Price-based Device-to-Device Communication Underlying Cellular Networks

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***Abstract*— Underlay device-to-device (D2D) communication is envisaged to improve the spectral efficiency in cellular networks. One main challenge in this technology is how to control transmit powers from D2D pairs in order to preserve a certain quality of service requirement for cellular users. To address this challenge, this paper proposes a price-based power control game, by which transmit power of D2D pairs is so adjusted that a given transmit rate for a cellular user is satisfied. Numerical results are conducted to evaluate the performance of the proposed scheme.**

Keywords— Device-to-device, price-based game, power control, optimization.

I. Introduction

The increasing demand for wireless services in cellular communication forces researchers seeking for new techniques to increase the coverage area using efficient radio resource allocation schemes. Device-to-device (D2D) communication is a radio technique that has received much attention recently in wireless cellular communication. It is defined as a direct communication between two mobile users without traversing the eNB or the core network [1]. As a result of eNB offloading, this technique can result in energy efficiency, smaller delay, fairness, and extended cellular coverage [1], [2].

D2D communication is categorized into out-band and in-band communication modes based on the utilized spectrum. In the out-band mode, D2D users utilize an unlicensed spectrum without any control from eNB. On the other hand, the in-band mode utilizes the cellular spectrum in two ways. In the first one, a part of the cellular spectrum is dedicated to D2D users and in the next one, D2D communication is allowed to reuse the same spectrum with cellular services as an underlay, thus improving the system throughput [3,4].

The motivation behind underlay D2D communication is efficient spectrum utilization, where the cellular spectrum is shared frequently in the network. However, the major challenge is the mutual interference between D2D and cellular users that might degrade the system-wide performance. Therefore, methods for efficient interference coordination must be developed to achieve a target performance level for both cellular and D2D users.

Power control is a well-known approach of interference management in wireless networks. Various research aspects include power control and resource allocations have been conducted to study these problems [5]-[7]. In [5], a deterministic network model was proposed to manage power control in a single-cell network, which adjusts D2D transmit power to protect the existing cellular links. In [6], the problem of radio resource allocation to D2D communication network was formulated as a mixed integer non-linear programing and a greedy heuristic algorithm was proposed to solve the problem. In [7], the authors applied a dynamic power control to a single D2D link to improve the performance of a cellular network. Power control of underlay D2D communication using game theory has also been investigated in the literature [8], [9], [10].

Power control interaction between mobile users is modeled as a game in which they make actions with mutual and possibly conflicting consequences [11]. In [12] and [13], the authors use combinatorial auction game to solve D2D allocation problems. In [14], the authors proposed a sequential price auction mechanism to allocate the spectrum resources for D2D communication. In [15], the authors use non-cooperative power control game and introduce pricing to improve the result.

We consider underlay D2D communication with a sharing uplink spectrum. The priority of the cellular communication is guaranteed by regarding the cellular user as a primary user. D2D pairs as secondary users aim at maximizing their own achieved rate over the shared uplink spectrum while guarantying a target performance level of the cellular user. This issue requires tracking the interference from D2D transmit power to the cellular user. In order to guarantee a certain performance level of the cellular user, D2D pairs controls its own transmit power. One basic requirement for this issue is the knowledge on the interference channel gain between D2D transmitters and the cellular user receiver, i.e., eNB. However, this knowledge is in general not available or imperfect as the D2D pairs might be appeared transparent to the eNB. To mitigate this deficiency, in this paper, a price-based power control scheme using game theory is proposed.

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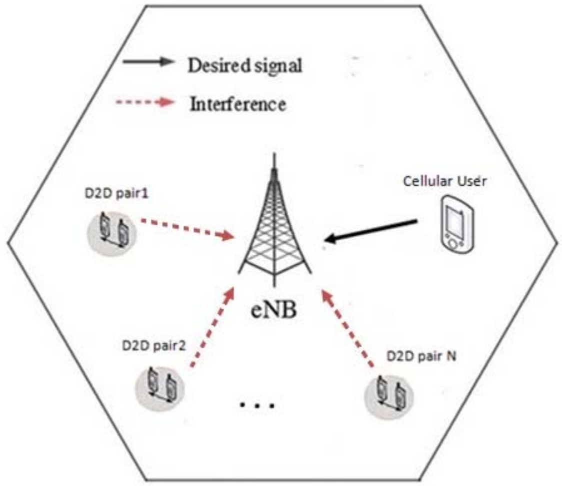

Fig.1. Underlay D2D communication with N D2D pairs

The power control is modeled as a game between eNB and the D2D pairs under the assumption of no knowledge of the interference channel gain. In the game, the objective of the D2D pairs is to maximize their own achieved rate from the shared uplink spectrum while satisfying a certain performance level of the cellular user. The performance of the proposed power allocation schemes is then evaluated.

