Uplink Power Control for D2D-enabled HetNet with Partial CSI via Fractional Programming

Engy Aly Maher
Faculty of Information Engineering and Technology
German University in Cairo
Cairo, Egypt
engy.aly@guc.edu.eg

Ahmed El-Mahdy
Faculty of Information Engineering and Technology
German University in Cairo
Cairo, Egypt
ahmed.elmahdy@guc.edu.eg

***Abstract*—Heterogeneous wireless networks (HetNets) are becoming an integral part of future generation networks, where the macro-cell base stations (MBSs), small cell base stations (SCBSs), and device-to-device (D2D) enabled links coexist together. Frequency reuse is employed to maximize capacity gains. However one major challenge is introducing the fundamental problem of interference management in the network caused by the sharing of the spectrum among the different tiers of the HetNet. Power control (PC) is one technique for interference management which can also be used to enhance the overall system efficiency. The objective of this paper is to study the problem of cross-tier interference management for underlay D2D users in a heterogeneous macro-small cell network assuming imperfect Channel State Information (CSI). The network consists of one macro-cell with a centered MBS and one small-cell cellular user equipment (SUE) linked to its SCBS. Fractional programming (FP) is used to solve the optimization problem of power allocation in the network to find the optimal power that maximizes the sum rate of D2D and small cellular users while guaranteeing a minimum quality of service (QoS) of the macro cellular user.**

***Index Terms*—Device-to-device, Interference Management, Power Control, Channel State Information, heterogeneous Networks**

I. INTRODUCTION

The development of future ultra-high data-rate mobile communications systems e.g. 5G and beyond 5G (B5G) mobile networks was introduced as a futuristic solution for applications involving huge amount of data, i.e. requires very high throughput per device (multiple Gbps) and per area efficiency (bps/km2) [1]–[3]. The proposed technologies, which would undergo standardization, include heterogeneous networks (HetNets), machine-to-machine (M2M) communications, device-to-device (D2D) networks and internet of things (IoT) among others [4] [5].

Densely deploying a number of small-cells (e.g. pico cells and femto cells) in a macro-cell results in reducing the overall energy consumption and enhancing the capacity in highly populated areas like, for example, business districts, universities, and malls as small-sized cells manage higher-quality links and allow for increased spatial reuse [6], [7]. To be specific, in heterogeneous cellular networks, a macro base station (MBS) and a small base station (SBS) are allowed to share the same spectrum leading to a higher spectrum utilization [8] [9].

Meanwhile, D2D communication underlaying cellular networks can further enhance the spectrum utilization efficiency via spectrum reuse under condition that the interference between D2D pairs as well as between D2D pair and cellular user are well controlled. Therefore, the introduction of D2D communication technology with small cellular technology into cellular networks, namely D2D based heterogeneous networks (HetNets), has attracted a lot of attention in the current research, becoming two important technologies to be introduced in the 5G network system [10] [11]. However, when D2D users and small cell users reuse the resources of macro cellular user, they will cause serious interference to cellular systems, which may severely degrades the quality-of-service (QoS). Thus, how to effectively manage these interference is one of the major challenges to be studied in this topic.

Interference management between D2D users and cellular users have been studied by a large number of scholars. Most of the existing work focused on interference management in only two-tier network, however, at present, research on interference management in the three-tier network of D2D, small cell, and macro cell becomes a trend. Considering three-layer HetNets, a resource allocation scheme based on the auction algorithm is proposed in [12], but with only one SCUE distributed in each small cell, so that resources cannot be fully utilized. The resource allocation strategy proposed in [13] can reduce the interference between layers and improve the system performance but without including D2D communication, which if added, the system performance will be further improved. Authors in [14] proposed a solution for the problem of interference caused by the introduction of D2D communication into the HetNet, but without considering the interference control problem of the D2D user and the small cellular user sharing the same resources with the macro cell user. Another heuristic resource allocation algorithm is proposed in [15] to D2D users and small cellular users in HetNets, which is composed of macro cell, small cells and D2Ds to achieve the goal of maximizing system throughput.

Another important issue to be considered in D2D communications is channel state information (CSI). The quality and performance of the interference management techniques depend on the availability of the CSI. Although the availability of CSI greatly simplifies the design of communication

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systems, in practical systems, such an assumption is not always practical. Partial CSI assumptions for D2D underlaying networks have been considered in [16]–[18]. In [16], the number of D2D pairs that can be accessed based on a certain outage probability of the cellular UE is optimized in order to maximize the system throughput. Authors in [17] analyzed the outage performance of D2D assisted three-stage transmission. Power coordination between cellular and D2D users has not been considered in [16], but in [17], time-division based D2D cooperation transmission design is considered. In [18], authors investigated the trade off between signalling overhead and performance in D2D communications with channel uncertainty. Two different approaches are proposed to reduce CSI feedback overhead; probabilistic and partial feedback schemes. In [19] authors formulate the optimization problem of power control and channel allocation in macro-Small Cell Networks. Their problem aimed to find the optimum power for D2D users in case of sharing resources with SUE only and the other case when the small-cell cellular user is using the same resources with the macro-cell cellular user, i.e. without considering D2D users. Moreover, their work is done assuming known CSI.

