

Fairness based Power Allocation Optimization in Dense Full Duplex D2D Networks

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Abstract—In 5th generation (5G) communication, the dense D2D network is a part of the ultra dense network. The features of short transmission distance and low transmission power of device-to-device (D2D) communication make it excellent to integrate the full duplex (FD) and D2D techniques for higher spectrum efficiency. In this paper, we consider the scenario of dense FD D2D network, in which the co-channel FD D2D pairs will interfere with each other. In such dense FD D2D network, fairness is an important factor for evaluating the network performance. In this paper, our objective is to optimize the data rate's fairness of co-channel FD D2D pairs in the network through power control, meanwhile protect the minimum achievable signal to interference plus noise ratio (SINR) of the cellular user. We first formulate the fairness optimization problem, which is a non-convex problem. Then we exploit the difference of two convex functions/sets (d. c.) structure of the utility function to search the transmission powers' global optimal iteratively. Simulation results show that the proposed algorithm is superior to the previous-proposed methods on data rate's fairness.

Keywords—D2D; full duplex; power control; fairness; dense networks

I. INTRODUCTION

Device-to-device (D2D) communications, which allow proximate user equipment (UE) directly communicate with each other [1-3], have been seen as a key technology in the fifth-generation (5G) communication [4]. D2D communications can enhance the spectrum and energy efficiency of wireless network, and offload the heavy traffic in cellular network, especially in populated areas, such as shopping mall [5]. Compared with cellular UE, D2D UE will have a high-rate channel due to the short range of D2D links.

Full duplex (FD) communications allow UE to transmit and receive signals on same spectrum resource, which improves the spectrum efficiency [6, 7]. However, the self-interference (SI) limits the channel capacity. It is proper to utilize the FD on low power transmission point to alleviate SI [4]. The D2D communications require low transmission power due to the short communication range. Thus, we can integrate the FD and D2D techniques for higher spectrum efficiency and lower SI [4, 5, 15, 16].

The FD D2D links reuse the spectrum resource of the cellular users, which creates co-channel interference to cellular users and other FD D2D links. In dense FD D2D networks, the channel conditions of the FD D2D links are of great difference due to various communication environments and interferences. Optimizing the data rate's fairness of the adjacent D2D links can improve the quality of experience of different users and make the network more stable. Meanwhile, since the cellular users have the priority for the spectrum resources, it is necessary protect the cellular users' quality of service (QoS).

Interference coordination plays a key role in data rate optimization in wireless networks. Power control is an efficient tool for interference coordination. However, up to now the power control techniques for fairness in dense FD D2D networks are not widely studied. Related work [5, 8, 9, 10] always assumes the scenario that consists of only one D2D pair and one cellular user. In [17, 18], the fairness of energy efficiency is studied, but the fairness of data rate is ignored.

In a hot spot, such as a shopping mall or a basketball court that contains thousands of users, one time-frequency resource will be shared by multiple FD D2D links. We define such scenario as a dense FD D2D network. In a dense FD D2D network, the interference among FD D2D links as well as the interference between FD D2D links and the cellular users need to be coordinated. In this work, we optimize the fairness of the FD D2D links, at the same time guarantee that the cellular user can achieve the target SINR. We first formulate the fairness problem in dense FD D2D networks, which is a non-convex problem. Then, we transform the utility function into a difference of two convex functions/sets (d. c.) structure, which allows us to apply the Frank-and-Wold (FW) procedure [14] to search the global optimal [12]. Simulation results shows that the proposed algorithm have a better fairness performance than the ergodic capacity maximization power allocation algorithm (ECMP) proposed in [5].

The rest of this paper is organized as follows. Section II gives the system model. Section III introduces the problem formulation and the iterative algorithm to obtain the optimal power settings for fairness. Simulation results are provided in Section IV and the conclusion is given in Section V.

II. SYSTEM MODEL

We consider an uplink dense FD D2D underlaid cellular network, where N FD D2D pairs share the same uplink spectrum resource of the cellular user (CUE), as shown in fig.1. One FD D2D pair consists of two FD D2D users. The users in one D2D pair transmit and receive signals on the same spectrum resource. Thus, the CUE suffers co-channel interference from FD D2D pairs, and the FD D2D pairs interfere with each other. The set of the FD D2D users are defined as $\mathbf{D}$.