The rest of the paper is organized as follows: In Section II, we describe the system model of underlay D2D communication. In Section III, a price-based power allocation scheme to satisfy the required rate of the cellular network is presented. The performance of this scheme is evaluated in Section IV. The paper in concluded in Section V.

II. SYSTEM MODEL

We consider a single cellular user equipment (UEc) and N D2D pairs that use the same channel, in a single cell environment, as shown in Fig. 1. It is assumed that all D2D UEs are closed enough to satisfy a threshold distance to support a D2D service, so the D2D pairs mode have been selected previously. The cellular UEc, communicates with the eNB with a predetermined spectrum allocation in the uplink mode. In the case of downlink communication, the transmit power of eNB is too large which causes serious interference to the D2D UEs and interrupts D2D connection accordingly. This is the main reason for choosing uplink mode.

We assume all D2D pairs can communicate in same bandwidth and in any random distance from eNB. It aims that the network should guarantee a minimum transmit rate for cellular UE. In other words, the interference from D2D pairs to the cellular user must be less than a specific threshold value.

As shown in Fig.1, we define $D=\{d:d=1,\ldots,N\}$ as a set of D2D pairs that share the same channel with cellular UE. Moreover, we assume transmitter and receiver in each one of Dash line shows D2D pairs interference to the eNB. These interference channel gains are denoted by $\{g_{de}\}_{d\in D}$. Moreover, g_{ce} is the channel gain for cellular communication.

The transmit rate of UEc in bit per second per Hertz (bps/Hz) is driven as

$$r_c=\log_2\left(1+\frac{g_{ce}p_c}{\sum_{d\in D}g_{de}p_d+\sigma_n^2}\right) \tag{1}$$

p_c is the transmit power of cellular and σ_n^2 is the AWGN noise power. Moreover the channel rate of each D2D pair $d\in D$ is

$$r_d=\log_2\left(1+\frac{g_{dd}p_d}{\sum_{d'\in D\backslash d}g_{d'd}p_{d'}+\sigma_n^2+p_c g_{cd}}\right) \tag{2}$$

where p_d and $p_{d'}$ are the transmit powers of D2D pairs d and d' respectively. $g_{d'd}$ denotes the channel interference gain between D2D pairs and similarly g_{cd} represent channel gain between the *d-th* D2D pair and the eNB. It is assumed that D2D pairs are far enough so that the amount of interference of one D2D pair on other ones is neglected and can be ignored. Therefore, (2) can be rewritten as

$$r_d=\log_2\left(1+\frac{g_{dd}p_d}{p_c g_{cd}+\sigma_n^2}\right) \tag{3}$$

The D2D pairs sum-rate is

$$r_D=\sum_{d=1}^{N}r_d \tag{4}$$

In this paper, the transit powers of D2D pairs are controlled in order to guarantee a certain performance level for the cellular user. Moreover, the objective is to maximize the D2D pairs sum-rate, as formulated in

$$\max_{\{p_d\}} r_D \quad (5a)$$

Subject to: $$r_c \geq r_c^T \quad (5b)$$

$$0 \leq p_d \leq \overline{p} \quad \forall d \quad (5c)$$

Constraint (5a) state that the sum-rate of D2D pairs is to be maximized under two constraints. The first one is (5b) implicitly states that the interference from D2D pairs should be less than a specific value. The second one is constraint (3c) which states that p_d must be positive and no larger than a maximum value $\overline{p}$.

A game-theoretic approach is employed in the following section to solve the problem.

III. PRICE-BASED POWER ALLLOCATION SCHEME

The knowledge on interference channel gains g_{de} is mostly imperfect from the side of D2D pairs. To mitigate this situation, we model D2D power allocation as a power control game between the D2D pairs as transmitters and eNB as the receiver. In the following, we provide an iterative approach over the time so that the transmit power of the D2D pairs captures the randomness of the channel gain g_{de} .

