Signal Processing 100 (2014) 23–31

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

Resource optimization for cellular network assisted multichannel D2D communication

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ARTICLE INFO

Article history:
Received 26 September 2013
Received in revised form
27 November 2013
Accepted 8 January 2014
Available online 18 January 2014

Keywords:
Cellular network assisted
Device-to-device communication
Multichannel
Resource optimization
Weighted sum rate

ABSTRACT

Cellular network assisted device-to-device (D2D) communication can improve spectrum utilization by jointly coordinating cellular and D2D users. This paper studies D2D communication sharing multiple cellular channels and optimizes the overall system performance by maximizing the weighted sum rate (WSR) of the cellular and D2D users. We first provide an analytical characterization of the optimal resource sharing in the single channel case. Then, based on it, we propose a simple but efficient algorithm to maximize the WSR in the general multichannel case. Furthermore, we also propose two alternative algorithms to achieve better performance at a cost of higher complexity. In addition, a simple condition is provided to verify the global optimality of the obtained solution. Numerical results show that the proposed algorithms outperform the existing single-channel design, and interestingly the optimality condition is satisfied in many cases, thus justifying the merit of the proposed algorithms from both theoretical and practical aspects.

1. Introduction

Recently, device-to-device (D2D) communication arises as a promising technique to provide better local wireless services in cellular systems. D2D communication allows two closely located users, instead of being relayed by a base station (BS), to communicate directly by using cellular resources. Consequently, cellular network assisted D2D communication enjoys the advantages of higher data rates, lower power consumption, and more efficient spectrum utilization [1]. Therefore, D2D communication has recently been proposed as an important supplement of the existing and future cellular systems for local wireless services [2].

D2D communication as an underlay of cellular systems shares the same resources with cellular users (CUs), like cognitive radio (CR) systems where secondary users (SUs) share the resources of primary users (PUs) [3]. However, there is a significant difference between CR and D2D systems: in CR systems SUs are usually oblivious to PUs and system optimization mainly focuses on SUs [4], whereas in D2D systems cellular and D2D users are both controlled by BSs and system optimization includes both D2D and cellular users [5]. Therefore, cellular network assisted D2D communication can comprehensively coordinate the interference between cellular and D2D users and achieve efficient spectrum utilization.

In principle, D2D communication can reuse cellular resources in either an orthogonal or nonorthogonal manner [2]. In the former case, a D2D link occupies one or several dedicated channels (e.g., frequency bands in GSM, codes in CDMA, or subcarriers in LTE [6]). In the latter case, a D2D link is allowed to share the same channels with one

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http://dx.doi.org/10.1016/j.sigpro.2014.01.005

or multiple CUs. The nonorthogonal resource sharing can lead to higher spectral utilization and thus attracts more research interests [1]. On the other hand, although conceptually either uplink or downlink resources are accessible, in practice D2D communication is more likely to use uplink resources due to asymmetric uplink and downlink service loads and the stronger processing ability of BSs to manage interference [1,2].

The full benefit of D2D communication hinges on jointly optimizing the resource sharing between cellular and D2D users. In the literature, Doppler et al. [2,5] introduced basic mechanisms to control the maximum D2D transmit power. Yu et al. [7] considered maximizing the sum rate of the D2D link and one CU, and Cheng et al. [8] studied the impact of D2D communication in uplink CDMA systems. In [9,10], the authors utilized multi-antenna techniques to suppress the interference between the cellular and D2D users. The recent work [11] considered paring each D2D link with one CU under QoS constraints, and Wang et al. [12] studied resource sharing between cellular and D2D users from a game theoretical perspective. These works have a common restriction that D2D communication is only allowed to share one channel of a single CU. In practical cellular systems (e.g., GSM or CDMA systems), there are generally multiple (uplink) channels that may be available at the same time and can be reused for D2D communication, which calls for more sophisticated resource sharing methods.

Therefore, in this paper, we consider multichannel channel D2D communication that can fully utilize cellular resources by allowing the D2D link to share multiple cellular channels. To improve the overall system performance and at the same time take into account the priorities of cellular and D2D communications, our design goal is to maximize the weighted sum rate (WSR) of the cellular and D2D users. A major obstacle in D2D resource optimization is the inherent nonconvex nature as a result of cross interference between cellular and D2D users. In fact, so far only Yu et al. [7] provided the optimal strategy in terms of the sum rate but only with one channel. Our multichannel D2D communication design is much more difficult than that in [7] and thus requires new efficient methods.

