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Resource and Energy Efficient Device to Device Communications in Downlink Cellular System

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***Abstract*—In this paper, we investigate the energy efficiency (EE) optimization for a downlink orthogonal frequency division multiple access (OFDMA) system with overlaying Device-to-Device (D2D) communications. Joint EE optimization is highly complex while a two-stage solution will utilize most of the bandwidth for cellular users and not providing sufficient bandwidth for D2D users. Using resource efficiency (RE) optimization approach that balances the bandwidth usage and EE, we propose a two-stage solution that optimizes RE for base station (BS) and EE for D2D pairs. To achieve higher EE, D2D communications operate in non-orthogonal mode, where each resource block (RB) not being assigned to the cellular users are reused by multiple D2D pairs. By exploiting a range of optimization tools including fractional programming, Dinkelbach approach, Lagrange dual decomposition, difference of convex functions, and concave-convex procedure, the original non-convex problem is transformed and we present an iterative two-stage RE-EE solution. Simulation results demonstrate that the proposed resource allocation scheme provides comparable EE performance to a two-stage EE-EE solution with significant gain on EE for D2D users, and achieves much higher EE compared to a sum rate maximization scheme.**

***Index Terms*—Device-to-Device (D2D) communication; resource efficiency; energy efficiency; power allocation.**

I. INTRODUCTION

Introducing D2D communication in LTE-Advanced system poses many new challenges and risks to the traditional cellular architecture and users. Many studies have been done to solve these issues and tackle the challenges of D2D communication particularly to reduce the interference in the network. The majority of works focus on the radio resource management (RRM) aspects of D2D communication such as resource allocation, power control, interference management and mode selection [1]. In recent years, the energy efficiency (EE) aspect of D2D communication has attracted a lot of attention.

Energy efficient D2D communications have been investigated in [2]-[6]. In [2], energy efficient power allocation schemes in three different resource sharing modes were discussed under the maximum transmission power constraint. Using a noncooperative game theory, a distributed interference-aware energy efficient resource allocation algorithm to maximize each user's EE subject to both transmission power and rate constraints is proposed in [3]. To maximize the EE of D2D communications, a joint resource allocation and power control scheme has been studied in [4]. In [5], two energy efficient problems for D2D links are formulated and solved using Dinkelbach and Hungarian methods. The energy-efficient power control for D2D user equipments (DUEs) underlaying cellular networks is studied in [6]. By considering only a single cellular user equipment (CUE), resource blocks (RBs) are reused by multiple DUEs to maximize the individual EE and attaining the max-min fairness. In all these works, D2D communications underlaying cellular networks using uplink resource sharing are considered. The EE optimization for D2D in downlink scenario has rarely been discussed mainly due to the overwhelming interference from the base station (BS) in the underlay mode.

On the other hand if overlay transmission is used, conventional EE optimization for downlink CUEs will fully utilize the bandwidth in order to maximize EE; leaving no RBs for DUEs to use. Had spectral efficiency (SE) be used for CUEs optimization, the solution will use less bandwidth, allowing DUEs to communicate but at the expense of higher energy consumption. Joint EE optimization for all CUEs and DUEs can be obtained but with very high complexity. Recently, a new metric called resource efficiency (RE) has been proposed which is capable of optimizing both EE and SE simultaneously by balancing the power consumption and occupied bandwidth [7]. It was shown that by slightly lowering the EE, a significant amount of bandwidth can be reduced, which can be used by other systems.

Motivated by previous works on EE optimization for D2D communications and the new RE metric, we formulate the RE and EE problems that aims to maximize the system EE for a multiuser downlink OFDMA network. The proposed scheme allows D2D communications to operate in an overlaying manner in which there is no interference between cellular and D2D users. In addition, by reusing the remaining RBs among D2D pairs, their EE can be further maximized.