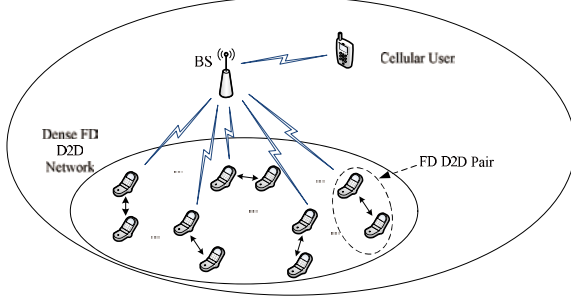


Figure 1. Dense FD D2D network underlaid cellular network

The signal to interference plus noise ratio (SINR) of CUE is defined as

$$SINR_{CUE} = \frac{p_{CUE} g_{B,CUE}}{\sum_{j \in \mathbf{D}} p_j g_{CUE,j} + \sigma^2}, \quad (1)$$

where p_{CUE} is the transmission power of CUE, $g_{B,CUE}$ is the path gain between CUE and base station (BS), $g_{CUE,j}$ is the path gain between D2D user j and CUE, p_j ($j \in \mathbf{D}$) is the transmission power of j^{th} FD D2D user that share the spectrum resource with CUE.

The SI cancellation techniques cannot entirely cancel the SI [6, 7]. We model the residual SI as

$$p_{SI} = \eta p_j, \quad (2)$$

where p_{SI} and p_j are the SI and the transmission power, respectively, η ($0 \leq \eta \leq 1$) is the SI mitigation coefficient. When $\eta = 0$, the SI cancellation is perfect and there is no SI. When $\eta = 1$, no SI is cancelled.

Assume i_1 and i_2 are the two users in FD D2D pair i . The SINRs of i_1 and i_2 are defined as

$$SINR_{i_1} = \frac{p_{i_1} g_{i_2,i_1}}{\eta_2 p_{i_2} + \sum_{j \neq i_1,i_2} p_j g_{i_2,j} + \sigma^2}, \quad (3)$$

$$SINR_{i_2} = \frac{p_{i_2} g_{i_1,i_2}}{\eta_1 p_{i_1} + \sum_{j \neq i_1,i_2} p_j g_{i_1,j} + \sigma^2}, \quad (4)$$

where p_{i_1} and p_{i_2} are the transmission powers of i_1 and i_2 , respectively, $\sum_{j \neq i_1,i_2} p_j g_{i_1,j}$ is the co-channel interference from

other FD D2D links and the cellular user, σ^2 is the noise power. The SI cancellation coefficients of i_1 and i_2 are denoted as η_1 and η_2 , respectively. The data rate of i_1 and i_2 are defined as

$$R_{i_1} = B_1 \log_2 (1 + SINR_{i_1}), \quad (5)$$

$$R_{i_2} = B_2 \log_2 (1 + SINR_{i_2}), \quad (6)$$

where B_1 and B_2 are the available bandwidth of i_1 and i_2 , respectively.

The sum rate of FD D2D pair i is

$$R_i = R_{i_1} + R_{i_2}. \quad (7)$$

III. FAIR DATE RATE OPTIMIZATION FOR DENSE FD D2D NETWORK VIA POWER CONTROL

A. Problem formulation

Our goal is to optimize the data rate's fairness of the FD D2D links, and at the same time guarantee that the cellular user's SINR is no less than a certain threshold γ_0 . Thus, we formulate a proportional fairness problem for the data rate of FD D2D pairs as follows

$$\begin{aligned} \max_{\mathbf{P}} \quad & F(\mathbf{P}) = \sum_{i=1}^N \ln(R_i) \\ \text{s.t.} \quad & 0 < \mathbf{P} < \mathbf{P}_{\max}, \\ & SINR_{CUE} \geq \gamma_0 \end{aligned} \quad (8)$$

where $\mathbf{P} = \{p_{11}, p_{12}; p_{21}, p_{22}; \dots; p_{N1}, p_{N2}\}$ is the set of transmission powers of N FD D2D pairs, $\mathbf{P}_{\max}$ is the power budget.

