Social-Aware Multi-File Dissemination in Device-to-Device Overlay Networks

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I. Introduction

Multi-File dissemination through wireless communication has attracted considerable attentions in recent years, especially when Device-to-Device (D2D) communication is developed to support peer-to-peer file transmission. To decrease the total delay, the authors in [1] proposed a cluster-based D2D network in which files are transmitted from the BS to several cluster-heads, and then shared inside each cluster through D2D communication. Distributed caching is another option to enhance the transmission rate by precaching files to users, with which mobile users with the same interest can share files directly through D2D communication [2]. However, most of the current studies on D2D-based file sharing schemes typically assume that all users are separated in non-overlapping communities that each user can only select one sort of files, and ignore the social relations among mobile users. When considering heterogeneous but overlapping interests of users, how to utilize social ties for multi-file sharing with minimum delay is still a challenging problem. To this end, we propose a graph based social aware algorithm in which cellular links and D2D links are established according to social ties and social contributions of users for efficient multi-file dissemination.

II. System Model

We consider a downlink transmission scenario in a wireless D2D overlay cellular network as shown in Fig. 1. Two types of communications exist in this scenario: the cellular communication from the base station to a user and the D2D communication between two users in a short distance, where D2D communications operated as an overlay to the cellular users which occupy orthogonal licensed spectrum resources with cellular users. M files procached in the BS need to be disseminated to N users through cellular and D2D communications. Each user prefers to acquire one or several of M files, which denotes an interest matrix $\mathcal{I}^{N\times M}$, where $\mathcal{I}_{n,m}=1$ if user n prefers file m otherwise $\mathcal{I}_{n,m}=0$. The popularity of a file is defined by the total number of its respective requests, which is in power distribution according to Zipf's Law. Besides, the size of each file is represented as F_0.

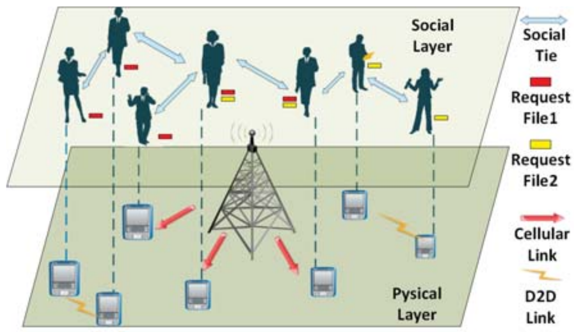

Fig. 1. System Model

A. Social Layer Model

For each user, a file can be obtained from the BS via a wireless cellular communication or from his neighbors who have cached the same file, via a D2D communication. Besides the distance constraint, a D2D link between users is not permitted unless they have some social relationships (i.e.,kinship, friendship, coworkers, etc), which can be generated by trace data mining and machine learning. Here, we simply assume that social ties between users are known, denoted a social matrix $\mathcal{S}^{N\times N}$, where $\mathcal{S}_{n_1,n_2}=1$ indicates that there exists a social tie between user n_1 and user n_2.

B. Physical Layer Model

Orthogonal Frequency Division Multiplexing (OFDM) technique is used for both cellular communications and D2D communications. There are totally K_0 OFDM subcarriers to be allocated by the BS, and the time scheduling process is operated per transmission time interval (TTI) under two basic assumptions: 1) each subcarrier can be allocated to at most one cellular user or one D2D pair, 2) either a cellular user or a D2D pair can occupy multiple subcarriers. The spectrum bandwidth of each subcarrier is represented as W_0. The transmit power of BS on each subcarrier is below P_0, which for each user's device's transmitter, is no more than P_1. For the BS, it can send data simultaneously to several cellular users on different subcarriers. But for a D2D user, it can transmit data to at most one receiver and receive data from one transmitter at the same time. The instantaneous data rate from the transmitter i ($i=N+1$ if the transmitter is the BS otherwise the transmitter is a D2D device) to a receiver j can be calculated by:

$$C_{i,j}=\sum_{k\in\mathcal{K}_{i,j}} W_0\cdot\log_2\left(1+\frac{p_{i,j}^k|h_{i,j}^k|^2}{\sigma^2}\right), \quad (1)$$

where $h_{i,j}^k$ is the channel gain between i and j on subcarrier k, $\mathcal{K}_{i,j}$ represents the set of subcarriers allocated to the link between i and j, and σ^2 is the channel noise.

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C. Problem Formulation

The delay for user n to achieve file m is defined by the time span between the moment user n that submits the request and the moment user n that finishes receiving file m, denoted by $D_{n,m}$. We assume that each file is an entirety, which indicates when user n has started receiving file m, other requests can not be responded until m has been entirely transmitted to him. Thus, $D_{n,m}$ contains the transmission time and the waiting time, which is influenced by both the link selection and the spectrum scheduling per TTI, and also the file order. The objective is to design a strategy to minimize the total delay:

$$\min \sum_{n=1}^{N} \sum_{m=1}^{M} \mathcal{I}_{n,m} \cdot D_{n,m}. \quad (2)$$

III. Social Aware Strategy

This problem can be solved by a social aware algorithm. At each TTI, we at first optimize the link and the file choices on the social layer, and then allocate resources to each links.

