Optimal joint Subchannel and Power Allocation for Green Underlay Device-to-Device Communication

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Abstract

In this paper, we provide an optimal solution of sub-channel and power allocation for the green underlay device to device (D2D) communication. The D2D communication is deployed by reusing sub-channels of a macrocell network for improving capacity and reducing power consumption in wireless network. We formulate an optimization problem to minimize the total CO2 emission while protecting the cellular users (CUs) and minimum data rate requirement of D2D pairs. Then, we find an optimal solution of subchannel and power allocation using a distributed algorithm based on the decomposition method. Finally, we show the proposed framework converging to an optimal solution.

I. Introduction

Recently, the D2D communication has emerged as the new paradigm, which is defined as direct communication between two mobile devices without forwarding the traffic via base station. This communication enables spectrum efficient usage, reducing power consumption, and improving capacity in wireless network [1].

In this paper, we consider the D2D communications underlying a macrocell network, in which the spectrum usages are reused from a macrocell network [1], [2], [3]. In order to deploy D2D communications, some challenges such as guaranteeing cellular users' data transmission in term of SINR threshold and data rate requirement of D2D communication need to be carefully considered [1]. Some previous works done deploying D2D communication network using underlay spectrum access paradigm in cognitive radio network [2] and [3]. However, they did not mention the optimal for joint power and subchannel allocation in the green underlay D2D communication. In the green underlay D2D network, we minimize residual energy in the network toward the CO2 emission minimization [5] while guaranteeing data rate requirement of D2D communications.

Our contribution in this paper as follows:

- We formulate an optimization problem, in which we minimize the CO2 emission while guaranteeing the minimum data rate requirements of D2D pairs and SINR threshold at the CUs.
- We propose a distributed algorithm that is designed based on the decomposition method to find optimal solution of power and subchannel allocation.

The remainder of this paper is organized as follows. The detailed system model and problem formulation are presented in section II. A joint subchannel and power allocation based on decomposition method is presented in section III. Next, some the simulation results are showed in section IV. Finally, some conclusions are presented in section V.

II. System model and formation problem

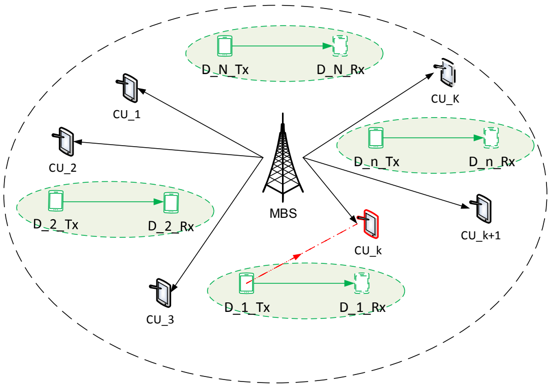

Figure 1: system model

System model.

We consider a D2D network consisting of a set $\mathcal{N}$ = {1…N} D2D pairs reusing sub-channels from a macrocell base station as in Fig.1. There are K sub-channels corresponding to K CUs are utilized from a macrocell base station (MBS). Moreover, we assume that the D2D network is managed by a controller which allocates available sub-channels to D2D pairs to guarantee that there is no interference among D2D pairs. Additionally, each D2D pair can be used at most one sub-channel for its transmitting data.

CO2 emission in the D2D data transmission. Once the D2D pair transmit its data, it emits a mount of CO2 which depends on kind of power supply for mobile devices [4]. Denoting c_n by the CO2 emission coefficients of the n-th D2D transmitter, the CO2 emission of the n-th D2D pair using subchannel k is determined by $c_n p_n^k$.

CU protection. In order to protect the k-th CU, total received interference power at the k-th CU has to guarantee the minimum $SINR_c^{\text{th}}$ as follows:

$$SINR_k(\text{A,P}) = \frac{g_{0k}^k P_0^k}{\sum_{n=1}^{N} a_n^k g_{nk}^k P_n^k + \delta_0^2} \geq SINR_k^{\text{th}},\ \forall k \tag{1}$$

where $\sum_{n=1}^{N}\sum_{k=1}^{K} a_n^k g_{nk}^k P_{nn}^k$ is the total interference from all D2D pairs to the k-th CU ; A = { a_n^k }$_{\text{NxK}}$ represents the subchannel allocation vector, in which a_n^k = {0,1} is a binary indicator, where a_n^k = 1 means that the n-th D2D pair is allocated the k-th subchannel; g_{nk}^k and g_{0k}^k are the power channel gain from transmitter of the n-th D2D pair to k-th CU and MBS to the k-th CU, respectively; P_n^k and P_0^k are transmit power of the n-th D2D pair and MBS on the k-th subchannel, respectively.

Problem formulation.