From the above discussions, and to the best of my knowledge, researches do not focus on PC and interference management in presence of channel estimation error for D2D-enabled HetNet. In this paper, fractional programming (FP) is used to solve optimization problem of power allocation in HetNet in presence of channel estimation error. The optimal power that maximizes the sum rate of D2D and small cellular users is obtained while guaranteeing QoS of the macro cellular user. To solve this problem, the original power control problem is reformulated using Lagrangian Dual transform, then an iterative method is used to search for the optimal solution for the dual problem. The rest of this paper is organized as follows. Section II describes the system model, while problem formulation and SINR calculations for the users are presented in Section III. In Section IV power control for underlaying MD, CD and SUE users is presented in details using closed-form FP approach. Section V presents the numerical results, and the conclusions are given in Section VI.

II. SYSTEM MODEL

A. Network Model

In a conventional D2D system underlying single tier cellular network, there are only two user types, cellular users and D2D users. However, the system model considered in this paper consists of heterogeneous macro-small cell networks enabling the D2D communications. It consists of one macrocell with a centered macro-base station (MBS) and one small-cell with a centered small cell base station (SCBS). The network model is shown in figure 1 and it consists of four categories of users:

- **Macrocell cellular user equipment (MUE):** The cellular user associated with macrocell eNB.
- **Small cell cellular user equipment (SUE):** The cellular user with small cell tier i.e. linked to the small cell base station (SCBS).
- **Macrocell D2D pair (MD):** Both of the D2D users belong to the macrocell tier outside the range of the small cells.
- **Cross-tier D2D pair (CD):** Each user of the D2D pair belongs to a different network tier; i.e. D2D transmitter is within the range of one of the small cells while the D2D receiver belongs to the macro cell tier.

Each SUE is assumed to be located at the edge of the coverage boundary of it’s small cell.

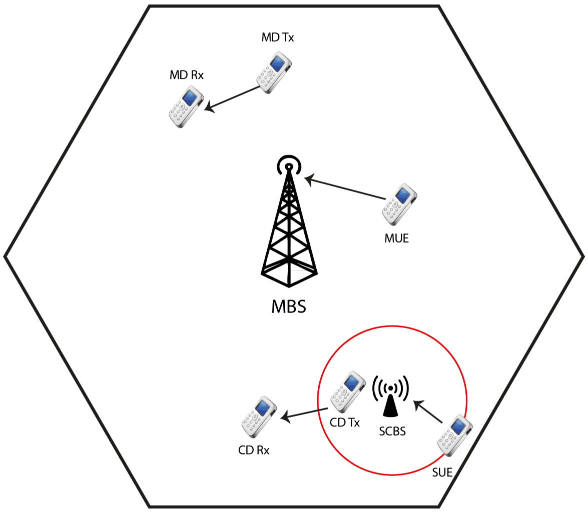

Fig. 1. Network model

B. Radio Channel Model

A general power-low pathloss model in which the signal power decays at the rate of $d^{-\delta}$ with propagation distance d is considered. In suburban areas usually the path loss exponent is taken close to 4. The channel fading coefficient is denoted by h. For a more realistic representation, we assume that only imperfect CSI is available [20]. Specifically, a minimum mean square error (MMSE) estimation is used to obtain the estimate $\hat{h}$. The fading channel model can be expressed as [20]:

$$h_{k,l} \; = \sqrt{1-\alpha}\; \hat{h}_{k,l} + \sqrt{\alpha}\; \tilde{h}_{k,l} \tag{1}$$

where $h_{k,l}$ is the fading channel gain between receiver k and transmitter l, $\hat{h}_{k,l}$ represents the estimate of $h_{k,l}$ and $\tilde{h}_{k,l}$ refers to the estimation error independent of $\hat{h}_{k,l}$ and whose entries are assumed to be $\sim \mathcal{CN}(0,1)$. The parameter α is the estimation error variance and has a fixed value between 0 and 1. It is assumed that the estimate $\hat{h}_{k,l}$ is known by both the transmitter and the receiver, and $\hat{h}_{k,l} \sim \mathcal{CN}(0,1)$ so that $|\hat{h}_{k,l}|^2$ is exponentially distributed with unit mean. Note that the case $\alpha = 0$ corresponds to perfect channel knowledge (best case scenario), while in case of case $\alpha = 1$, the estimated channel is completely in error. In this case the receiver must decode the received signal non-coherently where the expected power depends solely on the pathloss.