To satisfy the rate constraint $r_c \geq r_c^T$ in (5b) for the cellular user over the time, we use a price-based game [16]. Associated with each unit of power from D2D pairs, we consider a shadowing price. In other words, it is assumed that eNB penalizes the D2D pairs with a shadowing price $\lambda(t)$ per a unit of power during a time slot *t*. Therefore, each D2D pair aims to

$$\max \ u(p_d(t)) = r_d(t) - \lambda(t) p_d(t) \quad (6a)$$

Subject to: $$0 \leq p_d(t) \leq \overline{p} \quad (6b)$$

where $u(p_d(t))$ is the utility function of D2D pair. The solution of this problem can be derived by taking derivative of the objective function with respect to p_d and projecting it into the constraint (6b) as in the following.

$$\frac{\partial u(p_d)}{\partial p_d} = 0 \Rightarrow p_d(t) = \frac{1}{g_{dd}}\left(\frac{g_{dd}}{\lambda \ln 2} - p_c g_{cd} - n\right) \Rightarrow p_d^*(t) = \left[p_d(t)\right]_0^{\overline{p}} \quad (7)$$

Upon deriving the transmit power $p_d^*(t)$, the eNB measures the perceived interference $\sum_{d \in D} g_{de}(t) p_d^*(t)$ from D2D pairs and updates the shadowing price as

$$\lambda(t+1) = \lambda(t) + \alpha\left(\sum_{d \in D} g_{de}(t) p_d^*(t) - I^T\right) \quad (8)$$

where α is a step size and $I^T = \left(\frac{p_c g_{ce}}{2^{r_c^T} - 1} - \sigma^2\right)$ is the amount of interference to achieve constraint $r_c \geq r_c^T$ in (5b).

This solution can be modeled as a price-based power control game between the D2D pairs and eNB, formally written in Algorithm 1. At each time slot t, eNB broadcasts a price $\lambda(t)$ to D2D pairs. Using the solution in problem (6), the transmit side of the D2D pair solves the problem to determine $p_d^*(t)$. Power of each D2D pair generates interference $g_{de} p_d^*(t)$ that is perceived and measured by eNB. To feedback the impact of the transmit power to D2D pairs, eNB then updates the broadcasted price $\lambda(t+1)$ at time slot $t+1$. This loop will continue until the value of the announced price is converged. The proposed game is formally written in Algorithm 1.

IV. SIMULATION RESULT

To evaluate the performance of the proposed power allocation game under imperfect interference channel gains, we perform extensive simulations. Consider a single cell in which *N* D2D pairs are going to reuse the allocated spectrum to a cellular user that is working in the uplink mode. It is assumed that the D2D users are close enough to connect with each other. In this paper, the channel is assumed to be a Rayleigh fading channel, in which the channel gain over each link ij is expressed as $g_{ij} = g_0^2 / d_{ij}^{\alpha}$, where g_0 is a complex Gaussian channel

Algorithm 1: D2D power control game

1: Initialize $t = 1$, $\lambda(1) = \lambda_{init}$
2: While (1)
3: BS broadcast $\lambda(t)$ to D2D pairs.
4: each D2D pair computes $p_d^*(t)$ using (7).
5: eNB updates $\lambda(t+1)$ using (8).
6: If $\left|\lambda(t+1) - \lambda(t)\right| \leq \varepsilon$
7: algorithm is terminated.
8: End if
9: End While

