MULTI-CHANNEL POWER ALLOCATION FOR DEVICE-TO-DEVICE COMMUNICATION UNDERLAYING CELLULAR NETWORKS

Ruhallah AliHemmati[§] *Ben Liang*[§] *Min Dong*[⋆] *Gary Boudreau*[†] *S. Hossein Seyedmehdi*[†]

[§]Dept. of Electrical and Computer Engineering, University of Toronto, Toronto, Canada
[⋆]Dept. of Electrical, Computer and Software Engineering, University of Ontario Institute of Technology, Oshawa, Canada
[†]Ericsson Canada, Ottawa, Canada

ABSTRACT

In underlay device-to-device (D2D) communication, a D2D pair reuses the cellular spectrum and creates interference to regular cellular users. Optimal operation requires joint consideration for the achieved D2D rate and the added interference to cellular users. Most existing work on D2D rate maximization concerns only the simplified scenario where the D2D pair has access to a single channel or resource block. In this work, we present an optimization solution to allocate the D2D transmission power over multiple channels, to maximize the sum rate between D2D and cellular users, under a sum-power constraint on the D2D transmitter and minimum SINR guarantees at each RB for all cellular users. The proposed optimization is applicable to both uplink and downlink cellular spectrum sharing. Our simulation studies further shed light into how the maximum sum rate is impacted by the available D2D power and the SINR guarantees.

***Index Terms*—** Device-to-device communication, power allocation, rate maximization.

1. INTRODUCTION

Local service requirements and the need for higher spectral efficiency have led to the recent development of device-to-device (D2D) communication for LTE-Advanced and the planned 5G evolution [1–4]. In the D2D paradigm, nearby users can transmit data directly to each other without going through the base stations or the back-haul network. In this work, we focus on the underlaying D2D architecture, where D2D users share the same spectrum used by regular cellular users. Underlaying can improve spectral efficiency, but it requires effective interference management and resource sharing among all users.

There are many methods proposed in the literature for interference control and resource allocation in underlaying D2D systems. For example, power backoff approaches were studied in [5–7], and interference cancellation were proposed in [8]. Graph-based [9, 10] and game theoretic [11–15] approaches were also considered. None of them directly address the objective of sum rate maximization. In contrast, power optimization methods have been proposed in [16–19] to maximize the D2D rate, D2D-cellular sum rate, or power-rate efficiency. The authors of [16] gave an optimal power allocation solution for D2D users underlaying cellular users in downlink transmission without imposing any constraint on the D2D power. The authors of [17] provided performance bounds in the maximization of power efficiency under signal-to-noise ratio (SNR) constraints. In [18] and [19], sub-optimal power allocation solutions for D2D users in uplink transmission were proposed, which divide the original problem into several sub-problems to be solved separately. However, these methods only consider the overly simplified scenario where each D2D node accesses a *single* channel at a time. In reality, each user has access to *multiple* resource blocks (RBs) in an LTE network. The proposed methods in [16–19] cannot be directly applied to this multi-channel scenario, due to the difficulties arising from the non-convex objectives and the sum-power constraint over all channels.

In this paper, we propose an optimization approach to maximize the sum rate of D2D and cellular users, in a cell where the D2D nodes have access to multiple channels (i.e., RBs). The optimization framework accommodates a sum-power constraint on the D2D transmitter, as well as minimum signal-to-interference-to-noise ratio (SINR) guarantees at each RB for cellular users in the same cell as the D2D transmitter and in neighboring cells. Furthermore, it is applicable to both uplink and downlink cellular spectrum sharing. We focus on the practical scenario where the arrival of a new D2D pair does not alter the pre-exiting spectrum and power allocation of other users. This leads to substantial reduction in computational complexity, without impacting the performance guarantees to other users. We find optimal power allocation over different RBs at the D2D transmitter, under both high-interference and moderate-interference scenarios. Our simulation studies with multiple D2D pairs in multiple cells further provide insights into the relation between the maximum sum rate and the available D2D power and SINR guarantees.

Notations: We use a, $\mathbf{a}$, and $\mathbf{A}$ to represent a scalar, a vector, and a matrix, respectively. The notation $\mathbf{a} \succcurlyeq 0$ means all entries of vector $\mathbf{a}$ are nonnegative. We define $\left[x\right]_a^b \triangleq \max\{a, \min\{x, b\}\}$.

