own digital content based on their individual interests and may not be willing to expose it unless trust is established with a potential D2D partner. In real scenes (e.g., meeting, concert hall, sports competition), multiple users may request the same video. BS transmits the content to the users in the traditional way - through multiple retransmissions. To this end, some researchers proposed that the packets should be transmitted by cooperative communication [4], which not only strengthens the quality of packet transmission and reduces the transmission delay, but also enhances the coverage at the edge of the cellular network. The ever-increasing data volume of user generated video and the boundless coverage of socialized sharing have presented unprecedented challenges.

Based on the analysis above, the social domain is introduced to empower the communicating devices to become the autonomously deciding entities that can achieve effective video transmission and good quality of experience. A

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cooperative D2D communication model for video transmission that combines the social relationships and physical conditions between users is proposed to analyze the user's willingness to cooperate and the quality of the communication channel. Taking into account the preferences of the user to others, the paper apply economic two-sided matching theory [5] to transfer cooperative video transmission problem to dynamic and mutually beneficial relations among different types of rational and selfish agents.

2. SYSTEM MODEL

Consider the scenario in a single cellular network as shown in Figure 1, the BS acts as a centralized controller in order to support the functions of group formation as well as coordination and resource allocation for multiple content owners. In high-user-density scenarios, the mobile users often share common interest in delay-sensitive content, data packets are transmitted in two phases. In the first phase, the video packets are broadcasted from a cloud server to the devices over wireless cellular channels. Assume that the video adopts multiple description coding (MDC) to generate a number of independent and correlated code stream (description). Each description can be decoded independently to obtain the reconstruction quality, and the reconstruction quality increases with the number of received descriptions. Due to the fading of wireless channel and network heterogeneity, many users only get part of the video date packets. Note that the video is split into k video data packets, and $P = \{p_1, p_2, \cdots, p_k\}$. After the BS broadcasts the video stream, the user obtains at least one description at the end of the first phase and users who have the same description are grouped into the same cluster. In the second phase, the devices cooperate with each other to recover their missing packets using D2D links.

There are n users, $R = \{r_1, r_2, \cdots, r_n\}$, which are divided into k clusters due to the difference of received video data packets in physical domain. BS allocates each transmitter an orthogonal and independent channel in order to avoid collisions amongst multiple transmitters the necessary condition of D2D communication between users is analyzed in physical domain. In social domain, weighted graph $G_s = (V_s, E_s)$ is adopted to describe social network topology among users V_s is the corresponding user in physical domain and E_s is the corresponding edge. The edge weight $s_{ij} (\forall i, j \in V_s), 0 \leq s_{ij} \leq 1$ represents the social strength between different users. In practice, for any two users m_i and n_j, the value of s_{ij} is not equal to s_{ji}, which means the strength of social relations of any pair of D2D users is unequal, making the user having preference in choosing its cooperative partner. Therefore we will analyze the strength of social relations between users and the impact on throughput and delay that lays the foundation for subsequent analysis.

3. D2D COMMUNICATION FOR COOPERATIVE TRANSMISSION BASED ON SOCIAL NETWORK

3.1 Social unicast throughput analysis

Assume that the position of m_i during the t^{th} time interval follows a stationary and ergodic process having a uniform distribution in the area considered. Moreover, the positions of different UEs are independently and identically distributed (i.i.d.) [6]. Let the probability density function (PDF) of the random distance D_l between any two UEs be denoted by $f_Y(y)$