B. Fairness based FD D2D pair data rate optimization via power control

Since R_i in the objective function is nonconvex, the problem (8) is nonconvex. To achieve the optimization goal, we convert the nonconvex problem to an equivalent convex problem.

First, we transform the SINR constraint into a linear form as

$$p_B g_{CUE,B} - \gamma_0 \left(\sum_{j \in \mathbf{D}} p_j g_{CUE,j} + \sigma^2 \right) \geq 0. \quad (9)$$

Then by taking (5), (6), (7) in to (8), we have

$$\begin{aligned} F(\mathbf{P}) = \sum_{i=1}^N \ln \left[B_{i_1} \log_2 \left(p_{i_1} g_{i_2,i_1} + \eta_2 p_{i_2} + \sum_{j \neq i_1,i_2} p_j g_{i_2,j} + \sigma^2 \right) \right. \\ \left. - B_{i_1} \log_2 \left(\eta_2 p_{i_2} + \sum_{j \neq i_1,i_2} p_j g_{i_2,j} + \sigma^2 \right) \right. \\ \left. + B_{i_2} \log_2 \left(p_{i_2} g_{i_1,i_2} + \eta_1 p_{i_1} + \sum_{j \neq i_1,i_2} p_j g_{i_1,j} + \sigma^2 \right) \right. \\ \left. - B_{i_2} \log_2 \left(\eta_1 p_{i_1} + \sum_{j \neq i_1,i_2} p_j g_{i_1,j} + \sigma^2 \right) \right]. \end{aligned} \quad (10)$$

And Eq. (8) can be rewritten as

$$\begin{aligned}
 \max_{\mathbf{P}} \quad & F(\mathbf{P}) = \sum_{i=1}^M \ln(f_i(\mathbf{P}) - g_i(\mathbf{P})) \\
 \text{s.t.} \quad & 0 \prec \mathbf{P} \prec \mathbf{P}_{\max}, \\
 & p_B g_{CUE,B} - \gamma_0 \left(\sum_{i \in \mathbf{D}} p_i g_{CUE,i} + \sigma^2 \right) \geq 0,
 \end{aligned} \quad (11)$$

Where

$$\begin{aligned}
 f_i(\mathbf{P}) = & B_{i_1} \log_2 \left(p_{i_1} g_{i_2,i_1} + \eta_2 p_{i_2} + \sum_{j \neq i_1,i_2} p_j g_{i_2,j} + \sigma^2 \right) \\
 & + B_{i_2} \log_2 \left(p_{i_2} g_{i_1,i_2} + \eta_1 p_{i_1} + \sum_{j \neq i_1,i_2} p_j g_{i_1,j} + \sigma^2 \right),
 \end{aligned}$$

and

$$\begin{aligned}
 g_i(\mathbf{P}) = & B_{i_1} \log_2 \left(\eta_2 p_{i_2} + \sum_{j \neq i_1,i_2} p_j g_{i_2,j} + \sigma^2 \right) \\
 & + B_{i_2} \log_2 \left(\eta_1 p_{i_1} + \sum_{j \neq i_1,i_2} p_j g_{i_1,j} + \sigma^2 \right).
 \end{aligned}$$

Functions $f_i(\mathbf{P})$ and $g_i(\mathbf{P})$ are concave functions. In this way, we transform the objective function (8) into a d.c. function, which is defined as the difference of two concave functions [5]. Such problem can be solved by the FW procedure [11, 12]. With FW procedure, problem (11) is relaxed to

$$\begin{aligned}
 \max_{\mathbf{P}} \quad & \tilde{F}(\mathbf{P}) = \sum_{i=1}^M \ln \left(f_i(\mathbf{P}) - g_i(\mathbf{P}^{(\kappa)}) - \left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P} - \mathbf{P}^{(\kappa)} \right\rangle \right) \\
 \text{s.t.} \quad & 0 \prec \mathbf{P} \prec \mathbf{P}_{\max}, \\
 & p_B g_{CUE,B} - \gamma_0 \left(\sum_{j \in \mathbf{D}} p_j g_{CUE,j} + \sigma^2 \right) \geq 0,
 \end{aligned} \quad (12)$$

