Project Report

Xuecheng Liu ID: 5130309724

June 26, 2016

My project title is *Exploiting Social Weak Tie Structure for D2D Cooperative Communication: A Power Control Perspective*. D2D communication is a new pattern broadly applied in 5G technology. Unlike the traditional cellular networks, direct communication between devices is permitted in D2D communication. Base station serves as network assistance. Intuitively, high throughput, low energy consumption can be achieved.

Our work aims at the power control problem regarding interference. Specifically speaking, we use social weak tie structure to help choose relay node. Combining the channel condition and social relation, we define a utility function and put forward a game. Later we will do some analysis and conduct some experiments.

1 Communication Model

In D2D communication scenario, we consider a set of UEs $\mathcal{N} = \{1, 2, \ldots, N\}$ where N is the total number of UEs. Each UE $n \in \mathcal{N}$ represents a user with a wireless device that would like to conduct D2D communication to transmit data packets to its corresponding destination d_n. And a destination UE d_n may also be a transmit node in the UE set $\mathcal{N}$ of another D2D communication link, hence a D2D traffic flow may traverse one hop or multiple hops among the users. For tractability of analysis, we only consider the situation in which the locations of the nodes remain unchanged during a D2D communication scheduling period (e.g., several hundred milliseconds), while they may change across different periods due to users' mobility.

Without loss of generality, we assume that the transmitting power p_n for each UE $n \in \mathcal{N}$ is bounded as $0 < P_{n,1} \leq p_n \leq P_{n,2}$. $P_{n,2}$ is upper bound due to hardware and battery limits and $P_{n,1}$ is the minimum power consumption requirement for UE n to send a message. Denote by $\mathbf{p} = (p_1, p_2, \ldots, p_N)$ the power allocation of the nodes, then the signal-to-interference-plus-noise ratio (SINR) of the link from source node n to destination node m directly is given by

$$\mathrm{SINR}_{nm}(\mathbf{p}) = \frac{G\|n, m\|^{-\alpha} p_n}{N_0 + \sum_{k \neq n} G\|k, m\|^{-\alpha} p_k}. \tag{1}$$

where $\|m, n\|$ is the physical distance between node m and node n, $G > 0$ is a constant and $\alpha > 2$ is the path loss exponent. N_0 is the noise power. Note that in direct transmission mode for D2D communications, dense devices cluster together and the interference is crucial to the power control.

Data rate achieved by node n is given by

$$R_n^{Dir} = \frac{W}{N} \log(1 + \mathrm{SINR}_{nm}). \tag{2}$$

Sometimes, the distance between source node n and destination node m is too long, node n might seek for another node r_n nearby as a relay to save energy and achieve larger data rate. For ease of exposition, we consider the single relay selection scheme and the full duplex decode-and-forward(DF) relaying scheme for the cooperative D2D communication. The data rate achieved by node n is then given as

$$\begin{aligned} R_n^{DF} = & \frac{W}{N} \min\{\log(1 + \mathrm{SINR}_{nr_n}), \\ & \log(1 + \mathrm{SINR}_{nm} + \mathrm{SINR}_{r_n m})\}. \end{aligned} \tag{3}$$

For ease of organization, we define the data rate of node n as $R_n : \mathcal{N}_n^P \cup \{n\} \to R^+$, which is given by

$$R_n(r_n) = R_n^{Dir}\mathcal{I}_n(r_n) + R_n^{DF}(1 - \mathcal{I}_n(r_n)). \tag{4}$$

where $\mathcal{I}_n(r_n)$ is an 0-1 indicator function given as

$$\mathcal{I}_n(r_n) = \begin{cases} 0, & r_n \neq n; \\ 1, & r_n = n, \text{ namely without relay.} \end{cases} \tag{5}$$

Due to the physical constraints such as signal attenuation, only a part of nodes that are close enough (e.g., with a detectable signal strength) can be feasible relay candidates for the node n. Taking such physical constraints into account, we introduce the physical graph $\mathcal{G}^P = \{\mathcal{N}, \mathcal{E}^P\}$ where the set of nodes $\mathcal{N}$ is the vertex set and $\mathcal{E}^P = \{(n, m) : e_{nm}^P = 1, \forall n, m \in \mathcal{N}\}$ is the edge set where $e_{nm}^P = 1$ if and only if node m is a feasible relay for node n.

2 Social Weak Structure

We next introduce the social graph characterized by weak tie for cooperative D2D communications. The underlaying rationale of using social feature is that the handheld devices are carried by human beings and the knowledge of human social ties can be utilized to achieve energy efficient cooperation for D2D communications.

Specifically, we introduce the social graph $\mathcal{G}^S = \{\mathcal{N}, \mathcal{E}^S\}$ to model the social ties among the users. Here the vertex set is the same as the user set $\mathcal{N}$ and the edge set is given as $\mathcal{E}^S = \{(n, m) : e_{nm}^S = 1, \forall n, m \in \mathcal{N}\}$ where $e_{nm}^S = 1$ if and only if users n and m have social tie between each other, which is close strangers relationship between each other. Moreover, since two users with friends relationship typically are distant in geometry[1], it is more beneficial to consider the close strangers relationships (e.g., weak social tie) when it comes to energy efficiency. Furthermore, for a pair of users n and m who have a weak social tie between them on the social graph, we formalize the strength of social tie as $w_{nm} \in (0, 1]$, with a higher value of w_{nm} being a stronger social tie.

One critical task here is to identify the social weak ties among device users. To this end, we use data collected from mobile phones to infer the relational dynamics of individuals[2]. Based on users' proximity, location and time cluster information during a period, communication seems to break down into two factors: in-role communication/proximity and extra-role communication/proximity. In-role communication is simply the amount of work-associated communication that takes place, which is dominated by proximity at work during the weekdays. Extra-role communication is driven off-work proximity and quantity of phone calls. Both in-role and extra-role communication are strongly predictive of social weak ties.

3 Game Formulation

In D2D cooperative communications, not all nodes are willing to serve as a relay node at any time due to users' selfishness and devices' battery state. In order to improve data rate and save energy, we need to stimulate cooperation between different nodes. To that end, we design the utility function as follows

$$u_n(\mathbf{p}, r_n) = R_n(r_n) - c_n p_n - (1 - w_{nr_n}\frac{B_n(t)}{B_{n0}})p_{r_n}\mathcal{I}_n(r_n) \tag{6}$$

4 Future Work

Complete the model and design efficient algorithm based on game theory.