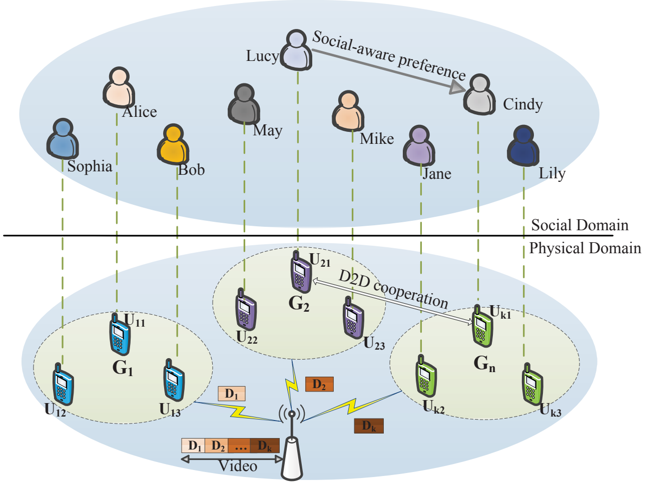

Figure 1: Video transmission model based on social network

$$f_Y(y) = \frac{dF_Y(y)}{dy} = \frac{2y}{R^2}, 0 \leq y \leq R \quad (1)$$

Suppose that the social distance for any two users m_i and n_j is α_{ij} , which describes the distance of similar characteristics between them. However, different people may prefer different characteristic on others, making the social tie strength unequal. Individuals with less in common are less likely to develop or maintain a strong tie. The physical distances reflect the dynamic process of users in calculating social tie. Define that when n_j is in the m_i's neighbor range r_0 from m_i's regular contacts the probability that m_i will to forward the packet is denoted as $\varphi = 1$. By contrast these opportunistic contacts are established with a specific probability of ϕ, which is inversely proportional to y with the social distance exponent of α_{ij}. Thus given a specific distance y the social tie strength between m_i and n_j is

$$s_{ij}(y) = \begin{cases} 1, 0 \leq y \leq r_0 \\ \frac{1}{\left(\frac{y}{r_0}\right)^{\alpha_{ij}}}, r_0 < y \leq R \end{cases} \quad (2)$$

In physical domain, the radio propagation in between any pair of sender and receiver is assumed to experience uncorrelated stationary Rayleigh flat-fading. Hence, the square of the fading amplitudes $X = |h(t)|^2$ during the t^{th} time slot (TS) follows an exponential distribution having a unity mean, whose tail distribution function (TDF) is

$$\Pr\left[|h(t)|^2 > x\right] = e^{-x} \quad (3)$$

Given an arbitrary distance y in meters, the path loss (PL) $\Omega(y)$ is expressed as [7]

$$\Omega(y) = \begin{cases} 1, 0 \leq y \leq d_0 \\ \left(\frac{4\pi f_c}{c}\right)^{\kappa} y^{\kappa}, d_0 < y \leq R \end{cases} \quad (4)$$

where c is the speed of light f_c is the carrier frequency, κ is the PL exponent and d_0 is the distance from the sender to the'near-field' edge.

During a TS, a packet of the content received by a UE is assumed to be successfully, provided that a social tie must exist between a pair of users, which is determined by the social strength s_{ij} of (2). Besides, the instantaneous received signal-to-noise-ratio (SNR) is higher than a predefined threshold γ. Assume that the social tie threshold r_0 is bigger than the 'near-field' edge d_0. By jointly considering the social domain and physical domain, the successful packet reception probability of a link is derived as

$$\begin{aligned} u_{ij}(y) &= \Pr\left(\frac{P_t\left|h(t)\right|^2}{\Omega(y)N_0W} > \gamma\right)\cdot s_{ij} \\ &= \begin{cases} e^{-\frac{\gamma N_0 W}{P_t}}, \quad 0 < y < d_0 \\ e^{-\frac{\gamma N_0 W}{P_t}\left(\frac{4\pi f_c}{c}\right)^{\kappa} y^{\kappa}}, d_0 < y < r_0 \\ \frac{e^{-\frac{\gamma N_0 W}{P_t}\left(\frac{4\pi f_c}{c}\right)^{\kappa} y^{\kappa}}}{\left(\frac{y}{r_0}\right)^{\alpha_{ij}}}, r_0 < y < R \end{cases} \end{aligned} \tag{5}$$

where P_t is the corresponding transmit power, N_0W is the noise power in a communication bandwidth W and γ is the instantaneous received SNR threshold.

Therefore, the average social unicast throughput during a TS can be expressed as

$$\begin{aligned} E_{ij}\left[u_{ij}(y)\right] &= \int_0^R u_{ij}(y) f_Y(y) dy \\ &= \underbrace{\int_0^{d_0} e^{-\frac{\gamma N_0 W}{P_t}} \cdot \frac{2y}{R^2} dy}_{A_1} + \underbrace{\int_{d_0}^{r_0} e^{-\frac{\gamma N_0 W}{P_t}\left(\frac{4\pi f_c}{c}\right)^{\kappa} y^{\kappa}} \cdot \frac{2y}{R^2} dy}_{A_2} \\ &+ \underbrace{\int_{r_0}^{R} e^{-\frac{\gamma N_0 W}{P_t}\left(\frac{4\pi f_c}{c}\right)^{\kappa} y^{\kappa}} \cdot \left(\frac{r_0}{y}\right)^{\alpha_{ij}} \cdot \frac{2y}{R^2} dy}_{A_3} \end{aligned} \tag{6}$$