where $\left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P} - \mathbf{P}^{(\kappa)} \right\rangle$ is the inner product of $\frac{dg_i(\mathbf{P})}{d\mathbf{P}}$ and $\mathbf{P} - \mathbf{P}^{(\kappa)}$. The term $g_i(\mathbf{P})$ in the objective function is replaced by $g_i(\mathbf{P}^{(\kappa)}) + \left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P} - \mathbf{P}^{(\kappa)} \right\rangle$, which is a linear function to $\mathbf{P}$. To be more specific,

$$\begin{aligned}
 \left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P} - \mathbf{P}^{(\kappa)} \right\rangle = & (p_{i_1} - p_{i_1}^{(\kappa)}) \frac{\eta_1}{\left(\eta_1 p_{i_1} + \sum_{j \neq i_1,i_2} p_j g_{i_1,j} + \sigma^2 \right) \ln(2)} + \\
 & (p_{i_2} - p_{i_2}^{(\kappa)}) \frac{\eta_2}{\left(\eta_2 p_{i_2} + \sum_{j \neq i_1,i_2} p_j g_{i_2,j} + \sigma^2 \right) \ln(2)} + \\
 & \sum_{j \neq i_1,i_2} (p_j - p_j^{(\kappa)}) \left[\frac{g_{i_1,j}}{\left(\eta_1 p_{i_1} + \sum_{j \neq i_1,i_2} p_j g_{i_1,j} + \sigma^2 \right) \ln(2)} + \right. \\
 & \left. \frac{g_{i_2,j}}{\left(\eta_2 p_{i_2} + \sum_{j \neq i_1,i_2} p_j g_{i_2,j} + \sigma^2 \right) \ln(2)} \right]
 \end{aligned} \quad (13)$$

So problem (12) is a concave problem with respect to $\mathbf{P}$. The FW procedure generates a sequence of feasible solutions $\{\mathbf{P}^{(\kappa)}\}$ and solve the problem by iteration. FW procedure initializes $\{\mathbf{P}^{(\kappa)}\}$ by $\mathbf{P}^{(1)}$. At step κ , $\mathbf{P}^{(\kappa)}$ is fixed and we can update the value of $\mathbf{P}$, which is denoted by $\mathbf{P}^{(\kappa)}$. At step $\kappa+1$, we give the optimal power value $\mathbf{P}^{(\kappa)}$ to $\mathbf{P}^{(\kappa+1)}$. Since $g_i(\mathbf{P})$ is concave, we have

$$g_i(\mathbf{P}) \leq g_i(\mathbf{P}^{(\kappa)}) + \left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P} - \mathbf{P}^{(\kappa)} \right\rangle. \quad (14)$$

Then the iteration follows [8]

$$\begin{aligned}
 & \left[f_i(\mathbf{P}^{(\kappa+1)}) - g_i(\mathbf{P}^{(\kappa+1)}) \right] \geq \\
 & \left[f_i(\mathbf{P}^{(\kappa+1)}) - \left(g_i(\mathbf{P}^{(\kappa)}) + \left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P}^{(\kappa)} - \mathbf{P}^{(\kappa)} \right\rangle \right) \right] \geq \\
 & \left[f_i(\mathbf{P}^{(\kappa)}) - g_i(\mathbf{P}^{(\kappa)}) \right].
 \end{aligned} \quad (15)$$

$\tilde{F}(\mathbf{P})$ monotonically increases as κ increases and $\mathbf{P}^{(\kappa+1)}$ is always better than $\mathbf{P}^{(\kappa)}$. Because of the compactness on the constraints, the sequence of feasible solutions $\{\mathbf{P}^{(\kappa)}\}$ will always converge [11, 12].