III. PROBLEM FORMULATION AND SINR CALCULATIONS

The received signal y_i at the i^{th} receiver, assuming no interference between , is given by

$$y_i = \sqrt{P_j}\; h_{i,j}\; d_{i,j}^{-\delta/2}\; S_j \;+\; n_i \tag{2}$$

where $h_{i,j}$ and $d_{i,j}$ refer to the distant independent fading channel gain and the distance between transmitter j and receiver i, respectively. S_j denotes the signal sent by transmitter j using power P_j. It is also assumed that all the data symbols have an average unit power, i.e., $\mathbb{E}\left[\,|S_{\mathrm{j}}|^2\right] = 1$. n_i denotes the additive noise at receiver i. It has a complex normal distribution with zero mean and variance σ^2, i.e., $n_i \sim \mathcal{CN}(0, \sigma^2)$. We assume uplink communication between cellular users and their corresponding base stations (either SUE or MUE) and that these channel can be shared for both the macro cell and small cell. In case of imperfect CSI, when an estimate $\hat{h}_{i,j}$ and the distribution of estimation error $\tilde{h}_{i,j}$ are available [20], and knowing that $|\tilde{h}_{i,j}|^2 = 1$, the SINR at MD, CD, SCBS, and MBS given respectively, by $\gamma_{MD}, \gamma_{CD}, \gamma_{SCBS}, \gamma_{MBS}$ as

$$\gamma_{MD} = \frac{\overbrace{(1-\alpha)\;|\hat{h}_{MD}|^2\; d_{MD}^{-\delta}}^{a}\;\; P_{MD}}{\underbrace{\alpha\; d_{MD}^{-\delta}}_{a'}\; P_{MD} \;+\; \underbrace{d_{MD,CD}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{MD,CD}|^2 + \alpha]}_{b}\; P_{CD} + \underbrace{d_{MD,SUE}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{MD,SUE}|^2\; + \alpha]}_{c}\; P_{SUE} \\ +\; \underbrace{d_{MD,MUE}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{MD,MUE}|^2\; + \alpha]}_{d}\; P_{MUE} + \sigma_{MD}^2} \tag{3}$$

$$\gamma_{CD} = \frac{\overbrace{(1-\alpha)\;|\hat{h}_{CD}|^2\; d_{CD}^{-\delta}}^{e}\;\; P_{CD}}{\underbrace{\alpha\; d_{CD}^{-\delta}}_{e'}\; P_{CD} \;+\; \underbrace{d_{CD,MD}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{CD,MD}|^2 + \alpha]}_{f}\; P_{MD} + \underbrace{d_{CD,SUE}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{CD,SUE}|^2\; + \alpha]}_{g}\; P_{SUE} \\ +\; \underbrace{d_{CD,MUE}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{CD,MUE}|^2\; + \alpha]}_{h}\; P_{MUE} + \sigma_{CD}^2} \tag{4}$$

$$\gamma_{SCBS} = \frac{\overbrace{(1-\alpha)\;|\hat{h}_{SUE}|^2\; d_{SUE}^{-\delta}}^{k}\;\; P_{SUE}}{\underbrace{\alpha\; d_{SUE}^{-\delta}}_{k'}\; P_{SUE} \;+\; \underbrace{d_{SCBS,MD}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{SCBS,MD}|^2 + \alpha]}_{l}\; P_{MD} + \underbrace{d_{SCBS,CD}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{SCBS,CD}|^2\; + \alpha]}_{m}\; P_{CD} \\ +\; \underbrace{d_{SCBS,MUE}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{SCBS,MUE}|^2\; + \alpha]}_{n}\; P_{MUE} + \sigma_{SCBS}^2} \tag{5}$$

$$\gamma_{MBS} = \frac{\overbrace{(1-\alpha)\;|\hat{h}_{MUE}|^2\; d_{MUE}^{-\delta}}^{v}\;\; P_{MUE}}{\underbrace{\alpha\; d_{MUE}^{-\delta}}_{v'}\; P_{MUE} \;+\; \underbrace{d_{MBS,MD}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{MBS,MD}|^2 + \alpha]}_{q}\; P_{MD} + \underbrace{d_{MBS,CD}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{MBS,CD}|^2\; + \alpha]}_{r}\; P_{CD} \\ +\; \underbrace{d_{MBS,SUE}^{-\delta}\;[(1-\alpha)\;|\hat{h}_{MBS,SUE}|^2\; + \alpha]}_{s}\; P_{SUE} + \sigma_{MBS}^2} \tag{6}$$

Note that, the first term in the denominator of each of the above SINR equations represents the unwanted part of each signal due to channel estimation error. We consider resource sharing mode, so that D2D users (both MD and CD) with the SUE all sharing the same resources with the MUE, thus all cause interference to and from each other.

IV. POWER CONTROL USING CLOSED-FORM FP APPROACH

When a channel estimate of each link is available at the central controller (MBS), a centralized power control algorithm is proposed. For other management strategies, centralized power control can provide an upper bound compared to that achieved with more decentralized algorithms. The optimization problem for this network model aims to allocate optimum powers for the MD, CD, and SUE users such that to maximize the sum rate and at the same time to guarantee QoS for the MUE connected to the MBS which is considered to have the higher priority in the network model. To satisfy this QoS, the SINR of the MBS must exceed or at least be equal to a certain threshold T. Then maximize the weighted sum rate of the three mentioned users with respect to their powers. The optimization problem can be written mathematically as

