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Opportunistic scheduling and incentive mechanism for OFDMA networks with D2D relaying

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A B S T R A C T

The device-to-device (D2D) relaying is considered one of promising technologies to improve the spectral efficiency and extend the coverage of the cellular system with low additional costs. In the system with D2D relaying, some of user equipments (UEs) can act as relay stations (RSs) that forward other UEs' data from/to the base station (BS). Compared with the RS, the D2D relaying has several advantages such as low deployment costs and high flexibility. We study an opportunistic subchannel scheduling problem in the OFDMA cellular network with D2D relaying in this paper. We formulate a stochastic optimization problem to maximize the sum-rate of the system with D2D relaying while satisfying the minimum average data rate requirement for each UE, and then develop an opportunistic scheduling algorithm by solving it. Due to a high computational complexity of the optimal scheduling algorithm, we also propose a heuristic algorithm with a lower computational complexity. In addition, since UEs that participate in D2D relaying sacrifice their resources to relay other UEs' data, we also study incentive mechanisms to compensate their sacrifices. Through simulation results, we show the performance of our algorithms and the effects of our incentive mechanisms.

1. Introduction

Recently, OFDMA and opportunistic scheduling are considered as essential technologies to improve the spectral efficiency of cellular systems. In OFDMA, the bandwidth is divided into multiple subchannels and each subchannel can be allocated to a different user based on the scheduling scheme. Due to this flexibility, OFDMA is widely used in cellular systems such as 3GPP LTE-Advanced. Opportunistic scheduling is a scheduling scheme which exploits instantaneous channel states when radio resources are scheduled. Therefore, if opportunistic scheduling is used in the OFDMA system, we can expect high spectral efficiency by allocating each subchannel flexibly and efficiently [2].

In next-generation cellular networks, the relay station (RS) is also considered as one of the essential technologies to improve the spectral efficiency and extend the system coverage. For instance, 3GPP LTE-Advanced adopts the RS as one of the new main functionalities [3]. Although the RS technology is promising, the additional costs to deploy and maintain RSs are disadvantageous to the wide deployment of RSs. However, if the cellular network is able to utilize user equipments (UEs) as device-to-device (D2D) relaying UEs by allowing some UEs to relay other UEs' data through D2D communication, we can improve the spectral efficiency and extend the system coverage without additional costs. Furthermore, previous studies showed that the spectral efficiency of cellular systems with RSs and D2D communication can be further improved with adopting opportunistic scheduling. For instance, in [4–6], the authors showed the spectral efficiency improvement of opportunistic scheduling in the OFDMA system with RS [4,5] and with D2D communication [6], respectively.

Even though the system with D2D relaying that we study in this paper looks similar to systems with RSs [4,5] and D2D communication [6], there are critical differences between

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them, which necessitates developing the resource scheduling algorithm tailored to the system with D2D relaying. First of all, D2D relaying UEs should not only transmit their own data but also relay other UEs' data, while RSs only have to relay other UEs' data and UEs in D2D communication only have to transmit their own data. Moreover, D2D relaying UEs may have their own QoS requirement that should be satisfied. Second, when D2D relaying UEs relay other UEs' data, D2D relaying UEs sacrifice their own resources, such as time and energy, to help other UEs. Hence, the system should compensate their sacrifices to promote D2D relaying UEs to help other UEs by incentive mechanisms, otherwise D2D relaying UEs are not likely to help other UEs. There are several studies on the incentive mechanisms in mobile ad-hoc networks, such as reputation-based incentive mechanisms [7,8] and credit-based incentive mechanisms [9,10]. However, there are only few studies on the incentive mechanisms in the cellular network with D2D relaying, for instances, [11–13].

There are several related studies on the cellular network with D2D relaying [11–16]. In [14], the authors developed the system architecture with D2D relaying based on LTE Release-10, including multiplexing, data scheduling, and discovery procedure for each UE to find neighbor D2D relaying UEs. In [15], the authors developed the D2D relaying mechanism, including data plane protocol architecture and multiplexing, and provide system capacities with D2D relaying in both uplink and downlink. In this study, a part of uplink bandwidth is assumed to be dedicated to D2D relaying UEs so that it is used exclusively by D2D relaying UEs to relay other UEs' data, and the system capacities were studied based on the static resource allocation. In [16], the authors studied a joint power control, subchannel selection, and relay selection problem in the uplink system. This study provided the optimal solution and the suboptimal solution with a low computational complexity for the power minimization problem without considering the instantaneous channel states.