The dual problem of (12) is

$$\begin{aligned}
 \min_{\lambda} \quad & \Phi(\lambda) = \max_{\mathbf{P}} \Xi(\mathbf{P}, \lambda) \\
 \text{s.t.} \quad & 0 \prec \mathbf{P} \prec \mathbf{P}_{\max}.
 \end{aligned} \quad (16)$$

where

$$\Xi(\mathbf{P}, \lambda) = \tilde{F}(\mathbf{P}) + \lambda \left(p_B g_{CUE,B} - \gamma_0 \left(\sum_{j \in \mathbf{D}} p_j g_{CUE,j} + \sigma^2 \right) \right). \quad (17)$$

According to the standard convex optimization techniques, the optimal transmission powers of the FD D2D users can be

obtained by taking the derivative of $\Xi(\mathbf{P}, \lambda)$ with respect to the transmission power. To be more specific,

$$\frac{d\Xi(\mathbf{P}, \lambda)}{dp_l} = \frac{d\tilde{F}(\mathbf{P})}{dp_l} - \lambda \gamma_0 g_{CUE,l}, \quad (18)$$

where l is the index of FD D2D users and $\frac{d\tilde{F}(\mathbf{P})}{dp_l}$ is

$$\frac{d\tilde{F}(\mathbf{P})}{dp_l} = \sum_{i=1}^M \frac{d \left(f_i(\mathbf{P}) - \left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P} - \mathbf{P}^{(\kappa)} \right\rangle \right) / dp_l}{\left(f_i(\mathbf{P}) - g_i(\mathbf{P}^{(\kappa)}) - \left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P} - \mathbf{P}^{(\kappa)} \right\rangle \right) \ln(2)}. \quad (19)$$

Then we calculate the gradients in (19), assume

$$A = \left(p_{i_1} g_{i_2, i_1} + \eta_2 p_{i_2} + \sum_{j \neq i_1, i_2} p_j g_{i_2, j} + \sigma^2 \right) \ln(2); \quad (20a)$$

$$A' = \left(\eta_2 p_{i_2} + \sum_{j \neq i_1, i_2} p_j g_{i_2, j} + \sigma^2 \right) \ln(2); \quad (20b)$$

$$B = \left(p_{i_2} g_{i_1, i_2} + \eta_1 p_{i_1} + \sum_{j \neq i_1, i_2} p_j g_{i_1, j} + \sigma^2 \right) \ln(2); \quad (20c)$$

$$B' = \left(\eta_1 p_{i_1} + \sum_{j \neq i_1, i_2} p_j g_{i_1, j} + \sigma^2 \right) \ln(2). \quad (20d)$$

We have

$$\frac{d(f_i(\mathbf{P}))}{dp_l} = \begin{cases} \frac{g_{i_2, i_1}}{A} + \frac{\eta_1}{B}, & \text{if } l = i_1 \\ \frac{\eta_2}{A} + \frac{g_{i_1, i_2}}{B}, & \text{if } l = i_2 \\ \frac{g_{i_1, l}}{A} + \frac{g_{i_2, l}}{B}, & \text{others;} \end{cases} \quad (21)$$

and

$$\frac{d \left(\left\langle \frac{dg_i(\mathbf{P})}{d\mathbf{P}}, \mathbf{P} - \mathbf{P}^{(\kappa)} \right\rangle \right)}{dp_l} = \begin{cases} \frac{\eta_1}{B'} + (p_{i_1} - p_{i_1}^{(\kappa)}) \frac{-\eta_1^2 \ln(2)}{B'^2} + \sum_{j \neq i_1, i_2} (p_j - p_j^{(\kappa)}) \left(\frac{-\eta_1 g_{i_1, j} \ln(2)}{B'^2} \right), & \text{if } l = i_1; \\ \frac{\eta_2}{A'} + (p_{i_2} - p_{i_2}^{(\kappa)}) \frac{-\eta_2^2 \ln(2)}{A'^2} + \sum_{j \neq i_1, i_2} (p_j - p_j^{(\kappa)}) \left(\frac{-\eta_2 g_{i_2, j} \ln(2)}{A'^2} \right), & \text{if } l = i_2; \\ (p_{i_1} - p_{i_1}^{(\kappa)}) \frac{-g_{i_1, j} \eta_1 \ln(2)}{B'^2} + (p_{i_2} - p_{i_2}^{(\kappa)}) \frac{-g_{i_2, j} \eta_2 \ln(2)}{A'^2} + \sum_{j \neq i_1, i_2} (p_j - p_j^{(\kappa)}) \left(\frac{-g_{i_1, j}^2 \ln(2)}{B'^2} + \frac{-g_{i_2, j}^2 \ln(2)}{A'^2} \right) + \left(\frac{g_{i_1, l}}{B' \ln(2)} + \frac{g_{i_2, l}}{A' \ln(2)} \right), & \text{others.} \end{cases} \quad (22)$$

where i_1 and i_2 are the index of FD D2D users in D2D link i .