A_1 in (12) is obtained as

$$A_1 = \int_0^{d_0} e^{-\frac{\gamma N_0 W}{P_t}} \cdot \frac{2y}{R^2} dy = e^{-\frac{\gamma N_0 W}{P_t}} \cdot \left.\frac{y^2}{R^2}\right|_0^{y_0} = \frac{d_0^2}{R^2} e^{-\frac{\gamma N_0 W}{P_t}} \tag{7}$$

by introducing the exponential integral function [8]

$$\begin{aligned} \Phi\left(y\middle|\beta,\alpha,A\right) &= \int y^{\beta-\alpha} e^{-Ay^{\kappa}} dy \\ &= \begin{cases} -\frac{A^{Z_1}}{\kappa}\int_{Ay^{\kappa}}^{\infty}\frac{1}{t^{Z_1+1}}e^{-t}dt, Z_1 = \frac{\alpha-\beta-1}{\kappa}, if \beta < \alpha \\ -\frac{1}{\kappa A^{Z_2}}\int_{Ay^{\kappa}}^{\infty} t^{Z_2-1}e^{-t}dt, Z_2 = \frac{\beta-\alpha+1}{\kappa}, if \beta \geq \alpha \end{cases} \end{aligned} \tag{8}$$

while A_2 in (12) can be further derived as

$$\begin{aligned} A_2 &= \frac{2d_0}{R^2}\int_{d_0}^{r_0} e^{-\frac{\gamma N_0 W}{P_t}\left(\frac{4\pi f_c}{c}\right)^{\kappa} y^{\kappa}} \cdot y dy \\ &= \frac{2d_0}{R^2}\,\Phi\left(y\middle| 1, 0, \frac{\gamma N_0 W}{P_t}\left(\frac{4\pi f_c}{c}\right)^{\kappa}\right)\Bigg|_{d_0}^{r_0} \end{aligned} \tag{9}$$

In a similar way, we may derive the third integral A_3 in (12) as

$$A_3 = \frac{2{d_0}^{\alpha_{ij}}}{R^2}\,\Phi\left(y\middle| 1, \alpha_{ij}, \frac{\gamma N_0 W}{P_t}\left(\frac{4\pi f_c}{c}\right)^{\kappa}\right)\Bigg|_{r_0}^{R} \tag{10}$$

Finally, the closed-form expression of social unicast throughput during a TS is

$$E_{ij} = A_1 + A_2 + A_3 \tag{11}$$

The purpose of our work is to achieve content delivery with high satisfactions of users by employing social-aware D2D techniques, in the mean time, maximizing the transmission throughput of D2D links. Hence, we need to consider an optimization problem involving both the social domain and the physical domain. Based on the analysis above, the D2D cooperative transmission model can be formulated as an optimization problem shown in (12), in which M and N represent the number of users of two clusters respectively. And a set of binary variables is used to formulate the user pairing $x_{ij} = 1$ denotes that a D2D link is established between m_i and n_j

$$\begin{aligned} &\max \sum_{i=1}^{M}\sum_{j=1}^{N} E_{ij}x_{ij} \\ &s.t. \begin{cases} (1)\sum_{i=1}^{M} x_{ij} \leq 1, \forall i \in \{1, 2, \cdots, M\} \\ (2)\sum_{j=1}^{N} x_{ij} \leq 1, \forall j \in \{1, 2, \cdots, N\} \\ (3)\, x_{ij} \in \{0, 1\}, \forall i \in \{1, 2, \cdots, M\}, \forall j \in \{1, 2, \cdots, N\} \end{cases} \end{aligned} \tag{12}$$