In this paper, we developed an RE-EE scheme to maximize the overall EE of a network in two stages. By decomposing the main problem into two subproblems, the overall complexity is lower than that of the joint EE optimization problem which involves the solving of cellular users and D2D pairs together. In the first stage, the RE optimization problem for BS is formulated and solved using an iterative algorithm based on Dinkelbach and Lagrange dual decomposition methods. Then, the EE optimization problem for D2D pairs is solved in the second stage. The EE problem is transformed into a subtractive form and then to an equivalent difference of convex functions (DC) problem. By employing concave-convex procedure (CCCP), the transformed EE problem can be solved efficiently using a standard optimization tool.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. System Model

A multiuser OFDMA downlink system consisting of one BS, K CUEs, and L DUEs is considered. The total bandwidth, W_{tot}, is divided into N RBs, each with a bandwidth of $W_s = (W_{tot}/N)$. The CUEs operate as conventional cellular users and take up orthogonal resources, so they will create no interference to each other. The DUEs can operate in an orthogonal or non-orthogonal resource sharing mode and utilize the remaining RBs not being assigned to the CUEs. In this work, we denote C as the number of RBs allocated to the CUEs and M as the number of RBs designated to DUEs. Both C and M are unknown before the RE optimization stage. C can take up to N RBs and the relationship between C, M, and N is given as $C + M \leq N$.

1) Cellular Users: Let $\mathcal{K} = \{1, 2, ..., K\}$ and $\mathcal{N} = \{1, 2, ..., N\}$ denote the sets of all CUEs and all RBs, respectively. The transmit power and the channel gain of the kth CUE on the nth RB are represented as $p_{k,n}$ and $h_{k,n}$, respectively. The achievable rate of the kth CUE on the nth RB is formulated as

$$r_{k,n} = W_s \log_2 (1 + p_{k,n}\Gamma_{k,n}) \tag{1}$$

where $\Gamma_{k,n} = \frac{h_{k,n}}{W_s N_0}$ denotes the channel to noise ratio (CNR). N_0 is the noise power spectral density. The channel gain from the BS to CUE k over RB n is modeled as $h_{k,n} = \varsigma_k g_{k,n} d_k^{-\alpha}$, where ς_k denotes the shadowing, $g_{k,n}$ accounts the effect of fading, d_k is the distance between eNB and CUE, and α is the pathloss exponent. The achievable rate for the kth CUE is denoted as R_k and the sum rate is represented as

$$R_c = \sum_{k=1}^{K} R_k = \sum_{k=1}^{K} \sum_{n=1}^{N} \omega_{k,n} r_{k,n} \tag{2}$$

where $\omega_{k,n}$ denotes the RB allocation indicator for the CUEs, which equals to 1 if RB n is allocated to the kth user and 0 otherwise. The overall transmit power for the kth user, P_k and the total transmit power, P_T are given by

$$P_k = \sum_{n=1}^{N} \omega_{k,n} p_{k,n}, \quad P_T = \sum_{k=1}^{K} P_k. \tag{3}$$

The overall power consumption model at the BS is given as

$$P = \varepsilon P_T + P_{cirBS} \tag{4}$$

where ε is the inverse of drain efficiency of power amplifier and P_{cirBS} denotes the BS circuit power. The overall power budget at the base station is modeled as

$$P_{tot} = \varepsilon P_{max} + P_{cirBS} \tag{5}$$

where P_{max} is the maximum transmission power of the BS.

2) D2D Users: A single DUE consists of a D2D transmitter (DTx) and a D2D receiver (DRx). The DUEs will use all remaining RBs not allocated to the CUEs and can operate in an orthogonal or non-orthogonal resource sharing modes. In the orthogonal mode, each D2D pair will be assigned a different RB; thus, no interference exists amongst DUEs. Although co-tier interference between DUEs can not be avoided when using non-orthogonal resource sharing, higher SE can be achieved by proper interference management [8]. Therefore, the non-orthogonal mode is adopted in this work. Let $\mathcal{L} = \{1, 2, ..., L\}$ and $\mathcal{M} = \{1, 2, ..., M\}$ denote the sets of all DUEs and all RBs designated to DUEs, respectively. The transmit power of the lth DUE on the mth RB is represented as $p_{l,m}$. The signal to interference plus noise ratio (SINR) of D2D pair l on RB m is given as

$$\Gamma_{l,m} = \frac{p_{l,m} h_{ll,m}}{\sum_{l'=1, l' \neq l}^{L} p_{l',m} h_{l'l,m} + W_s N_0}. \tag{6}$$