With the gradient descent method, we can search the optimal power setting in step κ , which is

$$\mathbf{P}^{(\kappa)} = \arg \max_{\mathbf{P}} \{ \Xi(\mathbf{P}, \lambda) \}. \quad (23)$$

where the optimal transmission powers is searched by

$$p_l \leftarrow p_l + \mu_p \frac{d\Xi(\mathbf{P})}{dp_l}, \quad (24)$$

where μ_p is the step size for power update. Since $\Xi(\mathbf{P})$ is concave, the iteration of Eq. (24) will converge to the optimal $\mathbf{P}^*$.

The Lagrangian multiplier is updated as

$$\begin{aligned} \lambda^{(\kappa+1)} &= \max \left\{ \left[\lambda^{(\kappa)} - \mu_\lambda \frac{d\Phi(\lambda)}{d\lambda} \right], 0 \right\} \\ &= \max \left\{ \left[\lambda^{(\kappa)} - \mu_\lambda \left(p_B g_{CUE, B} - \gamma_0 \left(\sum_{j \in \mathbf{D}} p_j g_{CUE, j} + \sigma^2 \right) \right) \right], 0 \right\} \end{aligned} \quad (25)$$

According to convex optimization, by taking the optimal power into (25), we can track the optimal Lagrangian multiplier λ^* , where μ_λ is the step size.

The iteration process converges when $\left| \mathbf{P}^{(\kappa+1)} - \mathbf{P}^{(\kappa)} \right| < \varepsilon$ or $\left| \tilde{F}(\mathbf{P}^{(\kappa+1)}) - \tilde{F}(\mathbf{P}^{(\kappa)}) \right| < \varepsilon$, where $\varepsilon > 0$ is the threshold [12].

To be more specific, the proposed algorithm is concluded in Algorithm 1.

Algorithm 1 FW procedure for fair FD D2D pair data rate optimization

1. Initialize $\mathbf{P}^{(1)}$ and Lagrangian multiplier $\lambda^{(1)}$;
 2. **Loop** :
 3. in step κ
 4. calculate $\frac{d\tilde{F}(\mathbf{P})}{dp_l}$ by taking (21) and (22) into (19);
 5. calculate the optimal transmission power $\mathbf{P}^{(\kappa)} = \arg \max_{\mathbf{P}} \{ \Xi(\mathbf{P}, \lambda) \}$;
 6. set $\mathbf{P}^{(\kappa+1)} = \mathbf{P}^{(\kappa)}$;
 7. update $\lambda^{(\kappa)}$ by (24);
 8. **if** $\left| \mathbf{P}^{(\kappa+1)} - \mathbf{P}^{(\kappa)} \right| < \varepsilon$ or $\left| \tilde{F}(\mathbf{P}^{(\kappa+1)}) - \tilde{F}(\mathbf{P}^{(\kappa)}) \right| < \varepsilon$
 9. **break**;
 10. **End if**;
 11. **End Loop**.
-

In each iteration in **Algorithm 1**, the computational complexity is $k * O(2N)$, where k is the number of iterations of searching $\mathbf{P}^{(\kappa)} = \arg \max_{\mathbf{P}} \{ \Xi(\mathbf{P}, \lambda) \}$, and $2N$ is the number of users in dense FD D2D network.

IV. SIMULATION RESULTS

We consider a dense FD D2D network underlaid cellular network, in which N co-channel FD D2D pairs are randomly deployed in a 200m*200m area and the radius of cellular BS is 400m. One cellular user is randomly deployed under the cellular coverage and outside dense FD D2D network. We compare our proposed algorithm with the ergodic capacity maximization power allocation algorithm (ECMP) [5]. The bandwidth of each D2D pair is assumed to be

$$B_1 = B_2 = 1\text{MHz}. \text{ The channel gain is } g_{i,j} = \left(\frac{1}{d_{i,j}}\right)^{-4} [10]. \text{ The}$$

maximum distance of the two users in one FD D2D pair is 15m. We assume all FD D2D users have the same SI mitigation coefficient $\eta = -90\text{dB}$. The minimum required SINR of the cellular user is $\gamma_0 = 2\text{dB}$. The step size of power updating and Lagrangian multiplier updating are $\mu_p = 50$ and $\mu_\lambda = 10^{-4}$, respectively.