2. SYSTEM MODEL AND PROBLEM DEFINITION

Consider a cellular system with underlaying D2D communication, where D2D users reuse the spectrum resources already assigned to the cellular users. A cell of interest is consist of a number of cellular users and D2D users. We assume that an idle D2D pair in the cell is requesting to reuse spectrum resource for communication. Due to the localized and low-power transmission of D2D users, the resource planning (e.g., spectrum allocation and power control) of existing cellular users in the network is not modified. In current cellular systems such as LTE, each cellular user typically is assigned multiple RBs. Also, all the RBs are assigned among cellular users in a cell orthogonally, and thus there is no intra-cell interference among these cellular users. However, due to frequency reuse at neighboring cells, these cellular users suffer from inter-cell interference.

We assume that there are N active cellular users in each cell. In this paper, we focus on the uplink communication scenario. However, the same model and results are applicable to the downlink sce-

978-1-4799-9988-0/16/$31.00 ©2016 IEEE

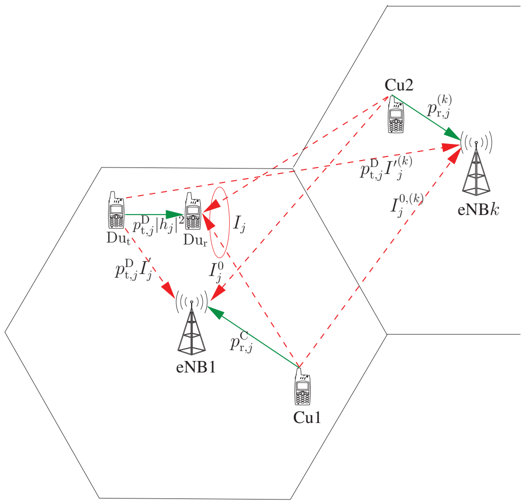

Fig. 1. The interference scenarios for a cellular network with D2D users in uplink resource sharing case. Solid and dashed lines are related to desired and interference signals, respectively. Downlink resource sharing is similar.

nario. Let C_i denote the set of all RBs assigned to the ith cellular user, and we define $C \triangleq \bigcup_{i=1}^{N} C_i$. We assume a D2D pair attempts to reuse the assigned RBs of an active cellular user in the cell. That is, if the ith cellular user is selected, the D2D pair and the ith cellular user share all the RBs in C_i. For $j \in C_i$, let $p^{\mathrm{D}}_{\mathrm{t},j}$ denote the transmit power of the D2D pair over the jth RB and $p^{\mathrm{C}}_{\mathrm{r},j}$ denote the received power from the ith cellular user over the jth RB. In addition, let S_j denote the set of all cellular users in the neighboring cells that are using the jth RB. Let $p^{(k)}_{\mathrm{r},j}$ denote the received power from the kth user over the jth RB, for $k \in S_j$. The selected ith cellular user experiences both intra-cell interference from the D2D transmission and inter-cell interference from neighboring cells. For $j \in C_i$, let I^0_j and $I^{0,(k)}_j$ denote the received interference over jth RB for the ith cellular user and the kth neighboring user, for $k \in S_j$, respectively, excluding the interference from the D2D pair under consideration. Let $I^{'}_j$ and $I^{'(k)}_j$ denote the channel power gains over the jth RB between the D2D transmitter and the base station (BS) and between the D2D transmitter and the kth neighboring cellular user's BS, for $k \in S_j$, respectively. Furthermore, let I_j denote the received interference over the jth RB at the D2D receiver. Fig. 1 shows the interference scenarios for a cellular network with D2D users in uplink resource sharing. In Fig. 1, $\mathrm{Du_t}$ and $\mathrm{Du_r}$ indicate the transmitter and receiver nodes of a D2D pair, respectively, and Cu indicates the cellular users which share resources with the D2D pair.

The received SINR over the jth RB at the cellular user and at the D2D receiver are given by

$$\mathrm{SINR}^{\mathrm{C}}_j = \frac{p^{\mathrm{C}}_{\mathrm{r},j}}{\sigma^2 + I^0_j + \alpha_i p^{\mathrm{D}}_{\mathrm{t},j} I^{'}_j}, \tag{1}$$

$$\mathrm{SINR}^{\mathrm{D}}_j = \frac{|h_j|^2 p^{\mathrm{D}}_{\mathrm{t},j}}{\sigma^2 + I_j} \tag{2}$$

where $\alpha_i \in \{0,1\}$ is an indicator variable with $\alpha_i = 1$ if the D2D pair selects the ith cellular user to share its assigned RBs, h_j is the D2D channel coefficient over the jth RB, and σ^2 is receiver noise variance which is assumed to be the same for all RBs.