To start with, we first study the WSR maximization (WSRM) problem in the single-channel case. As a result of introducing weights, the binary solution [7] is no longer available. Nevertheless, we still analytically characterize the optimal resource sharing between the D2D and cellular users in this special case. Then, based on the obtained results, we propose a simple but efficient algorithm to maximize the WSR in the general multichannel case. Furthermore, we also propose two alternative algorithms, one online and one offline, to achieve better performance at a cost of higher complexity. In addition, we provide a simple condition to verify the global optimality of the proposed algorithm. Interestingly, we find through simulations that the performance of the two alternative algorithms coincides and the global optimality condition is satisfied in most cases. Therefore, our proposed D2D optimization algorithms not only bear practical meanings but also provide a benchmark for multichannel D2D communication designs.

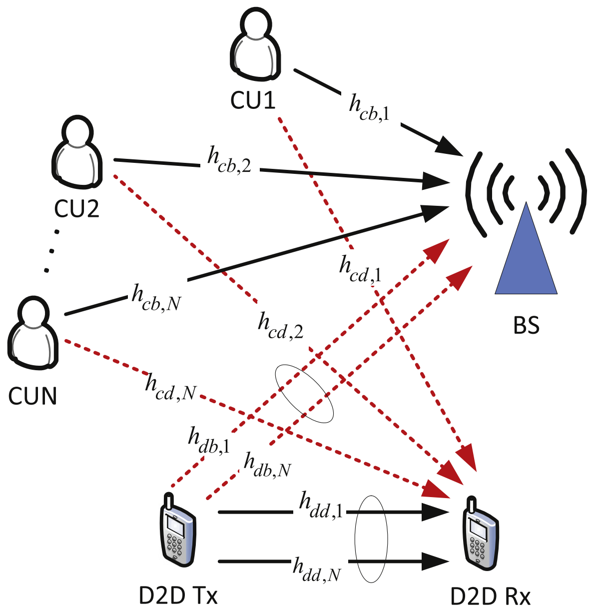

Fig. 1. Multichannel D2D communication in a cellular network.

2. Problem statement

Consider a cellular system consisting of one base station (BS) and $i=1,\ldots,n$ cellular users (CUs) as shown in Fig. 1, where a dedicated channel is allocated to each CU for his uplink communication. Without loss of generality (w.l.o.g.), we assume that the uplink channel of each CU i occupies a bandwidth of B_i Hz in the FDMA mode. Note that this model is also applicable to the TDMA or CDMA mode, where the uplink channel of each CU is represented by a time slot or spreading code instead. The channels of n CUs with bandwidths $B_1,\ldots,B_n$ are then shared by an underlaying D2D link, which allows multichannel D2D communication in the cellular network.

Denote the channel coefficient from CU i to the BS by $h_{cb,i}$, the channel coefficient from CU i to the D2D receiver (Rx) on B_i by $h_{cd,i}$. Denote the channel coefficient from the D2D transmitter (Tx) to its Rx on B_i by $h_{dd,i}$, and the channel coefficient from the D2D Tx to the BS on B_i by $h_{db,i}$. Let $p_{c,i}$ and $p_{d,i}$ denote the transmit power of CU i and the D2D user on B_i, respectively. Due to the cross interference between the cellular and D2D users, the data rates of CU i and the D2D link on B_i are given respectively by

$$R_{c,i}=B_i\log\left(1+\frac{|h_{cb,i}|^2p_{c,i}}{\sigma_{b,i}+|h_{db,i}|^2p_{d,i}}\right) \tag{1}$$

and

$$R_{d,i}=B_i\log\left(1+\frac{|h_{dd,i}|^2p_{d,i}}{\sigma_{d,i}+|h_{cd,i}|^2p_{c,i}}\right) \tag{2}$$

where $\sigma_{b,i}$ and $\sigma_{d,i}$ are the noise power at the BS and the D2D Rx on B_i, respectively. The maximum transmit power of each CU i is limited by $p_{c,i}\le P_{c,i}^{\max}$. To protect cellular communications, we assume that each CU i also has a minimum transmit power $p_{c,i}\ge P_{c,i}^{\min}$ with $0\le P_{c,i}^{\min}\le P_{c,i}^{\max}$