The channel gain from DTx l to DRx l over mth RB is modeled as $h_{ll,m} = c_0 \varsigma_l g_{ll,m} d_{ll}^{-\alpha}$, where c_0 is the pathloss coefficient, ς_l is the shadowing, $g_{ll,m}$ is the squared magnitude of the fading, and d_{ll} is the distance between D2D pair. Similarly, the channel gain from the DTx l' to DRx l on RB m is represented as $h_{l'l,m}$.

Therefore, the achievable rate of the lth D2D pair on the mth RB is formulated as

$$r_{l,m} = W_s \log_2 (1 + \Gamma_{l,m}). \tag{7}$$

The aggregate rate for the lth D2D pair is represented as R_l and the total rate for DUEs is given by

$$R_d = \sum_{l=1}^{L} R_l = \sum_{l=1}^{L} \sum_{m=1}^{M} r_{l,m}. \tag{8}$$

The overall transmit power for the lth DTx, P_l and the total transmit power of all D2D pairs, P_D are given by

$$P_l = \sum_{m=1}^{M} p_{l,m} \quad P_D = \sum_{l=1}^{L} P_l. \tag{9}$$

Finally, the overall power consumption model for DUEs is given as

$$P_{DT} = \varepsilon P_D + L P_{cirUE} \tag{10}$$

where P_{cirUE} represents the circuit power for each DTx.

B. Problem Formulation

In our previous work [9], a two-stage optimization framework is proposed to solve the overall EE for a cellular system with a CUE and a D2D pair sharing uplink resource. In this paper, we extend the proposed framework to solve the overall EE for multiple CUEs and DUEs in a downlink OFDMA system. The first problem aims to maximize the RE for cellular system. Introduced in [7], RE is defined as

$$RE = \frac{R_c}{P} \left(1 + \beta \frac{\tau_p}{\tau_w}\right) \tag{11}$$

where τ_p and τ_w represent power utilization and bandwidth utilization, respectively and are given by

$$\tau_p = \frac{P}{P_{tot}}, \quad \tau_w = \frac{W}{W_{tot}} \tag{12}$$

where W is the occupied bandwidth while β is the trade-off parameter which controls the balance between EE and SE. When $\beta = 0$, the problem turns into EE optimization. However, when β is larger, it tends towards SE problem.

In the first stage, the RE optimization problem for the cellular downlink transmission can be formulated as

$$\eta_{RE} = \max_{\omega_{k,n}, p_{k,n}} \frac{R_c}{P}\left(1+\beta\frac{\tau_p}{\tau_w}\right) \tag{13a}$$

$$\text{s.t} \quad \sum_{n=1}^{N} \omega_{k,n} r_{k,n} \geq R_{min}^{c} \tag{13b}$$

$$\sum_{k=1}^{K}\sum_{n=1}^{N} \omega_{k,n} p_{k,n} \leq P_{max} \tag{13c}$$

$$\sum_{k=1}^{K} \omega_{k,n} \leq 1, \ \forall n \in \mathcal{N} \tag{13d}$$

$$\omega_{k,n} \in \{0,1\} \tag{13e}$$

$$p_{k,n} \geq 0, \ \forall k \in \mathcal{K}, \ \forall n \in \mathcal{N} \tag{13f}$$

where R_{min}^{c} denotes the minimum rate requirement for each CUE.

The second problem maximizes the EE of the DUEs which can be expressed as

$$\eta_{EE} = \max_{p_{l,m}} \frac{R_d}{\varepsilon P_D + L P_{cirUE}} \tag{14a}$$

$$\text{s.t} \quad \sum_{m=1}^{M} r_{l,m} \geq R_{min}^{d} \tag{14b}$$

$$\sum_{m=1}^{M} p_{l,m} \leq P_{max}^{d}, \ \forall l \in \mathcal{L} \tag{14c}$$

$$p_{l,m} \geq 0, \ \forall l \in \mathcal{L}, \ \forall m \in \mathcal{M} \tag{14d}$$

where R_{min}^{d} and P_{max}^{d} represent the minimum rate requirement and the maximum transmission power for each DUE respectively.