We study the problem of scheduling the D2D pair for resource sharing with an existing cellular user. Our objective is to jointly optimize the cellular user selection for spectrum resource sharing and power allocation at the D2D transmitter to maximize the cell sum rate. For the spectrum resource reuse by the D2D pair, we impose the constraints that the received SINR at the ith cellular user in the cell of interest and at the kth user in the neighboring cells should meet their respective minimum requirements, *i.e.,* for $i = 1, 2, \cdots, N$,

$$\frac{p^{\mathrm{C}}_{\mathrm{r},j}}{\sigma^2 + I^0_j + \alpha_i p^{\mathrm{D}}_{\mathrm{t},j} I^{'}_j} \geq \zeta^{\mathrm{intra}}_{j,\min},\ j \in C_i, \tag{3}$$

$$\frac{p^{(k)}_{\mathrm{r},j}}{\sigma^2 + I^{0,(k)}_j + \alpha_i p^{\mathrm{D}}_{\mathrm{t},j} I^{'(k)}_j} \geq \zeta^{(k)}_{j,\min},\ k \in S_j, j \in C_i \tag{4}$$

where $\zeta^{\mathrm{intra}}_{j,\min}$ and $\zeta^{(k)}_{j,\min}$ are the respective SINR requirements. The SINR constraints (3) and (4) can be simplified to the following expression

$$\alpha_i p^{\mathrm{D}}_{\mathrm{t},j} \leq \eta_j, j \in C_i, \quad i = 1, 2, \cdots, N \tag{5}$$

where we define

$$\eta_j \triangleq \min\left\{ \frac{p^{\mathrm{C}}_{\mathrm{r},j}/\zeta^{\mathrm{intra}}_{j,\min} - (\sigma^2 + I^0_j)}{I^{'}_j}, \left\{ \frac{p^{(k)}_{\mathrm{r},j}/\zeta^{(k)}_{j,\min} - (\sigma^2 + I^{0,(k)}_j)}{I^{'(k)}_j}, \forall\, k \in S_j \right\} \right\}.$$

To limit the transmit power at the D2D transmitter, we impose a total power constraint for the D2D transmitter as follows

$$\sum_{i=1}^{N} \sum_{j \in C_i} \alpha_i p^{\mathrm{D}}_{\mathrm{t},j} \leq P^{\mathrm{D}}_{\max}. \tag{6}$$

The joint optimization of the cellular user selection and power allocation for the cell sum rate maximization is then formulated as follows:

$$\max_{\{\alpha_i\},\{p^{\mathrm{D}}_{\mathrm{t},j}\}} \sum_{i=1}^{N} \sum_{j \in C_i} \left[\log\left(1 + \mathrm{SINR}^{\mathrm{C}}_j\right) + \alpha_i \log\left(1 + \mathrm{SINR}^{\mathrm{D}}_j\right) \right] \tag{7}$$

$$\text{subject to} \quad \alpha_i \in \{0,1\},\ \sum_{i=1}^{N} \alpha_i \leq 1, \quad i = 1, \cdots, N, \tag{8}$$

$$p^{\mathrm{D}}_{\mathrm{t},j} \geq 0,\ \forall j \in C, \tag{9}$$

(5) and (6).

3. SUM-RATE MAXIMIZATION

Note that the cell sum-rate prior to the D2D pair entering the system is given by $\sum_{i=1}^{N} \sum_{j \in C_i} \log(1 + \frac{p^{\mathrm{C}}_{\mathrm{r},j}}{\sigma^2 + I^0_j})$. The cell sum-rate maximization problem (7) is equivalent to the problem of maximizing the cell sum-rate improvement due to the addition of the new D2D pair, given by

$$\max_{\{\alpha_i\},\{p^{\mathrm{D}}_{\mathrm{t},j}\}} \sum_{i=1}^{N} \sum_{j \in C_i} \Big[\log(1 + \mathrm{SINR}^{\mathrm{C}}_j) + \alpha_i \log(1 + \mathrm{SINR}^{\mathrm{D}}_j) - \log(1 + \frac{p^{\mathrm{C}}_{\mathrm{r},j}}{\sigma^2 + I^0_j}) \Big] \tag{10}$$

subject to (5), (6), (8), and (9).