A. Social Layer Algorithm

The graph theory based social aware algorithm is used to match transmitters and receivers, and to select the file on each link. The utility function $U_{i,j}^m$ for a link from user i ($i = N+1$ means BS) to transmit file m to user j can be written as:

$$U_{i,j}^m = \Theta_i^{Tr} \cdot \Theta_j^{Re} \cdot W_{i,j}^m \cdot (1 + \beta \cdot \mathcal{W}_{j,*}^m \cdot \mathcal{B}) / ||\mathcal{I}_{j,*}^B||, \quad (3)$$

where $W_{i,j}^m = \mathcal{I}_{i,m}^A \mathcal{I}_{j,m}^B \mathcal{S}_{i,j} \log_2(1 + \lambda L_{i,j}^{-\alpha})$, $\mathcal{I}_{i,m}^A = 1$ represents the user i has already received the file m, $\mathcal{I}_{j,m}^B = 1$ when $\mathcal{I}_{j,m} = 1$ and user j neither has the file m nor is receiving the file m, $\Theta_i^{Tr} = 1$ when the transmitter on user i's device is unoccupied or i is the BS, $\Theta_j^{Re} = 1$ when j's receiver is at leisure, $L_{i,j}$ is the distance between i and j, λ and α are constants, $\mathcal{W}_{j,*}^m \cdot \mathcal{B}$ represents the contribution that j can make for others to share file m defined as the social contribution, a larger $\mathcal{W}_{j,*}^m \cdot \mathcal{B}$ indicates that file m is need in more j's social neighbors, $\mathcal{W}_{j,*}$ is the row vector consisting of all $W_{j,*} > 0$ and $\mathcal{B}$ is the balanced column vector as $(\frac{1}{2}\ \frac{1}{3}\ \frac{1}{4} \ldots)^T$ with the same length as $\mathcal{W}_{j,*}$, β is a social contribution parameter to measure the importance of user j's social contribution, and $\beta = 0$ implies that only social ties are considered but social contributions are ignored.

A multi-mode directed graph $G(V, E)$ is established whose vertices represent users and the BS. To distinguish the transmitter and the receiver, each edge is a direct edge. The in-degree of each vertex is no more than one, and the out-degree is also at most one except for the BS vertex, defined as the one-indegree-one-outdegree (OIOO) constraint. The value of each edge is a vector with two parts: the mode part which represents the file number and the utility part calculated by (3). We propose a greedy edge-coloring algorithm to decide the link choices. At each TTI, first we color the edges in which the residue transmission link has not been accomplished, and then we iterate the following steps: screen out all uncolored edges that satisfy OIOO constraint forming a set Ψ, color the largest utility edge in Ψ, set the link on this edge such that the file number on this link is determined by the edge's mode, until $\Psi = \emptyset$.

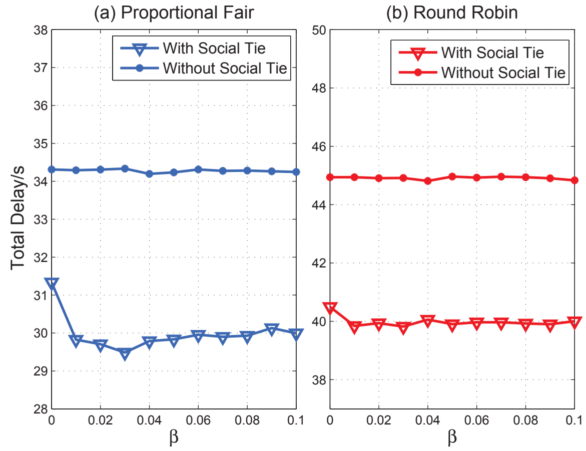

Fig. 2. Total delay vs. social structure parameter β

B. Physical Layer Algorithms

At each TTI, after the links have been established in the social layer, we jointly consider the residue links and the new links. The total spectrum resources are allocated proportionally to cellular users and D2D pairs. Two traditional algorithms for spectrum scheduling for both cellular users or D2D pairs are utilized: 1) the Round Robin Algorithm in which all resources are uniformly allocated, 2) the Proportional Fair Algorithm that the BS allocate the subcarrier k to the link that has the largest the instantaneous channel gain.

IV. Simulation Results

We set 30 users in a 50 m×50 m region, 20 files (each is 1 Mbits) precached in the BS 300 m away from the center of the region, the power constraint for each subcarrier $P_0 =$ 10 dBm and for each user $P_1 = 10$ dBm and the noise variance $\sigma^2 = -90$ dBm. The total number of subcarriers is $K_0 =$ 32, and each bandwidth is 180 kHz. Also, we consider the Rayleigh channel model for simulation. All requests of users are submitted to the BS at the same time. We compare the results with our proposed social-aware cross-layer strategy and the results without social tie and D2D links assistance.

In Fig. 2, it shows that the total delay decreases with our algorithm compared with the traditional method without social tie. Besides, the system performance gets better for both spectrum scheduling algorithms when considering social contributions ($\beta > 0$), in contrast to the case just with social ties but ignoring the social contributions, i.e. $\beta = 0$.

V. Acknowledgements

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