Next, the optimal for joint subchannel and power allocation in the green D2D network is formulated as follows:

$$\text{P-1:} \quad \min_{(\text{A,P})}. \sum_{n=1}^{N}\sum_{k=1}^{K} a_n^k c_n p_n^k \tag{2}$$

$$\text{s.t.} \quad (1),$$

$$\sum_{k=1}^{K} a_n^k \leq 1,\ \forall n, \tag{3}$$

$$0 \leq p_n^k \leq p_n^{\max},\ \forall n, \tag{4}$$

$$\sum_{k=1}^{K} a_n^k R_n^k \geq R_n^{th}, \forall n, \tag{5}$$

$$R_n^k = B_k \log_2\left(1+\gamma_n^k P_n^k\right), \tag{6}$$

where $\sum_{n=1}^{N}\sum_{k=1}^{K} a_n^k c_n p_{nn}^k$ is the total CO2 emission from all D2D pairs under the power and subchannel allocation policy (A,P); $\gamma_n^k = g_{nn}^k / (g_{0n}^k P_0^k + \sigma^2)$ is CIR at the receiver of the n-th D2D pair; constraint (3) represents each D2D can be assigned at most a sub-channel; constraint (4) represents the power limitation of D2D pairs; the constraint (5) represents the data rate requirement of each D2D pair; R_n^k is the rate of n-th D2D pair on k-th subchannel which is determined based on Shannon-capacity as in (6); B_k is bandwidth of sub-channel k; g_{nn}^k is channel gain between transmitter and receiver of the n-th pair on subchannel k; $g_{0n}^k P_0^k$ is interference level of MUE k to the receiver of the n-th pair; σ^2 is Gaussian Noise at the receiver.

III. Distributed algorithm for optimal joint subchannel and power allocation.

We now present our proposal to solve the problem P-1 given in previous section. It is observed that P-1 is an NP-hard combinatorial optimization problem. In order to make the problem more traceable, we relax the integer constraint on a_n^k= {0, 1} to a time sharing factor between 0 and 1 with problem reformulation $\tilde{p}_n^k = a_n^k p_n^k$. Then, this reformulation leads to a convex optimization problem for P-1. Using standard technique, the following Lagrangian of the reformulated P-1 is obtained:

$$L = -\sum_{n=1}^{N}\sum_{k=1}^{K} c_n \tilde{p}_n^k - \sum_{k=1}^{K} \mu^k \left(\sum_{n=1}^{N} \tilde{p}_n^k g_{nk}^k - \Delta_0^{k,th}\right) - \sum_{n=1}^{N} \lambda_n \left(\sum_{k=1}^{K} a_n^k - 1\right) + \sum_{n=1}^{N} \beta_n \left(\sum_{k=1}^{K} R_n^k(\tilde{\text{P}}) - R_n^{th}\right)$$

Where $\Delta_0^{k,th} = \frac{g_{0k}^k P_0^k}{SINR_k^{\text{th}}} - \delta_0^2$;

Thus, the dual problem is given as follows:

$$\min_{\lambda,\mu,\beta \geq 0} \quad \text{D}(\lambda,\mu,\beta) \tag{7}$$

where the dual function $\text{D}(\lambda,\mu)$ address as follows:

$$\begin{aligned} \text{D}(\lambda,\mu,\beta) &= \max_{\text{A},\tilde{\text{P}}} L\left(\text{A},\tilde{\text{P}},\lambda,\mu,\beta\right) \\ &= \sum_{k=1}^{K}\sum_{n=1}^{N} (\mu^k \Delta_0^{k,th} + \lambda_n - \beta_n R_n^{th}) + \Phi\left(\text{A},\tilde{\text{P}},\lambda,\mu,\beta\right) \end{aligned} \tag{8}$$

Without loss optimality, the dual problem $\Phi\left(\text{x},\tilde{\text{p}},\lambda,\mu\right)$ is decomposed into *NxK* sub problems as follows:

$$\Phi_{a_n^k,\tilde{p}_n^k,\lambda_n,\mu^k,\beta_n} = \max_{\text{A},\tilde{\text{P}}} \left\{-c_n \tilde{p}_n^k - \mu^k \tilde{p}_n^k g_{nk}^k - \lambda_n a_n^k + \beta_n R_n^k(\tilde{\text{P}})\right\} \tag{9}$$

By solving primal-dual problem, we propose the algorithm to find optimal solution of the P-1 as follows:

Joint power and channel allocation (JPC-O)

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1. Algorithm at the D2D pair:

1.1 *Power update.* Given the sub-channel allocation A, the optimal power allocation for the n-th D2D pair on subchannel *k* is obtained by taking $\delta\Phi_{a_n^k,\tilde{p}_n^k,\lambda_n,\mu^k,\beta_n} / \delta\tilde{p}_n^k = 0$ as follows:

$$P_n^k = \left[\frac{\beta_n B_k}{(c_n + \mu^k g_{nk}^k)\ln 2} - \frac{1}{\gamma_n^k}\right]_0^{P_n^{\max}}, \tag{10}$$

Where $[z]_0^{P_n^{\max}} = \min(\max(0,z), P_n^{\max})$.