To solve the optimization problem (10), we consider the maximization over α_i and $p_{\mathrm{t},j}^{\mathrm{D}}$ separately. In the following, we first consider the inner power optimization problem. Since the objective function in (10) is not convex with respect to $p_{\mathrm{t},j}^{\mathrm{D}}$, we first convexify the problem with given selected cellular user.

3.1. Convexification of the Power Allocation Problem

Assume that the lth cellular user is the best match for the D2D pair for spectrum sharing. Let $U(\{p_{\mathrm{t},j}^{\mathrm{D}}\})$ denote the component of the sum-rate objective function in (10) that corresponds to the lth cellular user. Since the rate of those cellular users not sharing the RBs with the D2D pair is not affected by the addition of the D2D pair, the cell sum-rate improvement is only with respect to the D2D pair and the selected cellular user. Thus, it suffices to consider only $U(\{p_{\mathrm{t},j}^{\mathrm{D}}\})$. Substituting the expression of $\mathrm{SINR}_j^{\mathrm{C}}$ and $\mathrm{SINR}_j^{\mathrm{D}}$ in (1) and (2) into (10), we have

$$U(\{p_{\mathrm{t},j}^{\mathrm{D}}\}) = \sum_{j\in C_l}\Big[\log\left(1+\frac{p_{\mathrm{r},j}^{\mathrm{C}}}{\sigma^2+I_j^0+p_{\mathrm{t},j}^{\mathrm{D}}I_j'}\right) - \log\left(1+\frac{p_{\mathrm{r},j}^{\mathrm{C}}}{\sigma^2+I_j^0}\right)+\log\left(1+\frac{|h_j|^2p_{\mathrm{t},j}^{\mathrm{D}}}{\sigma^2+I_j}\right)\Big]. \quad (11)$$

Typically, we only match the D2D user with a cellular user with sufficiently high SINR condition over its assigned RBs. Thus, the SINR of this selected cellular user after spectrum sharing is still relatively high. Thus, we assume the SINR requirement $\zeta_{j,\min}^{\mathrm{intra}} \gg 1$, for all $j \in C_l$. With this assumption, we can approximate $U(\{p_{\mathrm{t},j}^{\mathrm{D}}\})$ in (11) as follows:

$$\begin{aligned} U(\{p_{\mathrm{t},j}^{\mathrm{D}}\}) &\approx \sum_{j\in C_l}\left[\log\left(\frac{p_{\mathrm{r},j}^{\mathrm{C}}}{\sigma^2+I_j^0+p_{\mathrm{t},j}^{\mathrm{D}}I_j'}\right) - \log\left(\frac{p_{\mathrm{r},j}^{\mathrm{C}}}{\sigma^2+I_j^0}\right)+\log\left(1+\frac{|h_j|^2p_{\mathrm{t},j}^{\mathrm{D}}}{\sigma^2+I_j}\right)\right] \\ &= \sum_{j\in C_l}\log\left(\frac{a_j+b_jp_{\mathrm{t},j}^{\mathrm{D}}}{a_j+c_jp_{\mathrm{t},j}^{\mathrm{D}}}\right). \end{aligned} \quad (12)$$

where $a_j \triangleq (\sigma^2+I_j^0)(\sigma^2+I_j)$, $b_j \triangleq (\sigma^2+I_j^0)|h_j|^2$, and $c_j \triangleq (\sigma^2+I_j)I_j'$. Thus, the inner power allocation problem (10) is approximated as follows:

$$\max_{\{p_{\mathrm{t},j}^{\mathrm{D}}\}} \sum_{j\in C_l}\log\left(\frac{a_j+b_jp_{\mathrm{t},j}^{\mathrm{D}}}{a_j+c_jp_{\mathrm{t},j}^{\mathrm{D}}}\right) \quad (13)$$

$$\text{subject to} \quad \sum_{j\in C_l} p_{\mathrm{t},j}^{\mathrm{D}} \le P_{\max}^{\mathrm{D}}, \quad (14)$$