III. PROPOSED RE AND EE OPTIMIZATION

A. Resource Efficiency Optimization for the Base Station

In the first stage, RE optimization is performed to obtain the optimal transmission power and RB allocation required to guarantee the quality of service (QoS). By maximizing the RE of the BS, some RBs can be saved and then utilized by the D2D communications. This allows DUEs to communicate in an overlaying mode where the strong interference from the BS can be avoided.

Problem (13) is a mixed integer nonlinear programming (MINLP) problem as well as a nonconvex problem due to the fractional form of the objective function. In order to obtain the optimal $\omega_{k,n}$ and $p_{k,n}$ for this nonconvex problem, exhaustive search with very high complexity is required. By relaxing the integer variables, $\omega_{k,n} \in \{0,1\}$ into continuous variables [10], $\tilde{\omega}_{k,n} \in [0,1]$, problem (13) can be written as

$$\eta_{RE} = \max_{\tilde{\omega}_{k,n}, p_{k,n}} \frac{R_c}{P}\left(1+\beta\frac{\tau_p}{\tau_w}\right) \tag{15a}$$

$$\text{s.t} \ (13b) \text{ - } (13d), \ (13f) \tag{15b}$$

$$\tilde{\omega}_{k,n} \in [0,1]. \tag{15c}$$

The fractional form of (15) can be transformed into an equivalent problem in subtractive form. According to [11], [12], the non-linear fractional optimization problem can be transformed into a parameterized function as

$$F_c(q_c) = R_c\left(1+\beta\frac{\tau_p}{\tau_w}\right) - q_c P$$
$$\text{s.t} \ (13b) \text{ - } (13d), \ (13f), \ (15c). \tag{16}$$

The new function $F_c(q_c)$ monotonically decreases with an increase in q_c. The optimal solution $q_c = q_c^*$ of (16) can be obtained by finding the root to the $F_c(q_c)$.

B. Proposed Scheme to Solve RE Problem

In this section, we exploit dual decomposition method for solving (16). First, the Lagrangian function of (16) is given by

$$\begin{aligned}\mathcal{L}_{RE}(\tilde{\omega}_{k,n}, p_{k,n}, \boldsymbol{\lambda}, \mu) = &\sum_{k=1}^{K}\sum_{n=1}^{N} \tilde{\omega}_{k,n} r_{k,n}\left(1+\beta\frac{\tau_p}{\tau_w}\right) \\ &- q_c\left(\varepsilon\sum_{k=1}^{K}\sum_{n=1}^{N} \tilde{\omega}_{k,n} p_{k,n} + P_{cirBS}\right) \\ &- \sum_{k=1}^{K}\lambda_k\left(R_{kmin} - \sum_{n=1}^{N}\tilde{\omega}_{k,n} r_{k,n}\right) \\ &- \mu\left(\sum_{k=1}^{K}\sum_{n=1}^{N}\tilde{\omega}_{k,n} p_{k,n} - P_{max}\right)\end{aligned} \tag{17}$$

where $\boldsymbol{\lambda}$ and μ are the Lagrange multipliers for constraints $(13b)$ and $(13c)$, respectively. The corresponding dual problem can be expressed as

$$\min_{\boldsymbol{\lambda},\mu \geq 0} \max_{\tilde{\omega}_{k,n}, p_{k,n}} \mathcal{L}_{RE}(\tilde{\omega}_{k,n}, p_{k,n}, \boldsymbol{\lambda}, \mu). \tag{18}$$

By taking the first-order derivation of (17) w.r.t $p_{k,n}$, we get

$$\frac{d\mathcal{L}_{RE}}{dp_{k,n}} = \frac{\tilde{\omega}_{k,n} W_c\left[\left(1+\beta\frac{\tau_p}{\tau_w}\right)+\lambda_k\right] \times \Gamma_{k,n}}{\left(1+\Gamma_{k,n} p_{k,n}\right)\ln(2)} - (\mu + \varepsilon q_c). \tag{19}$$