$$\max_{P_{MD},P_{CD},P_{SUE}} \quad g_o(P_{MD}, P_{CD}, P_{SUE}) \tag{7a}$$

$$\text{s.t.} \quad \gamma_{MBS} \geq T, \tag{7b}$$

$$0 \leq P_i \leq P_{max}, \tag{7c}$$

where

$$\begin{aligned} g_o(P_{MD}, P_{CD}, P_{SUE}) = w_1 log_2(1+\ \gamma_{MD}) \\ + w_2 log_2(1+\ \gamma_{CD}) \\ + w_3 log_2(1+\ \gamma_{SCBS}) \end{aligned} \tag{8}$$

where w_1, w_2, w_3 are non-negative weights and T is the SINR threshold that satisfies the minimum acceptable QoS at the MBS. Using the lower bound of (7b), the minimum QoS for MUE user, the power P_{MUE} can be written in terms of the powers of the other three users as:

$$P_{MUE} = \overbrace{\frac{T}{v\ -\ T\ v'}}^{h'}\ (q\ P_{MD}\ + r\ P_{CD}\ + s\ P_{SUE} + \sigma^2_{MBS}) \tag{9}$$

By substituting (9) in (3), (4), and (5), the SINRs can now be re-written as

$$\gamma_{MD} = \frac{a\ P_{MD}}{\underbrace{(a' + dh'q)}_{a''}\ P_{MD} + \underbrace{(b + dh'r)}_{b''}\ P_{CD} + \underbrace{(c + dh's)}_{c''}\ P_{SUE} + \sigma^2_{MD}}, \tag{10}$$

$$\gamma_{CD} = \frac{e\ P_{CD}}{\underbrace{(e' + hh'r)}_{e''}\ P_{CD} + \underbrace{(f + hh'q)}_{f''}\ P_{MD} + \underbrace{(g + hh's)}_{g''}\ P_{SUE} + \sigma^2_{CD}}, \tag{11}$$

$$\gamma_{SCBS} = \frac{k\ P_{SUE}}{\underbrace{(k' + nh's)}_{k''}\ P_{SUE} + \underbrace{(l + nh'q)}_{l''}\ P_{MD} + \underbrace{(m + nh'r)}_{m''}\ P_{CD} + \sigma^2_{SCBS}}. \tag{12}$$

Then, Lagrangian Dual Transform [21] is used to move the fractional SINR term to the outside of the logarithm, and subsequently allow the quadratic transform to express all optimization variables in linear terms. Thus, the weighted sum-of-logarithms in problem (8) is equivalent to

$$\max_{\mathbf{P},\boldsymbol{\gamma}} \quad g_o(\mathbf{P}, \boldsymbol{\gamma}) \tag{13a}$$

$$\text{s.t.} \quad 0 \leq P_i \leq P_{max}, \tag{13b}$$

where

$$\begin{aligned} g_o(\mathbf{P}, \boldsymbol{\gamma}) &= w_1 log_2(1 + \gamma_{MD}) - w_1 \gamma_{MD} \\ &+ \frac{w_1(1 + \gamma_{MD})a\ P_{MD}}{(aP_{MD} + a''P_{MD} + b''P_{CD} + c''P_{SUE} + \sigma^2_{MD})} \\ &+ w_2 log_2(1 + \gamma_{CD}) - w_2 \gamma_{CD} \\ &+ \frac{w_2(1 + \gamma_{CD})e\ P_{CD}}{(eP_{CD} + e''P_{CD} + f''P_{MD} + g''P_{SUE} + \sigma^2_{CD})} \\ &+ w_3 log_2(1 + \gamma_{SCBS}) - w_3 \gamma_{SCBS} \\ &+ \frac{w_3(1 + \gamma_{SCBS})k\ P_{SUE}}{(kP_{SUE} + k''P_{SUE} + l''P_{MD} + m''P_{CD} + \sigma^2_{SCBS})} \end{aligned} \tag{14}$$

and $\mathbf{P}$ is the set of $\{P_{MD}, P_{CD}, P_{SUE}\}$. Then an iterative algorithm based on the above reformulation is used. When the powers P_{MD}, P_{CD}, P_{SUE} are held fixed, the optimal $\gamma_i,\ \forall i = MD, CD, SCBS$ is obtained by setting $\partial g_o / \partial \gamma_i$ to zero.

When the powers P_{MD}, P_{CD}, P_{SUE} are held fixed, only the terms of g_o which has a sum-of-ratio form, is involved in the optimization of P_i. Using the quadratic transform [21], g_o can be further recasted to

$$\begin{aligned} g_o(\mathbf{P}, \mathbf{y}) &= 2y_1\sqrt{aw_1P_{MD}(1 - \gamma_{MD})} \\ &- y_1^2(aP_{MD} + a''P_{MD} + b''P_{CD} + c''P_{SUE} + \sigma^2_{MD}) \\ &+ 2y_2\sqrt{ew_2P_{CD}(1 - \gamma_{CD})} \\ &- y_2^2(eP_{CD} + e''P_{CD} + f''P_{MD} + g''P_{SUE} + \sigma^2_{CD}) \\ &+ 2y_3\sqrt{kw_3P_{SUE}(1 - \gamma_{SCBS})} \\ &- y_3^2(kP_{SUE} + k''P_{SUE} + l''P_{MD} + m''P_{CD} + \sigma^2_{SCBS}) \\ &+ const(\gamma_{MD}) + const(\gamma_{CD}) + const(\gamma_{SCBS}) \end{aligned} \tag{15}$$

where $y_i,\ \forall i = 1, 2, 3$ are auxiliary variables introduced for each ratio term and $const(\gamma_{MD}), const(\gamma_{CD})$, and $const(\gamma_{SCBS})$ refer to constant terms when $\gamma_{MD}, \gamma_{CD}, \gamma_{SCBS}$ are set fixed, respectively.