In [11–13], the authors studied the uplink system with D2D relaying considering an incentive mechanism which is called bandwidth exchange. In this bandwidth exchange, each UE has its own dedicated uplink resources. If one D2D relaying UE helps another UE, the D2D relaying UE receives a part of resource which is allocated to the UE as an incentive. The authors in [11] modeled bandwidth exchange as a repeated game between UEs and analyzed it using a Nash Bargaining Solution. In this study, the minimum data rate of each UE is guaranteed in each time-slot. The authors in [12] modeled bandwidth exchange as a stackelberg game between the BS and each UE, where the BS first decides how much bandwidth is given as an incentive to each D2D relaying UE and then each D2D relaying UE decides how much it helps the other UEs. In [13], the authors modeled a bandwidth and data rate allocation problem with bandwidth exchange as a maximum weighted matching problem and suggested a suboptimal algorithm with a low computational complexity in a snap-shot system.

Contrary to the previous works [11–16] that considered a snap-shot model in which the problem for each time-slot is solved independently with given channel conditions of wireless links in that time-slot, we study an opportunistic scheduling problem for the downlink OFDMA cellular system with D2D relaying UEs with explicitly considering the variations of channel conditions of wireless links over time. We first develop an optimal scheduling algorithm with D2D relaying UEs which maximizes the average sum-rate of the system while the system is guaranteeing the minimum data rate requirement to each UE. Due to the high computational complexity of the optimal scheduling algorithm, we also develop a suboptimal heuristic algorithm with a lower computational complexity that provides a good approximation to the optimal solution. In addition to developing the scheduling algorithms, we also propose two incentive mechanisms to promote the cooperation of D2D relaying UEs: performance-based incentive mechanism and monetary incentive mechanism. Contrary to the previous works [11–13] that studied incentive mechanisms separately with resource allocation assuming that there is pre-assigned resource (bandwidth) for each UE (including D2D relaying UE), in this paper, we study resource allocation and incentive mechanism jointly in a unified optimization framework.

The rest of this paper is organized as follows. We provide the system model in Section 2. We formulate an optimization problem and develop opportunistic scheduling algorithms solving the problem in Section 3. We propose the incentive mechanisms to promote the D2D relaying UEs' willingness to participate in relaying other UEs' data in Section 4. We provide the numerical results in Section 5 and conclusion in Section 6.

2. System model

In this paper, we consider a single cell downlink OFDMA system that consists of one BS and M UEs as in Fig. 1. We refer to each of the BS and UEs as a node. We denote the set of UEs by $\mathcal{M} = \{1, 2, \ldots, M\}$. Among these UEs, K UEs can act as D2D relaying UE that are able to relay the data from the BS to the other UEs. We denote the set of D2D relaying UEs by $\mathcal{K}$, which is a subset of $\mathcal{M}$, i.e., $\mathcal{K} \subseteq \mathcal{M}$. Without loss of generality, we denote the BS by index 0, and let first K UEs be D2D relaying UEs, i.e., $\mathcal{K} = \{1, 2, \ldots, K\}$. We assume that the set of D2D relaying UEs is predetermined, and it is out of the scope of this paper to determine it.

We have several assumptions for D2D relaying UEs and relay-based transmission. First, we assume decode-and-forward relaying. Second, we assume that D2D relaying UEs

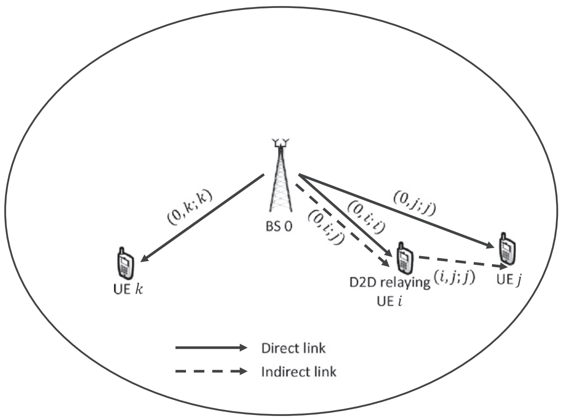

Fig. 1. A single cell downlink system.