The power for user k on RB n can be computed by setting (19) to zero, yielding

$$p_{k,n} = \left[\frac{W_s\left(\left(1+\beta\frac{\tau_p}{\tau_w}\right)+\lambda\right)}{(\mu+\varepsilon q_c)\ln(2)} - \frac{1}{\Gamma_{k,n}}\right]^{+} \tag{20}$$

where $[x]^+ = \max\{0, x\}$. Similarly, the first-order derivative of (17) with respect to $\tilde{\omega}_{k,n}$ is

$$\begin{aligned}\frac{d\mathcal{L}_{RE}}{d\tilde{\omega}_{k,n}} &= W_s \log_2\left(1 + p_{k,n}\Gamma_{k,n}\right)\left[\left(1 + \beta\frac{\tau_p}{\tau_w}\right) + \lambda\right] \\ &\quad - p_{k,n}\left(\varepsilon q_c + \mu\right) \\ &= Q_{k,n}.\end{aligned} \tag{21}$$

Since only a single user is allowed to transmit on each RB, the RB assignment index $\tilde{\omega}_{k,n}$ can be determined as

$$\tilde{\omega}_{k,n} = \begin{cases} 1, & k = \max_{1 \le k \le K} Q_{k,n} \\ 0, & \text{otherwise.} \end{cases} \tag{22}$$

In order to update the dual variable $\boldsymbol{\lambda}$ and μ, the subgradient method [13] is used to solve (18). The subgradient updating equations are given as

$$\lambda_k\left(i+1\right) = \left[\lambda\left(i\right) - \zeta_\lambda^i\left(\sum_{n=1}^{N}\tilde{\omega}_{k,n}r_{k,n} - R_{kmin}\right)\right]^+ \tag{23}$$

$$\mu\left(i+1\right) = \left[\mu\left(i\right) - \gamma_\mu^i\left(P_{max} - \sum_{k=1}^{K}\sum_{n=1}^{N}\tilde{\omega}_{k,n}p_{k,n}\right)\right]^+ \tag{24}$$

where i is the iteration index, ζ_λ^i and γ_μ^i are positive step sizes. The resource allocation algorithm is presented in Table I.

TABLE I
RE OPTIMIZATION FOR BS

```
Algorithm 1 RE Optimization Algorithm
Initialization : Set $\epsilon$, $t = 0$, $q_c(t) = 0$, $T_{max}$
while $(|F_c(q_c)| > \epsilon)$ or $(t < T_{max})$
Set $i = 0$, $\lambda_k(i)$, $\mu(i)$, $I_{max}$
    while $((|\lambda_k(i+1) - \lambda_k(i)| > \epsilon)$ or $(|\mu(i+1) - \mu(i)| > \epsilon))$
          and $i \le I_{max}$
        for $n = 1 : N$
            for $k = 1 : K$
                Find $p_{k,n}$ and $Q_{k,n}$ using (20) and (21) respectively
            end for
            Obtain the resource block allocation using (22)
        end for
        Update Lagrangian multipliers $\boldsymbol{\lambda}$ and $\mu$ according to (23)
        and (24) respectively
        $i = i + 1$
    end while
Update $q_c(t+1) = \frac{R_c\left(1+\beta\frac{\tau_p}{\tau_w}\right)}{\varepsilon P_T + P_{cirBS}}$
Update $F_c(q_c)$
$t = t + 1$
end while
```

In order to guarantee the minimum rate requirement, at least one RB must be allocated to each CUE. Therefore, the RB with the highest channel gain will be assigned to each CUE in the first place. Then the power allocation for each CUE on each RB is performed. To solve the overall RE optimization problem, Algorithm 1 is applied to different number of RBs, until the total number of RBs is reached. Finally, the number of required RBs to achieve the maximum value of RE for the cellular system, C can be obtained. The remaining RBs, M, will be allocated to DUEs and used in the second stage of optimization.