The optimal P^*_{MD} is obtained by getting $\partial g_o / \partial P_{MD}$ as

$$\begin{aligned} \partial g_o / \partial P_{MD} = \frac{ay_1(1 + \gamma_{MD})}{\sqrt{aP_{MD}(1 + \gamma_{MD})}} - y_1^2 aP_{MD} - y_1^2 a'' P_{MD} \\ - y_2^2 f'' P_{MD} - y_3^2 l'' P_{MD} \end{aligned} \tag{16}$$

Then setting (16) equal to zero to get

$$P^*_{MD} = min\left\{\frac{ay_1^2(1 + \gamma_{MD})}{(ay_1^2 + a''y_1^2 + f''y_2^2 + l''y_3^2)^2}, P_{max}\right\}, \tag{17}$$

Similarly, by maximizing $g_o(\mathbf{P}, \mathbf{y})$ iteratively over $\mathbf{P}$ and $\mathbf{y}$, we find closed-form update equations as

$$P^*_{CD} = min\left\{\frac{ey_2^2(1 + \gamma_{CD})}{(b''y_1^2 + ey_2^2 + e''y_2^2 + m''y_3^2)^2}, P_{max}\right\}, \tag{18}$$

$$P^*_{SUE} = min\left\{ \frac{ky_3^2(1+\gamma_{SCBS})}{(c''y_1^2 + g''y_2^2 + ky_3^2 + k''y_3^2)^2}, P_{max} \right\}, \tag{19}$$

and

$$y_1^* = \frac{\sqrt{aw_1 P_{MD}(1+\gamma_{MD})}}{(aP_{MD} + a''P_{MD} + b''P_{CD} + c''P_{SUE} + \sigma^2_{MD})}, \tag{20}$$

$$y_2^* = \frac{\sqrt{ew_2 P_{CD}(1+\gamma_{CD})}}{(eP_{CD} + e''P_{CD} + f''P_{MD} + g''P_{SUE} + \sigma^2_{CD})}, \tag{21}$$

$$y_3^* = \frac{\sqrt{kw_3 P_{SUE}(1+\gamma_{SCBS})}}{kP_{SUE} + k''P_{SUE} + l''P_{MD} + m''P_{CD} + \sigma^2_{SCBS})}. \tag{22}$$

These updating steps amount to an iterative optimization as stated in Algorithm 1.

Algorithm 1 Closed-Form FP for Power Control

```
Initialize $P$ and $\gamma$ with initial feasible values
while $|g_o(n) - g_o(n-1)| > \epsilon$ do
    Step 1: Update $\mathbf{y}$ by (20), (21), and (22)
    Step 2: Update $\gamma$ by (10), (11), and (12)
    Step 3: Update $\mathbf{P}$ by (17), (18), and (19)
end while=0
```

The above algorithm is not a conventional block coordinate ascent, because the optimizing objective is not fixed, i.e. $\mathbf{y}$ and $\mathbf{P}$ are optimally updated for $g_o(\mathbf{P}, \mathbf{y})$. Nonetheless, its convergence to the stationary point can still be established [21]. As a remark, Algorithms 1 can be initialized with simple but reasonable heuristic.

V. NUMERICAL RESULTS AND DISCUSSIONS

A MATLAB-based simulator is developed to evaluate the performance of the macro-small cellular network adopting the fractional power control scheme with imperfect channel state information. We simulate a single macro-cell where the MBS is located in the center. Both MUE and one MD pair are randomly distributed within the cell radius. The SUE is assumed to be located at the edge of the coverage boundary of its small-cell, assuming uplink communication between cellular users and their corresponding base stations (either SUE or MUE). Moreover, a single CD pair is included where its users belong to different tiers. It is assumed that the users operate outdoors in a typical urban environment and are stationary throughout all simulation runs. We consider sum rate maximization by setting all the weights to 1. The used simulation parameters are given in Table I.

In order to guarantee fair comparisons in simulations, we use random starting points then average out the results. Moreover, we set some small constant $\epsilon > 0$ and use the convergence criterion $|g_o(n) - g_o(n-1)| < \epsilon|$ where n is the iteration index.