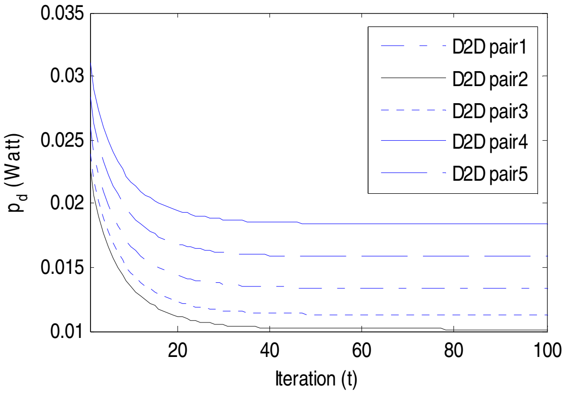

Fig. 2. Allocated power to D2D pairs

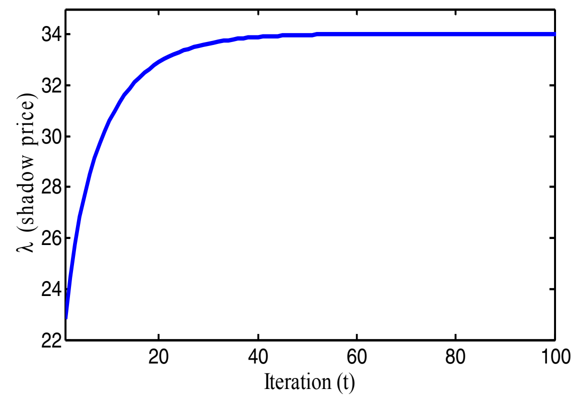

Fig. 3. Shadowing price

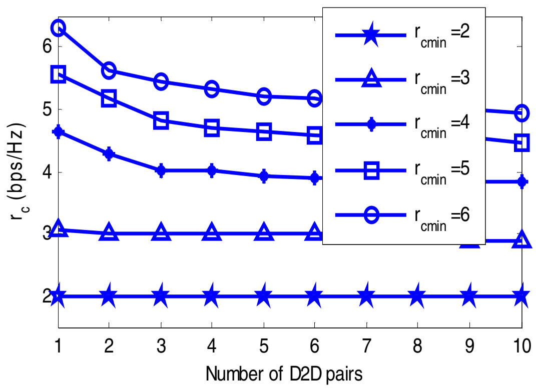

Fig. 4. Allocated power to D2D pairs communication

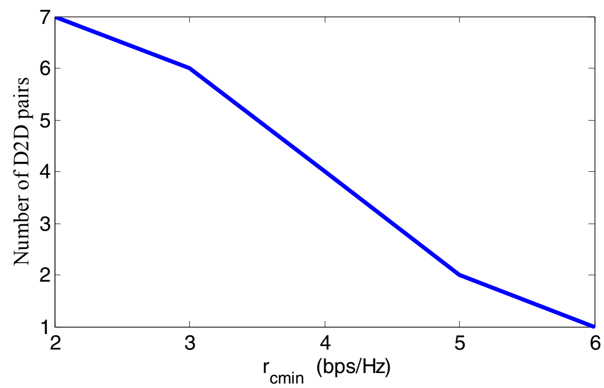

Fig. 5. Allowable number of D2D pairs

coefficient that follows the distribution $CN(0,1)$, d_{ij} is the distance. Simulation parameters are summarized in Table 1.

The proposed game is run in 100 iterations for 5 D2D pairs. It is assumed that D2D pairs are randomly located in a distance

TABLE I
SIMULATION PARAMETERS

SYMBOL	PARAMETER	VALUES
Lce	Cellular communication distance	250m
Ldd	D2D communication distance	50m
Lde	D2D UE distance to eNB	100-300m
N	Number of D2D pair	5
r_c^T	Minimum accepted bitrate for cellular communication	3 bps/Hz
$\overline{p}$	Maximum power for D2D UE	1 Watt
Pc	UEc power	1 Watt
σ_n^2	Noise power	-90dB

between 100 to 300 meters from eNB, and $r_c^T = 3$ bps/Hz. Allocated power for D2D pairs and variation of the shadowing price over the time are shown in Fig. 2 and Fig. 3, respectively. As shown, transmit powers and shadowing price converge over the time. Moreover, allocated powers are differentiated depending on the distance from eNB.

In order to have a comprehensive comparison, we vary r_c^T or the minimum required rate by the cellular user from 2 to 6 bps/Hz in Fig. 4, and evaluate the average achieved rate for the cellular UE versus different number of D2D pairs. As observed, the small required rates are well satisfied even with large number of D2D pairs, e.g., $r_c^T = 2$ and 4. For high required rates, e.g., $r_c^T = 5$ and 6, we observe that the average rate provided by the game is satisfied in small number of D2D pairs. However, this rate decreases as the number of D2D pairs increases. This is due to the fact that a large amount of interference from D2D pairs cannot be compensated by the limited power in the cellular user. In other words, for high required rates, more power from cellular user is needed when the number of D2D pairs increases.