C. Energy Efficiency Optimization for the D2D Pair

In the second stage, the DUEs can use all remaining RBs to maximize their EE. To achieve higher EE, each RB is shared by multiple DUEs with optimal power allocation in order to mitigate the co-tier interference. Problem (14) is also a fractional programming problem and hence can be transformed into subtractive form as

$$\max_{\boldsymbol{p}\in\mathcal{P}} \quad F_d\left(q_d, \boldsymbol{p}\right) = R_d - q_d\left(\varepsilon P_D + LP_{cirUE}\right) \tag{25}$$
$$s.t \quad (14b) \; - \; (14d)$$

where $\mathcal{P}$ is the set consisting of feasible power allocation strategies. The transmission power for lth DTx on each RB is given as $\varrho_l = [\rho_1, \rho_2, ..., \rho_M]$. Therefore, the vector of all power allocation strategies is denoted as $\boldsymbol{p} = [\varrho_1, \varrho_2, ..., \varrho_L]$.

The objective function in (25) is still a non-convex function due to the interference term in the capacity equation. However, we can further transform the problem to a DC programming problem [14] by expressing the objective function as

$$f\left(\boldsymbol{p}\right) = f_{cave1}\left(\boldsymbol{p}\right) - f_{cave2}\left(\boldsymbol{p}\right) \tag{26}$$

where

$$\begin{aligned}f_{cave1}\left(\boldsymbol{p}\right) = &\sum_{l=1}^{L}\sum_{m=1}^{M} W_s \log_2\left(ph_{ll,m} + \sum_{l'=1, l'\neq l}^{L} p_{l',m}h_{ll',m}\right. \\ &\left. + W_sN_0\right) - q_d\left(\varepsilon\sum_{l=1}^{L}\sum_{m=1}^{M} p_{l,m} + LP_{cirUE}\right)\end{aligned} \tag{27}$$

and

$$f_{cave2}\left(\boldsymbol{p}\right) = \sum_{l=1}^{L}\sum_{m=1}^{M} W_s \log_2\left(\sum_{l'=1, l'\neq l}^{L} p_{l',m}h_{ll',m} + W_sN_0\right). \tag{28}$$

The constraint $(14b)$ can be arranged as linear form. Therefore, problem (25) can be converted as maximizing a DC objective function under a convex constraint set and given as

$$\max_{\boldsymbol{p}\in\mathcal{P}} \quad \left\{f_{cave1}\left(\boldsymbol{p}\right) - f_{cave2}\left(\boldsymbol{p}\right)\right\}. \tag{29}$$

A DC programming problem can be solved using DC algorithm (DCA). Since $f_{cave2}\left(\boldsymbol{p}\right)$ in (29) is differentiable, CCCP can be utilized [15]. The basic idea of CCCP is to iteratively linearize the convex part of the DC objective function, $-f_{cave2}\left(\boldsymbol{p}\right)$ [16]. As in [15], the following iterative updating procedure is used in CCCP algorithm

$$\boldsymbol{p}^{(i+1)} = \arg\max_{\boldsymbol{p}\in\mathcal{P}}\left\{f_{cave1}\left(\boldsymbol{p}\right) - \triangledown f_{cave2}\left(\boldsymbol{p}^{(i)}\right) * \boldsymbol{p}^T\right\}$$

where $\triangledown f_{cave2}\left(\boldsymbol{p}^{(i)}\right) \triangleq \left[\triangledown_1^{(i)}, \triangledown_2^{(i)}, ..., \triangledown_{LM}^{(i)}\right]$ represents the gradient of $f_{cave2}\left(\boldsymbol{p}\right)$ at $\boldsymbol{p}^{(i)}$ and $\boldsymbol{p}^T$ denotes the transpose of $\boldsymbol{p}$. The resource allocation algorithm is presented in Table II.