3.2 D2D cooperative transmission algorithm based on stable matching

Table 1: D2D cooperative transmission algorithm based on stable matching

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Input: $\alpha_{ij}$, $d_0$, $c$, $f_c$, $P_t$, $\gamma$, $\kappa$, $N_0W$
Output: A stable match $u$
set $M_{D_a} = (m_i)_{i=1}^{M}$, $N_{D_b} = (n_j)_{j=1}^{N}$
for $m_i \in M_{D_a}$ do
Calculate its preference over any $n_j \in N_{D_b}$ as (17) and establish $m_i^{list}$ by sorting each $n_j \in N_{D_b}$ in descending order.
end for
for $n_j \in N_{D_b}$ do
Calculate its preference over any $m_i \in M_{D_a}$ as (17) and establish $n_j^{list}$ by sorting each $m_i \in M_{D_a}$ in descending order.
end for
Construct the list of $m$ that are not matched, denoted by $M_{matchlist}$.
while($M_{matchlist} \neq \emptyset$, $m_i \in M_{matchlist}$)
    for $i = 1$ to $M$ do
        Each $m_i$ makes a proposal to $n_j$ that is the first in its preference list.
        if $m_i \succ_{n_j} m_i'$
            $n_j$ accepts $m_i$'s proposal and rejects her current partner $m_i'$, $m_i$ will be removed from $M_{matchlist}$, and $m_i'$ will be added to $M_{matchlist}$.
        else
            $n_j$ rejects $m_i$'s proposal and holds his current partner $m_i'$ and $m_i$ updates his preference list, $m_i^{list}$, by removing $n_j$.
        end if
    end for
end while
```

The D2D cooperative transmission of user in two different sets can be regarded as bilateral matching problem [9]. Assume that agents who receive video data packet D_a and D_b are define as $M_{D_a} = \{m_1, m_2 \cdots, m_i, \cdots, m_M\}$ and $N_{D_b} = \{n_1, n_2 \cdots, n_j, \cdots, n_N\}$, respectively. In the process of searching for a neighbor to cooperate with each other, the agents of one side select the user with the highest preference

Table 2: Simulation Parameters

Simulation parameter	value
Experiment times	1000
Cell radius	100
D2D communication distance	0-50
Transmit power of D2D user	23
Carrier frequency	2.4
Noise power	-174
System bandwidth	10
Near-field edge	10
SNR threshold	10
Pathloss exponent	3

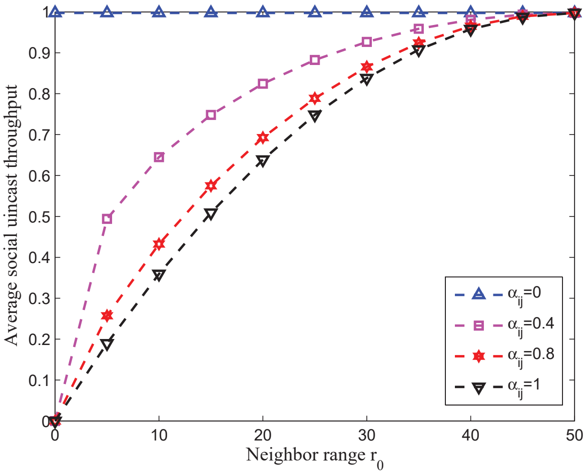

Figure 2: The impact of social coefficient and neighbor range on average throughput.

on the other side to send the D2D request. Because that the requested user also has its own preference, the user can choose to accept or reject the new request according to his preference list until all the other users find the best partner, and the BS allocates spectrum for D2D cooperative communications. In this case, a pair of D2D users can not find others that have higher preferences over the current partner at the same time. The specific steps of the algorithm are shown in Table 1.

4. NUMERICAL RESULTS

In this section, the performance of the proposed matching algorithm, the impacts of the social relationships on social unicast throughput and delay are validated through simulations. The simulation scene is a fan-shaped area with a radius of 100m, in which the BS is located in the center of the circle and the users are uniform distributed. The specific simulation parameters are shown in Table 2. The distribution of social contact between users and the distance between neighbors should be based on the specific environment, so the neighbor range is between [0,50m]. We mainly focus on the average throughput in a TS in different neighbor range and different social tie strength. At the same time, the performance of the proposed cooperative transmission algorithm is analyzed.

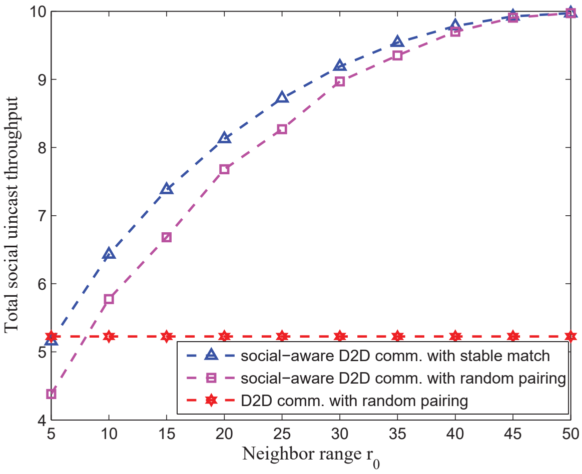

Figure 3: The impact of neighbor range and cooperation mode on communication utility.

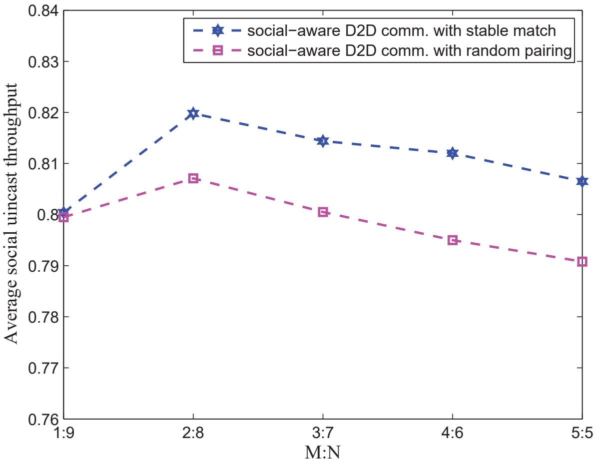

Figure 4: The impact of $M : N$ on communication utility.