1.2 *Sub-channel allocation.* Given power allocation in (10), we take the first derivative of (9). Then, the the n-th D2D pair assigns subchannel k as follows:

$$a_n^{k*} = 1 \mid k^* = \arg\max_k \left[\mu^k P_n^k g_{nk}^k + c_n P_n^k - B_k \log_2\left(1+\gamma_n^k P_n^k\right)\right] \tag{11}$$

1.3 *Update D2D-QoS price.*

$$\beta_n^{t+1} = \left[\beta_n^{(t)} + s_1^{(t)}\left(\sum_{n=1}^{N} a_n^k R_n^k - R_n^{th}\right)\right]^+ \tag{12}$$

2. Algorithm at the MBS:

2.1 Update CU-QoS price of all CUs:

$$\mu^{k,(t+1)} = \left[\mu^{k,(t)} - s_2^{(t)} \left(\sum_{n=1}^{N} a_n^k P_n^k g_{nk}^k - \Delta_0^{k,th} \right) \right]^+ \quad (13)$$

Results: the optimal allocation A^*, P^*

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where the dual variables updated using sub-gradient method; $s_i^{(t)}$ (i= 1, 2) are the steps size of iteration, which should be satisfy

$$\sum_{t=1}^{\infty} s_i^{(t)} = \infty, \ \lim_{t \to \infty} (s_i^{(t)}) = 0. \quad (14)$$

IV. Simulation results

In this section we present our simulation with Matlab to evaluate the performance of our proposals. We consider an indoor environment where M= 20 D2D pairs are located inside a MBS. Some parameters are installed as follows: K = 10 sub-channels; $SINR_k^{th}$ = 8 dBm; P_n^{max} = 20 dBm; P_0^k = 30 dBm; σ^2 =-105 dBm; B$_k$ =125 kHz. The channel gain is assumed to be iid Rayleigh random variables with mean value h(d) = h$_0$(d/15)$^{-4}$ where h$_0$ is a reference channel gain at a distance 15 m; c$_n$ = 0.057 kgCO2/kWh; data transmission time T= 300 s; $R_n^{th} = 2.048$ Mbps. Error e = 0.01;

In Figure 2, we can see that, in order to reduce residual energy for D2D pairs, D2Ds' transmitters will select sub-channels to reduce its transmit power while still guarantee minimum their data rate requirement based on Algorithm 1. Additionally, the interference at the CUs are also guaranteed to avoid SINR threshold for decoding data.

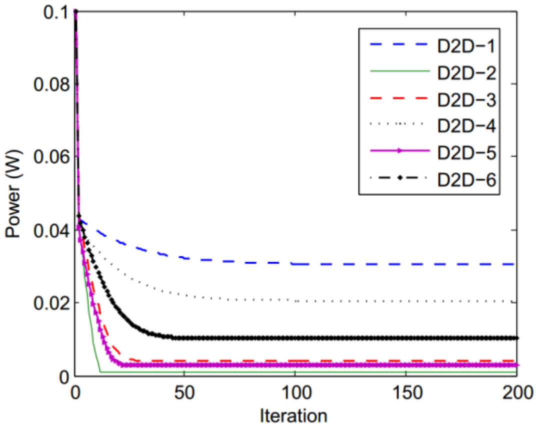

Fig.3. The minimum transmit power of D2D pairs to satisfy D2D pairs and CU's QoS.

In order to estimate the total CO2 emission of all D2D pairs, we perform transmit data of all D2D pairs around T = 300 s. Then, the total CO2 emission can be determined by $T * \sum_{n=1}^{N} \sum_{k=1}^{K} a_n^{k,*} c_n P_n^{k,*}$. The simulation result is shown in Figure 3. We can see that, the optimal power and channel allocation can be achieved after 42 iteration with error estimation e = 0.01, in which we use Gurobi optimizer for finding optimal solution [6]. Finally, all D2D pairs will go to the data transmission phase for transmitting data.

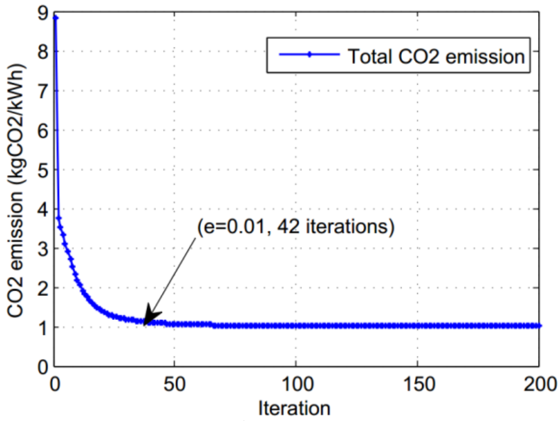

Fig.2. Estimation of D2D pairs' CO2 emission with data transmission.

V. Conclusions

In this paper, we have proposed a frame work for optimal joint sub-channel and power allocation in green underlay device to device (D2D) communications. The D2D communications have deployed by reusing sub-channels of a macrocell network to improve capacity and reduce power consumption. We formulate an optimization problem to minimize the total CO2 emission of all D2D pairs while protecting the cellular users (CUs) and minimum data rate requirement of D2D pairs. Then, we have found optimal solution of subchannel and power allocation based on decomposition method. Finally, the simulation results have shown the proposed framework converging to an optimal solution.

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