TABLE II
EE OPTIMIZATION FOR DUEs

```
Algorithm 2 EE Optimization Algorithm
Initialization : Set $\epsilon$, $t = 0$, $q_d\left(t\right) = 0$, $T_{max}$
while $\left(\left|F_d(q_d)\right| > \epsilon\right)$ or $\left(t < T_{max}\right)$
Set $i = 0$, $\forall \boldsymbol{p}^{(i)} \in \mathcal{P}$,
    while $\left(\left|\boldsymbol{p}^{(i+1)} - \boldsymbol{p}^{(i)}\right| > \epsilon\right)$
        Update the power allocation by
        $\boldsymbol{p}^{(i+1)} = \arg\max_{\boldsymbol{p}\in\mathcal{P}} \left\{f_{cave1}\left(\boldsymbol{p}\right) - \bigtriangledown f_{cave2}\left(\boldsymbol{p}^{(i)}\right) * \boldsymbol{p}^T\right\}$
        $i = i + 1$
    end while
Update $q_d\left(t+1\right) = \frac{R_d}{\varepsilon P_D + L P_{cirUE}}$
Update $F_d\left(q_d\right)$
$t = t + 1$
end while
```

IV. SIMULATION RESULTS

In this section, we evaluate the performance of the proposed RE and EE optimization scheme. In the simulation, CUEs and D2D transmitters are uniformly distributed in a cell with radius of 500 m. The D2D receivers are uniformly distributed within a maximum distance of d_{max} from the D2D transmitters. The RB bandwidth is set to 200 kHz and the noise power spectral density is -174 dBm/Hz. The minimum rate requirements for each CUE and each DUE is 0.5 Mbps and 1 Mbps respectively. The downlink frequency-selective fading channel is generated with the ITU Pedestrian-B model [17]. The specific channel model parameters for DUE links include pathloss coefficient of -20dB, and unit mean for the Rayleigh fading process. For all links, a pathloss exponent of 4, and a standard deviation of 8dB for the log-normal shadowing are used. The drain efficiency of the power amplifier is set to 38%. Other simulation parameters are summarized in Table III.

TABLE III
SIMULATION PARAMETERS

Parameters	Value
Number of cellular users (K)	4
Number of D2D pairs (L)	$2, 4$
Number of resource blocks (N)	25
Maximum D2D pair distance (d_{max})	$20, 40, ..., 120$ m
Maximum transmit power of BS (P_{max})	10 W
BS circuit power (P_{cirBS})	5 W
Maximum transmit power of D2D link (P_d^{max})	250 mW
D2D circuit power (P_{cirUE})	100 mW

Fig. 1 shows the impact of trade-off parameter to EE and SE. The EE decreases with increasing β while the SE increases with increasing β. Varying this β in RE could provide the desirable trade-off between EE and SE for the cellular network. From the figure, we can observe that the maximum value of EE for cellular communication is achieved when $\beta = 0$. At this point, all RBs will be allocated to the CUEs. On the other hand, when β is high, the focus is on SE and less RBs are utilized to maximize the SE.

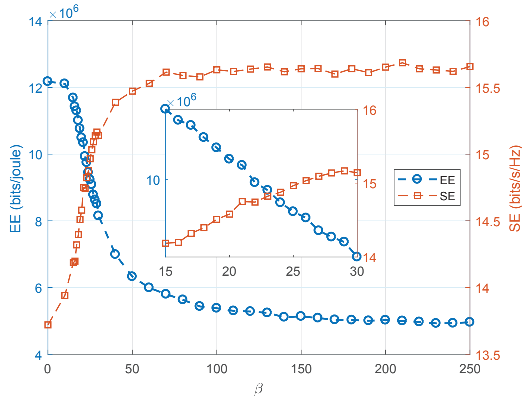

Fig. 1. Impact of weighted parameter to EE and SE.

The EE comparison between non-orthogonal and orthogonal resource sharing mode for D2D communications using a fixed M are shown in Fig. 2. The orthogonal mode forms an MINLP problem which is also difficult to be solved directly. Therefore, a continuous relaxation version of the problem is solved using an optimal numerical tool and presented as comparison. The figure shows that the EE for DUEs obtained using the proposed algorithm is close to the optimal solution. It can be observed that the EE achieved by using non-orthogonal resource sharing is higher than that of the orthogonal mode for the same number of DUEs and RBs. In addition, the EE for non-orthogonal case of $L = 4$ is lower than that of $L = 2$. This is because when more DUEs are sharing the same RB, larger co-tier interference is generated which result in degradation of EE.