As shown in Figure 2, the average social unicast throughput increases as the neighbor range increases when $\alpha_{ij} \neq 0$. A higher value of the neighbor range r_0 indicates that a user is more likely to be the content owner's regular contacts, which substantially enhances the social unicast throughput and increases the probability of successful transmission of video date packets. However, a higher social exponent α_{ij} reduces the attainable throughput, the reason is that a higher α_{ij} indicates a large difference in user attributes, individuals with less in common are less likely to develop or maintain a strong tie. Because users are selfish, the users are more reluctant to share their own data packets to whom has a weak social tie with him, and the throughput declines. In contrast to all other cases, $\alpha_{ij} = 0$ indicates that the opportunistic contacts of the user are equivalent to his regular contacts. Therefore, the average social unicast throughput, shown by the top trace of Figure 3, is no longer affected by the user's neighbor range.

Figure 3 considers a network system of any two sets consisting of 5 users uniformly and randomly located in the coverage area of a BS, the devices need to cooperate with each other to recover their missing packets by using D2D links. The total social unicast throughput of cooperative transmission under three different cooperation modes and different neighbor range are compared. The simulation considers the performance of D2D communications with random pairing without considering social factors. In the case that each D2D link cannot obtain the social network information to establish the belief function, but can only establish a physical preference over the users, so the neighbor range r_0 does not affect the performance of cooperation. It can be observed that the total social unicast throughput of D2D communications can be significantly improved by utilizing the social similarity between D2D pairs when the neighbor range is large. In addition, the stable matching algorithm has better performance than random matching, the reason is that the one-to-one matching u is weak Pareto optimal for D2D pairs on cooperative transmissions, each user has reached an ideal state of cooperation.

Figure 4 reflects the impact of different value of $M : N$ on average social unicast throughput. With the increasing proportion of M to N, the average throughput of users shows a trend of rising first and then decreasing. The communication utility reaches a maximum when $M : N = 2 : 8$. This is because when M is small, the user collaboration is less competitive and the average social unicast throughput is subject to the communication utility of $m_i \in M_{D_a}$, and the UE will switch into a cellular mode and be served by the BS if the neighbor is not found to establish D2D link. With the increase of the number M, each $n_j \in N_{D_b}$ has more chance to choose m_i that he wants to cooperate with, n_j needs to achieve optimal cooperation through multiple consultations. The competition rise and the communication utility shows a downward trend. At the same time, it can be seen from the simulation results that the stable matching algorithm is better than random matching.

5. CONCLUSIONS

This paper proposes a cooperative video transmission model that combines the social relationships and physical conditions between users. Unicast throughput and delay are derived by considering the social relations and wireless propagation conditions. Taking into account the preferences of the user to others, the paper applies economic two-sided matching theory to transfer cooperative video transmission problem to dynamic and mutually beneficial relations among different types of rational and selfish agents. Simulation results demonstrate that D2D communications can be enhanced by considering social aspects, the performance of the proposed algorithm can be improved by higher throughput compared to the traditional cooperative scheme.

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