In fig.2 we compare the fairness indexes of the proposed algorithm and the ECMP. The fairness index on data rate is defined as [13]

$$\text{Fairness Index} = \frac{\left(\sum_{j \in \mathbf{D}} R_j\right)^2}{|\mathbf{D}| * \sum_{j \in \mathbf{D}} R_j^2}, \quad (25)$$

where $\mathbf{D}$ is the set of FD D2D users and $|\mathbf{D}|$ is the number of users in $\mathbf{D}$. The simulation results are averaged from 100 Monte-Carlo runs. The number of the D2D links varies from 8 to 16 (thus the number of users varies from 16 to 32). Fig.2 shows that fairness index's values of the proposed algorithm and ECMP are around 0.9 and less than 0.8, respectively. The data rate's fairness of the proposed algorithm is significantly better than the ECMP, which proves the effectiveness of our methods.

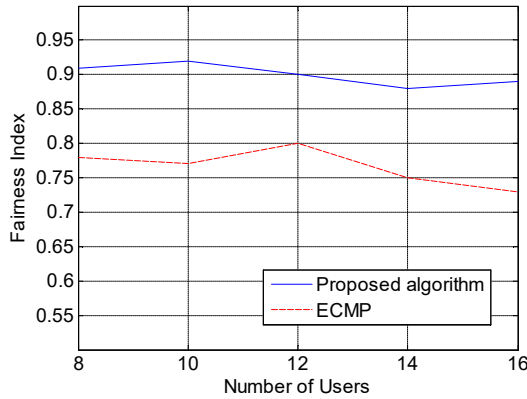


Figure 2. Fairness indexes comparison on data rate of the proposed algorithm and ECMP

In fig.3, we compare the data rate's cumulative distribution function (CDF) between the proposed algorithm and the ECMP. The results are averaged from 100 Monte-Carlo runs. In each run, we assume the dense FD D2D network contains 8 D2D pairs. In fig.3, for the proposed algorithm, the data rate of most users ranges from 2Mbps to 8Mbps. Although the proposed algorithm has less users of high data rate than ECMP, it also has less users of low data rate, which means that the proposed algorithm has a fairer performance than ECMP. The proposed algorithm has about 6% users whose data rate is less than 2Mbps. However, it is about 15% users for the ECMP, and most of these users' data rate is even less than 0.3Mbps. Thus this result also shows the performance on fairness optimization.

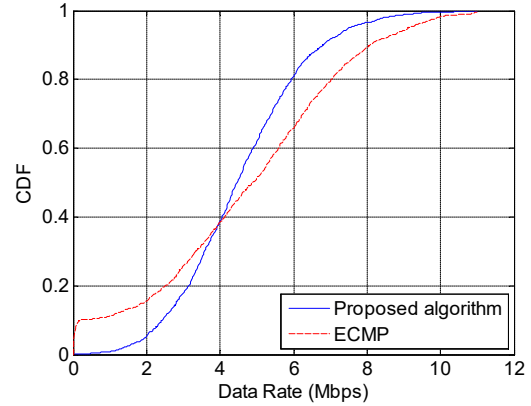


Figure 3. Data rate's CDF comparison between the proposed algorithm and ECMP

V. CONCLUSIONS

The data rate's fairness of D2D pairs in co-channel dense FD D2D network is considered. The related works seldom consider the co-channel FD D2D network. Thus, few works have been done on fairness optimization in the dense FD D2D network. In this paper, we proposed a power control algorithm for fairness constrained data rate optimization in dense FD D2D network. By exploiting the d.c. structure, we search the global optimum solution of D2D users' transmission powers through FW procedure. The simulation results show that the proposed power control algorithm is superior to the previous-proposed methods on data rate's fairness.

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