$$0 \le p_{\mathrm{t},j}^{\mathrm{D}} \le \eta_j, \quad j\in C_l. \quad (15)$$

Notice that for $b_j \le c_j$, $\log(\frac{a_j+b_jp_{\mathrm{t},j}^{\mathrm{D}}}{a_j+c_jp_{\mathrm{t},j}^{\mathrm{D}}})$ is a decreasing function with respect to $p_{\mathrm{t},j}^{\mathrm{D}}$, while for $b_j > c_j$, it is a strictly increasing function. Hence, if $b_j \le c_j$, for some jth RB, we have $p_{\mathrm{t},j}^{\mathrm{D}*} = 0$ at optimality, *i.e.,* the D2D pair do not use this RB. Define the subset $C_l' = \{j : j\in C_l,\ b_j > c_j\}$. We only need to determine $p_{\mathrm{t},j}^{\mathrm{D}}$, for $j \in C_l'$. Therefore, the optimization problem in (13) is equivalent to

$$\max_{\{p_{\mathrm{t},j}^{\mathrm{D}}\}} \sum_{j\in C_l'}\log\left(\frac{a_j+b_jp_{\mathrm{t},j}^{\mathrm{D}}}{a_j+c_jp_{\mathrm{t},j}^{\mathrm{D}}}\right) \quad (16)$$

$$\text{subject to} \sum_{j\in C_l'} p_{\mathrm{t},j}^{\mathrm{D}} \le P_{\max}^{\mathrm{D}}, \quad (17)$$

$$0 \le p_{\mathrm{t},j}^{\mathrm{D}} \le \eta_j, \quad j\in C_l'. \quad (18)$$

Now the optimization problem (16) is convex and we can obtain the power allocation solution. In the following, we obtain the power solution for two interference scenarios.

3.2. High Interference Scenario

For the D2D per RB power constraint (18), if $\sum_{j\in C_l'}\eta_j \le P_{\max}^{\mathrm{D}}$, the total power constraint (17) will not be active. Since the objective function is an increasing function, it follows that the optimal $p_{\mathrm{t},j}^{\mathrm{D}*} = \eta_j$, for all $j\in C_l'$. By (3) and (5), this case corresponds to a high interference scenario where per RB SINR for the lth cellular user is already close to the minimum requirement $\zeta_{j,\min}$, prior to the addition of the D2D pair. This limits the D2D transmit power at each shared RB, resulting in a small value of η_j, for $j\in C_j'$. We state the power solution below.

Proposition 1 *Assume $\sum_{j\in C_l'}\eta_j \le P_{\max}^{\mathrm{D}}$. The optimal power allocation at the D2D transmitter is given by $p_{\mathrm{t},j}^{\mathrm{D}*} = \eta_j$, $\forall j\in C_l'$, and $p_{\mathrm{t},j}^{\mathrm{D}*} = 0$, $\forall j \in C_l\backslash C_l'$.*

3.3. Moderate Interference Scenario

In contrast to the above scenario, when the interference at the selected lth cellular user is moderate, we have $\sum_{j\in C_l'}\eta_j > P_{\max}^{\mathrm{D}}$. Both per RB power constraints in (17) and total power constraint in (18) are active. In this case, we can show that the total power constraint in (18) must be satisfied with equality. Otherwise, we can increase $p_{\mathrm{t},j}^{\mathrm{D}}$ for some $j\in C_l'$ where $p_{\mathrm{t},j}^{\mathrm{D}} < \eta_j$ to further increase the value of the objective function in (16). In this case, the optimization problem (16) can be rewritten as

$$\max_{\{p_{\mathrm{t},j}^{\mathrm{D}}\}} \sum_{j\in C_l'}\log\left(\frac{a_j+b_jp_{\mathrm{t},j}^{\mathrm{D}}}{a_j+c_jp_{\mathrm{t},j}^{\mathrm{D}}}\right) \quad (19)$$

$$\text{subject to} \quad (18) \text{ and } \sum_{j\in C_l'} p_{\mathrm{t},j}^{\mathrm{D}} = P_{\max}^{\mathrm{D}}.$$

Since the optimization problem (19) is convex, we can use the KKT optimality condition [20] to obtain the optimal power solution. Let $\lambda > 0$ denote the Lagrangian multiplier corresponding to the total power equality condition in the optimization problem (19). The power solution is provided in the following proposition.