Following the result in Fig. 4, it is our interest to find the maximum number of allowable D2D pairs in order to satisfy a given transmit rate for the cellular user. To address this issue, Fig. 5 illustrates the maximum number of allowable D2D pairs versus different required transmit rates by the cellular user. As shown, as the required rate by the cellular user increases, the allowable number of D2D pairs decreases. This result is reasonable and expected.

V. CONCLUSION

The power control of a number of D2D pairs underlaying a cellular user has been investigated using a price-based game. The performance of the game is satisfactory for small number of D2D pairs. The required transmit rate by the cellular user is provided in this case. However, for a high number of D2D pairs, the provided rate for the cellular user decreases, due to a limited transmit power. Indeed, more power from the cellular user is needed in this case.

REFERENCES

[1] A. Asadi, Q. Wang, and V. Mancuso, "A survey on device-to-device communication in cellular networks," Communications Surveys & Tutorials, IEEE, vol. 16, pp. 1801-1819, 2014 .J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[2] X. Lin, J. G. Andrews, and A. Ghosh, "Spectrum sharing for device-to-device communication in cellular networks," Wireless Communications, IEEE Transactions on, vol. 13, pp. 6727-6740, 2014.K. Elissa, "Title of paper if known," unpublished.

[3] C.-H. Yu et al., "Resource Sharing Optimization for D2D Communication Underlaying Cellular Networks," IEEE Trans. Wireless Commun., vol. 10, no. 8, Aug. 2011 pp. 2752–63.

[4] C. Xu et al., "Resource Allocation Using a Reverse Iterative Combinatorial Auction for Device-to-Device Underlay Cellular Networks," IEEE Global Commun. Conf. (Globecom), Los Angeles, CA, Dec. 2012.

[5] C. H. Yu, O. Tirkkonen, K. Doppler, and C. Ribeiro, " On the performance of device-to-device underlay communication with simple power control," in proc. IEEE Veh. Technol. Conf., 2009, pp.1-5.

[6] M. Zulhasnine, C. Huang, and A. Sinivasan,"Efficient resource allocation for device-to-device communication underlaying LTE network," in proc. IEEE International Wireless and Mobile Computing, Networking and Communications Conference, Niagara Falls, Nj, Oct. 2010,pp.368-375.

[7] J. Gu, S. J. Bae, B.-G. Choi, and M. Y. Chung, "Dynamic power control mechanism for interference coordination of device-to-device communication in cellular networks," in proc. 3rd Int. Conf. Ubiquitous Future Netw.,Jun. 2011, pp. 71-75.

[8] A. Mas-Colell, M. D. Whinston, and J. R. Green, Microeconomic theory vol. 1: Oxford university press New York, 1995.

[9] D. Fudenberg and J. Tirole, "Game theory," 1991.

[10] L. Song, D. Niyato, Z. Han, and E. Hossain, "Game-theoretic resource allocation methods for device-to-device communication," Wireless Communications, IEEE, vol. 21, pp. 136-144, 2014.

[11] M. Felegyhazi and J.-P. Hubaux, "Game theory in wireless networks: A tutorial," 2006.

[12] F. Wang, C. Xu, L. Song, and Z. Han, "Energy-Efficient Resource Allocation for Device-to-Device Underlay Communication," Wireless Communications, IEEE Transactions on, vol. 14, pp. 2082-2092, 2015.

[13] F. Wang, L. Song, Z. Han, Q. Zhao, and X. Wang, "Joint scheduling and resource allocation for device-to-device underlay communication," in Wireless Communications and Networking Conference (WCNC), 2013 IEEE, 2013, pp. 134-139.

[14] M. S. Corson, R. Laroia, J. Li, V. Park, T. Richardson, and G. Tsirtsis, "Toward proximity-aware internetworking," Wireless Communications, IEEE, vol. 17, pp. 26-33, 2010.

[15] C. U. Saraydar, N. B. Mandayam, and D. J. Goodman, "Efficient power control via pricing in wireless data networks," Communications, IEEE Transactions on, vol. 50, pp. 291-303, 2002.

[16] M. Fathi "Price-based spectrum sharing and rate allocation in multicarrier wireless networks," IET Networks, vol. 3, no. 4, pp. 252–258, Nov. 2014.