TABLE I
SIMULATION PARAMETERS

Macrocell radius	500m	Small cell radius	50m
Noise spectral density		-174 dBm/Hz	
System bandwidth		80MHz	
D2D Range		50m	
Path Loss Coeffecient δ		4	
estimation error variance α		varies between [0 - 1]	
Initial power level $P_{initial}$		$P_{max}/2$	
Maximum power level P_{max}		23 dBm	

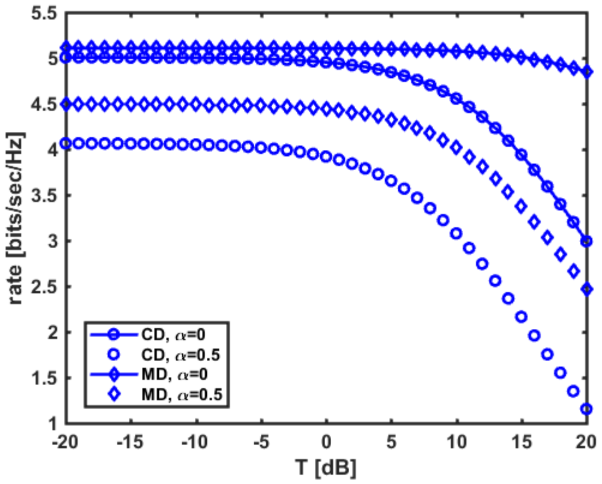

Fig. 2. Achievable D2D SINR vs Threshold T

Figures 2 and 3 show the rate of the cellular (SCBS and MBS) and D2D (MD and CD), respectively, versus the SINR threshold T and for different values of α. Figure 2 shows that the MD is achieving higher rate values than the CD. This is due to the higher interference on the CD caused by the SUE which is located within the same area. Results also show that when the target threshold T is less than -5 dB, the rate for both users is not affected by increasing T. This is because at low threshold values, the users are allowed to increase their power values which could reach P_{max}, thus maintaining a constant rate till the threshold at the MBS increases and exceeds -5 dB, then the other users are forced to decrease their own power and consequently decreasing their rates. For both users, increasing the value of α from 0 to 0.5 leads to a degradation in the rate. This is because when α increases, the value of the estimate fade channel gain term decreases, while at the same time increasing the value of the channel estimation error term. The same conclusions are obtained for SCBS in figure 3. However the results in figure 3 also show that the MBS is increasing with the threshold T to achieve the lower bound of the constraint given in (7b).

Figure 4 shows the distance between SUE and CD receiver for different values of α. The figure shows that the SINR of SCBS does not change with changing the distance. This is because this distance is not an effective distance for the SCBS which means that when the CD receiver is getting

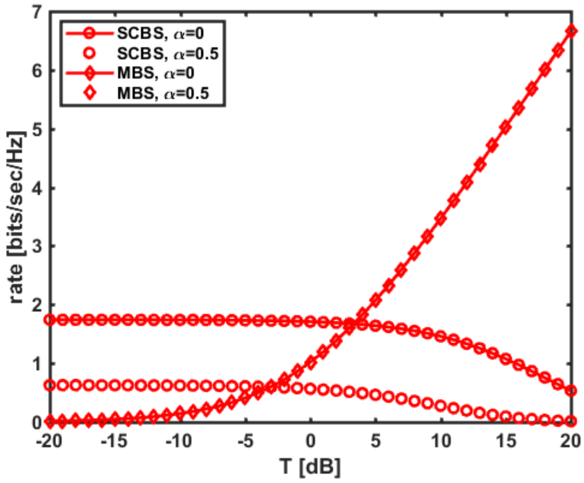

Fig. 3. Achievable Cellular SINR vs Threshold T

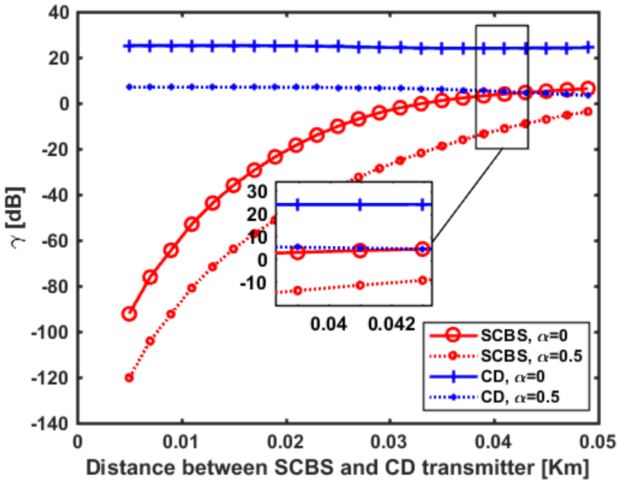

Fig. 5. Achievable SINR for Small cell users (CD and SCBS) vs distance between SCBS and CD transmitter