Proposition 2 *Assume $\sum_{j\in C_l'}\eta_j > P_{\max}^{\mathrm{D}}$. The optimal power allocation at the D2D transmitter is given by*

$$p_{\mathrm{t},j}^{\mathrm{D}*} = \Big[\frac{-\beta_j+\sqrt{\beta_j^2-4\kappa_j(1-\frac{\gamma_j}{\lambda^*})}}{2\kappa_j}\Big]_0^{\eta_j}, \ \forall j\in C_l \quad (20)$$

where $\kappa_j \triangleq \frac{b_jc_j}{a_j^2}$, $\beta_j \triangleq \frac{b_j+c_j}{a_j}$, $\gamma_j \triangleq \frac{b_j-c_j}{a_j}$, and the optimal λ^* is such that $\sum_{j\in C_l'}p_{\mathrm{t},j}^{\mathrm{D}*} = P_{\max}^{\mathrm{D}}$.

Since $p_{\mathrm{t},j}^{\mathrm{D}}$ is a decreasing function of λ, we can use the bisection method to efficiently determine the optimal λ^*.

Table 1. Default System Parameters

per RB Bandwidth = 12x15 KHz
Cell Radius = 100 m
D2D distance = 20 m
$N_d = 7$
$P_{\max}^{\mathrm{D}} = 8.5$ dBm
$\zeta_{j,\min}^{\mathrm{intra}} = \zeta_{j,\min}^{(k)} = 3$ dB, $\forall j \in C$ and $\forall k \in S_j$
Ave. received SNR= 30 dB (uplink cellular users)
Path loss exponent = 4
Standard deviation for shadowing= 4 dB

3.4. Cellular User Selection for Spectrum Sharing

So far, we focused on the optimal power allocation problem given the selected lth cellular user for spectrum sharing. Let R_l^{improv} denote the objective function in (13), *i.e.,* the cell sum-rate improvement by letting the D2D pair share the lth cellular user's assigned RBs. To determine the optimal α_i^*, for $i = 1, \cdots, N$, in the optimization problem (10), we perform exhaustive search by solving (16), for $l = 1, \cdots, N$. The best cellular user for sharing is given by $l^* = \arg\max_l R_l^{\mathrm{improv}}$. Thus, we have $\alpha_{l^*}^* = 1$ and $\alpha_i^* = 0$, for $i \neq l^*$.

4. SIMULATION RESULTS

For the cellular network setup, we consider the first-tier interference for the cell of interest, consisting of its six neighboring cells. The cellular users and D2D pairs are uniformly distributed in each cell. We set $N = 10$ for cellular users in each cell. We assume each cellular user is assigned 10 distinct RBs. The RBs are assigned randomly to cellular users following a uniform distribution. We assume there are N potential D2D pairs in each cell. Each pair may be active for communication with probability p. The average number of active D2D pairs per cell, denoted by N_d, is $N_d = pN$. When there are multiple active D2D pairs requesting for RB sharing, they are queued based on a first-come-first-serve rule. We solve the optimization problem (7) for the D2D pairs one-by-one based on their order in the queue for each cell.

We consider an uplink communication scenario for the cellular users, and assume all the cellular users have a power control mechanism which compensates path loss effects. For the link between any two nodes, we use a simple path loss model $K_0 D^{-\alpha}$, where we have the pass loss constant $K_o = 0.01$, and the pass loss exponent $\alpha = 4$. We assume Rician fading for the link between each cellular user and its BS with K-factor [21] being set to 2, and Rayleigh fading for all inference links and the D2D links. The default values of system parameters is shown in Table 1. We use Monte Carlo runs for generating user locations, the active D2D pairs, and channel realizations to obtain the average cell sum-rate performance.

Fig. 2 shows the average cell sum-rate per RB in the main cell versus different values of $P_{\max}^{\mathrm{D}}$ for $N_d = 4, 7, 10$. For comparison, we also plot the cell sum-rate without the D2D pairs. By increasing $P_{\max}^{\mathrm{D}}$, the cell sum-rate initially benefits from the optimal spectrum sharing of the D2D pairs and cellular users. However, as $P_{\max}^{\mathrm{D}}$ becomes high, the interference from the D2D users at the neighboring cells to the main cell increases, and the cell sum-rate decreases. Thus, the value of $P_{\max}^{\mathrm{D}}$ should be carefully selected to maximize the cell sum-rate. In addition, we see that as the density of active D2D pairs increases, the cell sum-rate improvement becomes saturated.