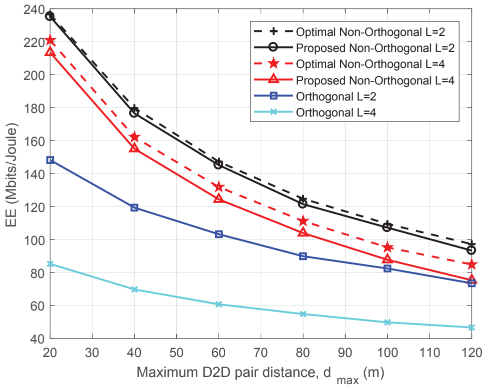

Fig. 2. DUEs EE versus maximum D2D pair distance ($M = 8$).

Finally, we compare the performance of the proposed scheme with a sum rate maximization and a two-stage EE optimization scheme (EE-EE). In the EE-EE scheme, EE optimization for BS and DUEs is performed in the first and second stage respectively with a fixed number of RBs. It must be noted that numerical optimization tool is used to solve this scheme which provides an upper bound solution, while the proposed scheme is an iterative algorithm. As shown in Fig. 1, a good EE-SE balance can be achieved using β between 23 to 24. If larger β is used, e.g. 50, the BS is operating at high SE region which is not energy efficient. Since CUEs have higher priority and DUEs are considered as supplement to cellular system, β is set as 23 to enhance the EE of the BS, which result in an average of 19 RBs allocated to the CUEs. Therefore, to provide a fair comparison, the EE-EE scheme is set to have 19 RBs for CUEs and 6 RBs for DUEs. Fig. 3 shows the EE comparison of the system. It is shown that the overall EE achieved by the proposed RE-EE scheme is close to the upper bound EE-EE result. Although the difference of overall EE is small, the EE improvement for the DUEs is significant with 24.6%. The overall EE is dominated by the high power consumption in the BS and as such the overall gain is diminished. Rather more important is that the proposed scheme can enhance the EE performance of DUEs, which is more critical as it is battery limited. It must also be noted that the EE of BS is slightly reduced, which is inline with the concept of RE that slightly reducing the EE performance can result large bandwidth saving for other systems (in this case the DUEs) to utilize. Also for comparison, the proposed scheme achieves much larger EE compared to the sum rate maximization scheme. As an example, the proposed scheme achieves an overall EE of 13 Mbits/Joule for $d_{max} = 80$ m compared to 2.9 Mbits/Joule obtained by the sum rate maximization scheme. The plot of sum rate maximization scheme is not presented as it is significantly lower than the EE schemes and as such will distort the presentation of the figure.

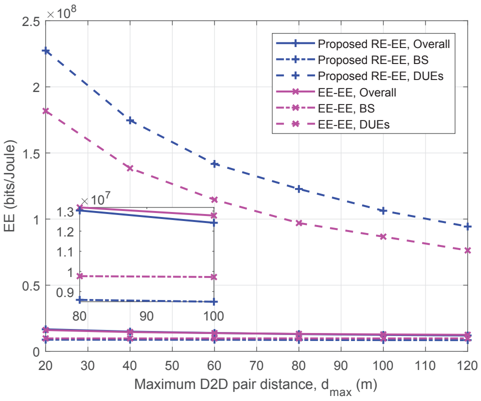

Fig. 3. EE versus maximum D2D pair distance ($L = 2$).

V. CONCLUSIONS

In this paper, we have presented a two-stage RE-EE scheme for energy efficient D2D communication overlaying cellular system. In the first stage, an efficient resource allocation algorithm is designed using fractional programming and Lagrange dual decomposition to maximize the RE of the BS. To obtain higher EE, each unallocated RB is reused by multiple D2D pairs in the second stage where fractional and DC programming approaches are used to find the optimal power allocation for D2D pairs. Simulation results showed that the proposed RE-EE scheme attains comparable overall EE performance to the two stage EE-EE solution and significant EE improvement is achieved for DUEs.

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