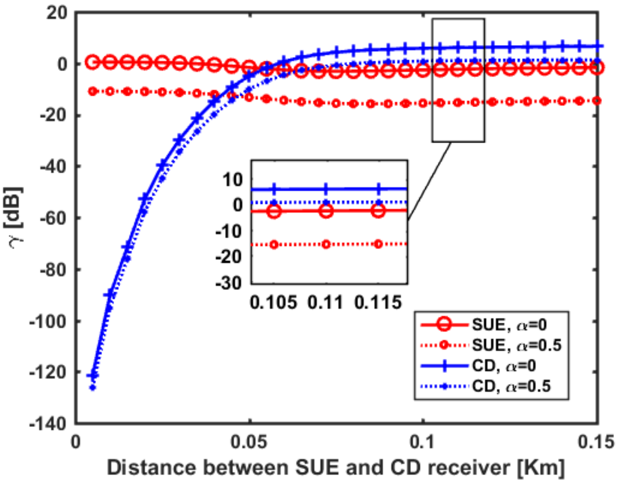

Fig. 4. Achievable SINR for Small cell users (CD and SCBS) vs distance between SUE and CD receiver

further away from the SUE, this does not affect the SCBS SINR. However, for the CD, the SINR increases significantly with increasing the distance until 0.07 km (greater than the small-cell radius), then after that distance the SINR almost remains constant. This is because moving the SUE further away from the CD receiver, decreases the interference caused by the SUE, causing increasing the SINR. Until reaching the other side of the small-cell, where moving further will not cause a significant change in the SINR. The figure also shows that α has much greater effect on the SCBS (10 dB) than on the CD (5 dB).

Similarly, figure 5 shows the distance between CD transmitter and SCBS for different values of α. Although here, this distance is not an effective distance for the CD (thats why we can see a constant SINR for the CD), the SINR for the SCBS is greatly affected. The SINR of SCBS increases significantly with increasing the distance. This is again because moving the CD transmitter away from the SCBS, decreases the interference caused by the CD transmitter and consequently increases the SCBS SINR. Increasing α leads to achieving lower SINR values having the same effect on both users (a difference of 20 dB).

The allowed distance between the SUE and CD receiver as well as the distance between the CD transmitter and the SCBS can be obtained from both figures 4 and 5. For example, in case of $\alpha = 0$, for achieving SINR value of -10 dB at the CD receiver, the distance between SUE and CD receiver should be at least 0.05 Km (at least equal to the small-cell radius). On the other side, for achieving SINR value of -10 dB at the SCBS, the distance between SCBS and CD transmitter should be at least equal to 25 m. The intersection between these two areas resulting in the area for achieving a good QoS for both CD and SUE users.

Another parameter for determining the performance of the system is the outage probability. For both MD and CD users, it is defined as

$$Pr\{\gamma < T_2\} \leq \zeta, \tag{23}$$

where T_2 denotes the desired SINR at both MD and CD receivers to keep good QoS for D2D communication.

Figure 6 shows the outage probability both MD and CD vs their SINR threshold for different values of α. The results show that as the desired threshold increases the outage probability also increases. This is because as the desired threshold increases, the probability of MD user to exceed the desired threshold decreases causing outage, this is due to the fact that the power of MD and CD users does not depend on the desired threshold but instead depends on the SUE SINR threshold. Again, it is noticed that increasing α leads to a decrease in the performance as illustrated by a higher outage probability, i.e. increasing α from 0 to 0.7 at threshold 0 dB, leads to an increase in the outage probability by 30%.

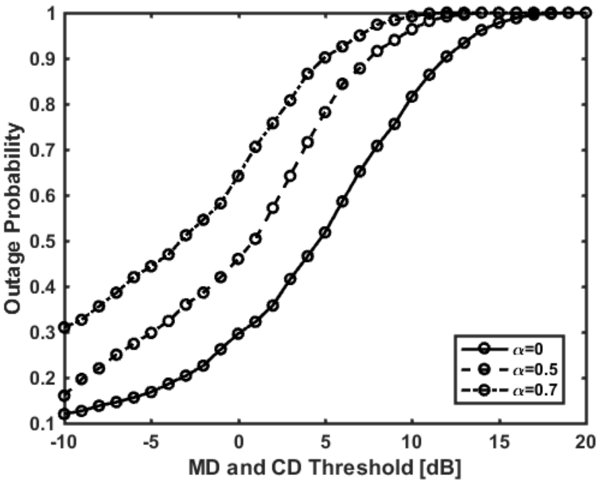

Fig. 6. Outage probability for D2D users (MD and CD) vs. Threshold

VI. CONCLUSIONS

In this paper, FP is used to find the optimal power for MD, CD, and SUE users that maximizes their corresponding sum rate while guaranteeing minimum QoS of the macro cellular user in presence of channel estimation error. Lagrangian dual transform is applied to reformulate the original power control problem, then an iterative method is adopted to search for the optimal solution for the dual problem. Simulation results show that the achievable rate for both MD and CD decreases with increasing the SINR threshold at the MBS and it also decreases with increasing the channel state information error. Better system performance can be reached when taking the distance between CD and SUE into consideration.

REFERENCES

[1] S. Chen, F. Qin, B. Hu, X. Li, and Z. Chen, ”User-centric ultra-dense networks (UUDN) for 5G: Challenges, methodologies and directions,” IEEE Wirel. Commun., vol. 23, no. 2, pp. 78-85, Apr. 2016.