Fig. 3 shows the effect of changing the minimum required SINR $\zeta_{j,\min}^{\mathrm{intra}} = \zeta_{j,\min}^{(k)} = \zeta_{\min}$ in each cell on the performance. By increasing $\zeta_{j,\min}^{\mathrm{intra}}$, the power limit η_j for D2D users reduces, and the total cell sum-rate for the main cell decreases. Furthermore, Fig. 3 shows the effect of changing the average received SNR value for the cellular users. By increasing the transmit power of the cellular users, the interference level to the D2D users increases. At the same time, the SINR of each cellular user improves, which increases the power limit over each RB for the D2D transmitter. As a result, the cell sum-rate is increased as the received SNR of cellular users increases from 24dB to 30dB.

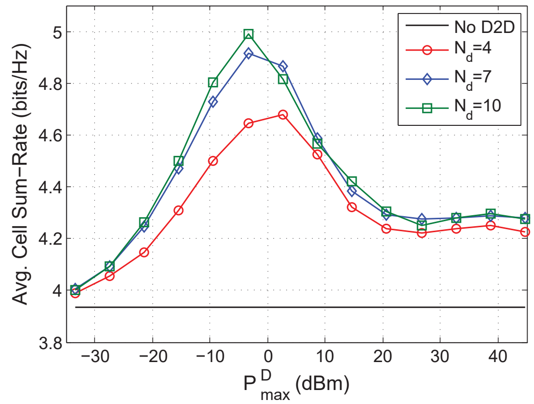

Fig. 2. The achieved cell sum-rate vs. $P_{\max}^{\mathrm{D}}$.

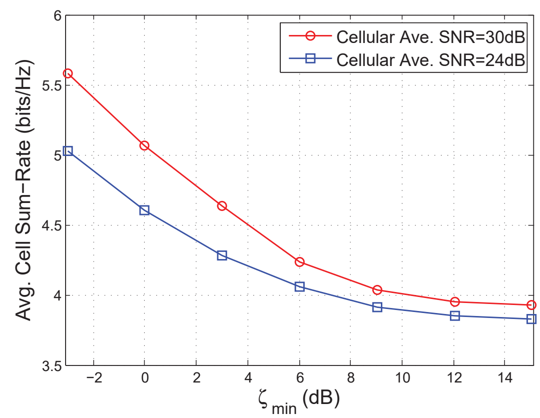

Fig. 3. The achieved cell sum-rate vs. $\zeta_{\min}^{\mathrm{intra}}$ $(= \zeta_{j,\min}^{(k)} = \zeta_{\min})$.

5. CONCLUSION

In this paper, we have considered optimal resource sharing by the D2D users in a cellular network for underlying D2D communication. We formulate the problem as cell sum-rate maximization to find optimal D2D transmitter powers, under cellular user minimum SINR requirements and a sum-power constraint on the D2D transmitter. Through convexification of the sum-rate objective function, we obtain an asymptotically optimal solution for the problem. The effect of the transmit power of the D2D and cellular users as well as the number of the D2D pairs are studied through simulation.

6. REFERENCES

[1] G. Fodor, E. Dahlman, G. Mildh, S. Parkvall, N. Reider, G. Miklos, and Z. Turanyi, "Design aspects of network assisted device-to-device communications," *IEEE Commun. Mag.*, vol. 50, no. 3, pp. 170–177, Mar. 2012.

[2] K. Doppler, M. Rinne, C. Wijting, C.B. Ribeiro, and K. Hugl, "Device-to-device communication as an underlay to LTE-advanced networks," *IEEE Commun. Mag.*, vol. 47, no. 12, pp. 42–49, Dec. 2009.

[3] Xingqin Lin, J. Andrews, A. Ghosh, and R. Ratasuk, "An overview of 3GPP device-to-device proximity services," *IEEE Commun. Mag.*, vol. 52, no. 4, pp. 40–48, Apr. 2014.

[4] T. Doumi, M.F. Dolan, S. Tatesh, A. Casati, G. Tsirtsis, K. Anchan, and D. Flore, "LTE for public safety networks," *IEEE Commun. Mag.*, vol. 51, no. 2, pp. 106–112, Feb. 2013.

[5] P. Janis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler, and K. Hugl, "Interference-aware resource allocation for device-to-device radio underlaying cellular networks," in *Proc. IEEE 69th Vehicular Technology Conference (VTC Spring)*, Apr. 2009, pp. 1–5.