[2] C. Wang, F. Haider, X. Gao, et al., ”Cellular architecture and key technologies for 5G wireless communication networks,” IEEE Commun. Mag., vol. 52, no. 2, pp. 122-130, Feb. 2014.

[3] S. Chen, B. Ren, Q. Gao, et al., ”Pattern division multiple access (PDMA) - A novel non-orthogonal multiple access for fifth-generation radio networks,” IEEE Trans. Veh. Tech., vol. 66, no. 4, pp. 3185-3196, Apr. 2017.

[4] S. Talwar, D. Choudhury, K. Dimou, E. Aryafar, B. Bangerter, and K. Stewart, ”Enabling technologies and architectures for 5g wireless,” in 2014 IEEE MTT-S International Microwave Symposium (IMS2014). IEEE, 2014, pp. 14.

[5] P. Pirinen, ”A brief overview of 5g research activities,” in 5G for Ubiquitous Connectivity (5GU), 2014 1st International Conference on. IEEE, 2014, pp. 1722.

[6] M. I. Kamel and K. M. F. Elsayed, ”Performance Evaluation of a Coordinated Time Domain eICIC Framework based on ABSF in Heterogeneous LTE-Advanced Networks,” 2012 IEEE Global Communications Conference (GLOBECOM), Anaheim, CA, 2012, pp. 5326-5331.

[7] E. Hossain, M. Rasti, H. Tabassum, and A. Abdelnasser, ”Evolution toward 5G multi-tier cellular wireless networks: An interference management perspective,” in IEEE Wireless Communications, vol. 21, no. 3, pp. 118-127, June 2014.

[8] C. Yang, J. Li, A. Anpalagan, and M. Guizani, ”Joint power coordination for spectral-and-energy efficiency in heterogeneous small cell networks: A bargaining game-theoretic perspective,” IEEE Trans. Wirel. Commun., vol. 15, no. 2, pp. 1364-1376, Feb. 2016.

[9] X. Li, T. Jiang, S. Cui, J. An, and Q. Zhang, ”Cooperative communications based on rateless network coding in distributed MIMO systems,” IEEE Wirel. Commun., vol. 17, no. 3, pp. 60-67, Jun. 2010.

[10] X. M. Shen, ”Device-to-device communication in 5G cellular networks,” IEEE Network, vol.29,no.2, 2015, pp:2-3.

[11] M. Peng ,C. Wang ,J. Li ,H. Xiang and V Lau, ”Recent Advances in Underlay Heterogeneous Networks: Interference Control, Resource Allocation, and Self-Organization,” IEEE Communications Surveys and Tutorials, vol. 17, no.2, 2015, pp:700-729.

[12] M. Hasan and E. Hossain., ”Distributed resource allocation in D2Denabled multi-tier cellular networks: An auction approach,” IEEE International Conference on Communications, 2015, pp:2949-2954.

[13] S. K. Pal , T. A. Nugraha , S. Shams and A. Rahman, ”Resource Allocation Strategy using optimal power control for mitigating twotier interference in heterogeneous networks,” Wireless Communications and NETWORKING Conference Workshops IEEE, 2014, pp:104-109.

[14] A. H. Tsai , L. C. Wang , J. H. Huang and T. M. Lin, ”Intelligent resource management for device-to-device (D2D) communications in heterogeneous networks,” International Symposium on Wireless Personal Multimedia Communications IEEE, 2012, pp:75-79.

[15] Liu. H, Ren. Z, Gong. Z, and Zhuang. Y, ”Resource allocation algorithm for D2D and small cell users in HetNet”, 2016, 36, 1-7.

[16] S. Shalmashi, G. Miao, and S. Ben Slimane, ”Interference management for multiple device-to-device communications underlaying cellular networks,” in Proc. IEEE 24th Int. Symp. on Personal, Indoor and Mobile Radio Commun. (PIMRC 13), Sept. 2013, pp. 223227.

[17] A. Abu Al Haija and M. Vu, ”Spectral efficiency and outage performance for device-to-device cooperation in uplink cellular communication,” IEEE Trans. Wireless Commun., vol. 14, no. 3, pp. 1183 1198, Mar. 2015.

[18] D. Feng, lu Lu, Y. Yuan-Wu, Y. Li, G. Feng, and S. Li, ”QoS-Aware resource allocation for device-to-device communications with channel uncertainty,” IEEE Transactions on Vehicular Technology, pp. 1-1, 2015.

[19] W. Chen, T. Li, Z. Xiao and D. Wang, ”On mitigating interference under device-to-device communication in macro-small cell networks,” 2016 International Conference on Computer, Information and Telecommunication Systems (CITS), Kunming, 2016, pp. 1-5.

[20] A. Memmi, Z. Rezki and M. S. Alouini, ”Power Control for D2D Underlay Cellular Networks With Channel Uncertainty,” IEEE Transactions on Wireless Communications, vol. 16, no. 2, pp. 1330-1343, Feb. 2017.

[21] K. Shen and W. Yu, ”Fractional programming for communication systems, Part II: Uplink scheduling via matching,” January 2017, IEEE Transactions Signal Process