[6] Hyunkee Min, Jemin Lee, Sungsoo Park, and Daesik Hong, "Capacity enhancement using an interference limited area for device-to-device uplink underlaying cellular networks," *IEEE Trans. Wireless Commun.*, vol. 10, no. 12, pp. 3995–4000, Dec. 2011.

[7] Tao Peng, Qianxi Lu, Haiming Wang, Shaoyi Xu, and Wenbo Wang, "Interference avoidance mechanisms in the hybrid cellular and device-to-device systems," in *Proc. IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, Sept. 2009, pp. 617–621.

[8] Shaoyi Xu, Haiming Wang, Tao Chen, Qing Huang, and Tao Peng, "Effective interference cancellation scheme for device-to-device communication underlaying cellular networks," in *Proc. IEEE 72nd Vehicular Technology Conference Fall (VTC Fall)*, Sept. 2010, pp. 1–5.

[9] Rongqing Zhang, Xiang Cheng, Liuqing Yang, and Bingli Jiao, "Interference-aware graph based resource sharing for device-to-device communications underlaying cellular networks," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, Apr. 2013, pp. 140–145.

[10] Rongqing Zhang, Xiang Cheng, Qi Yao, Cheng-Xiang Wang, Yang Yang, and Bingli Jiao, "Interference graph-based resource-sharing schemes for vehicular networks," *IEEE Trans. Veh. Technol.*, vol. 62, no. 8, pp. 4028–4039, Oct. 2013.

[11] R. Yin, C. Zhong, G. Yu, Z. Zhang, Kai-Kit Wong, and X. Chen, "Joint spectrum and power allocation for D2D communications underlaying cellular networks," *To Appear IEEE Trans. Veh. Commun.*

[12] Feiran Wang, Chen Xu, Lingyang Song, and Zhu Han, "Energy-efficient resource allocation for device-to-device underlay communication," *IEEE Trans. Wireless Commun.*, vol. 14, no. 4, pp. 2082–2092, Apr. 2015.

[13] Rui Yin, Guanding Yu, Huazi Zhang, Zhaoyang Zhang, and G.Y. Li, "Pricing-based interference coordination for D2D communications in cellular networks," *IEEE Trans. Wireless Commun.*, vol. 14, no. 3, pp. 1519–1532, Mar. 2015.

[14] Yong Li, Depeng Jin, Jian Yuan, and Zhu Han, "Coalitional games for resource allocation in the device-to-device uplink underlaying cellular networks," *IEEE Trans. Wireless Commun.*, vol. 13, no. 7, pp. 3965–3977, July 2014.

[15] Zhenyu Zhou, Mianxiong Dong, Kaoru Ota, Jun Wu, and T. Sato, "Distributed interference-aware energy-efficient resource allocation for device-to-device communications underlaying cellular networks," in *Proc. IEEE Global Communications Conference (GLOBECOM)*, Dec. 2014, pp. 4454–4459.

[16] Daohua Zhu, Jiaheng Wang, A.L. Swindlehurst, and Chunming Zhao, "Downlink resource reuse for device-to-device communications underlaying cellular networks," *IEEE Signal Processing Lett.*, vol. 21, no. 5, pp. 531–534, May 2014.

[17] Minchae Jung, Kyuho Hwang, and Sooyong Choi, "Joint mode selection and power allocation scheme for power-efficient device-to-device (D2D) communication," in *Proc. IEEE 75th Vehicular Technology Conference (VTC Spring)*, May 2012, pp. 1–5.

[18] Daquan Feng, Lu Lu, Yi Yuan-Wu, G.Y. Li, Gang Feng, and Shaoqian Li, "Device-to-device communications underlaying cellular networks," *IEEE Trans. Commun.*, vol. 61, no. 8, pp. 3541–3551, Aug. 2013.

[19] Daquan Feng, Lu Lu, Yi Yuan-Wu, G.Y. Li, Gang Feng, and Shaoqian Li, "Optimal resource allocation for device-to-device communications in fading channels," in *Proc. IEEE Global Communications Conference (GLOBECOM)*, Dec. 2013, pp. 3673–3678.

[20] S. Boyd, *Convex Optimization*, Cambridge University Press, 2004.

[21] J. Proakis and M. Salehi, *Digital Communications*, McGraw-Hill, 5th edition, 2007.