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Joint channel allocation and power control based on PSO for cellular networks with D2D communications

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ABSTRACT

Introducing D2D communications into wireless cellular networks is viewed as a potential method to relieve the increasing traffic in the base stations. However, the cellular users will suffer from high interference without efficient interference management scheme. In this paper, we study two joint channel allocation and power control problems with different constraints, and propose a joint channel allocation and power control scheme based on Particle Swarm Optimization (PSO) to efficiently manage interference and improve the network throughput. The proposed scheme deals with continuous powers and discrete channels simultaneously. By carefully designing the fitness values for the two problems, the algorithm avoids trapping into infeasible solutions. Numerous simulations show that the proposed algorithm could improve the network throughput in cellular networks with D2D communications, and the algorithm outperforms the compared non-joint interference management algorithm in terms of D2D throughput, cellular throughput, and further the overall network throughput.

1. Introduction

Device-to-Device (D2D) communication allows direct communications between approximate users. It is considered to be a key technique in the next generation wireless networks (i.e., 5G) [1,2], and it has received lots of attentions in different scenarios. In [3], the authors have introduced it into LTE HetNets to guarantee the minimum SINR requirements of users. In [4], D2D communication is adopted to improve the performance of converged networks which consist of heterogeneous networks including a LTE-A cellular network and IEEE 802.11n WLANs. In [5], D2D communication is used as a technique for user's cooperation in cooperative interference cancellation (CIC). Fairness problem and delay-aware D2D communication problem are studied in [6] and [7], respectively. Besides these, D2D communication is considered to be a useful method to relieve the increasing traffic burden (caused by the increasing mobile users) at the base station in cellular networks since D2D devices communicate with each other directly without traversing the base station [8]. In addition, D2D communication can improve the overall network throughput when the D2D users reuse the channels of the cellular users (CUs). In this paper, we focus on the applications of D2D communications in cellular networks.

Despite of the advantages of D2D communication, it also introduces some challenges. One is the interference caused by the D2D communications to CUs when channel reusing is supported. Therefore, interference management between CUs and D2D users is considered to be one of the most critical issues in cellular networks with D2D communications [2,9]. Researchers have tried to manage the interference by mode selection, channel allocation or power control [10–15]. However, the works most related to our works are designed for limited number of D2D pairs and CUs sharing the same channel, e.g. [13–15]. This limitation will restrain the potential to improve the network throughput. Hence, it's necessary to study the interference management schemes without the limitation. In this study, we consider a general cellular network allowing arbitrary number of CUs and D2D users coexist and the number of D2D users sharing the same channel with one CU is not constrained. It's important to note that the cancellation of the constraints on the number of D2D pairs sharing the same channel with one CU brings great challenges to the interference management.

Another challenge in designing high efficient interference management strategies in cellular networks with D2D communications is the increasing network size in the future. The large network size will lead to high computation time of the interference management strategy especially when the problem is NP-Hard.

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Considering the simplicity and efficiency of the bio-inspired algorithm when dealing with the large size problems, we investigate the joint channel allocation and power control problem based on one of the bio-inspired algorithms named as Particle Swarm Optimization (PSO) method. PSO is originally proposed by James Kennedy and Russell Eberhart in 1995 [16]. It has attracted lots of attentions in wireless areas due to its simplicity and efficiency on seeking for optimal solutions for difficult optimization problems, e.g. [17–20]. To our knowledge, there are no state-of-the-art PSO based algorithms for the joint channel allocation and power control problems in cellular networks with D2D communications supporting arbitrary number of D2D users sharing the same channel with one CU.

In this paper, we investigate two joint channel allocation and power control problems. Both of them try to maximize the overall network throughput. However, one has constraints on the minimum achievable rate of each user, and the other one requires that the total throughput of CUs should be greater than a specified lower bound. The two joint channel allocation and power control problems contain continuous variables (powers) and discrete variables (channels). However, the standard PSO is designed to solve continuous problems while the discrete PSO algorithm is explored to solve discrete problems which are not applicable in this study. In addition, dealing with the constraints suitably in the two problems is important to avoid converging to local optimal or infeasible solutions.

Aiming to solve these problems, our main contributions include the following aspects:

- *We propose the PSO based joint channel and power allocation (JCPPSO) algorithm for cellular networks with D2D communications aiming to maximize the overall network throughput:* Unlike most of the previous studies which support at most two D2D pairs sharing the same channel with one CU, there are no limitations on the number of D2D pairs adopting the same channel used by one CU in this study.
- *Efficient fitness values are designed to avoid the PSO based algorithm trapping into infeasible solutions:* For the joint channel allocation and power control problems with different constraints, we design different fitness values considering constraints to avoid the algorithm trapping into infeasible solutions and achieve high performance. By this design, the JCPPSO algorithm could efficiently escape from the infeasible solutions. In addition, if the JCPPSO algorithm converges to a point, it is at least feasible and local optimal.
- *Extensive simulations have been done to evaluate the proposed algorithms:* In order to demonstrate the efficiency of the PSO based joint channel allocation and power control algorithm, we compare it with a typical non-joint algorithm which has a typical framework for all the other non-joint algorithms. The simulations have been conducted in various topologies, and by varying the key parameters in the network. Additionally, the throughputs of D2D users and CUs are also shown clearly.

The remainder of the paper is organized as follows. The related works are introduced in Section 2. We illustrate the network model and problem formulation for the joint channel allocation and power control problems in Section 3. In Section 4, we introduce the PSO based joint channel allocation and power control algorithm in details. In Section 5, we theoretically analyze the convergence, implementation method and time complexity of the proposed JCPPSO algorithm. In Section 6, we evaluate the JCPPSO algorithm by simulations. Finally, we conclude this paper and propose the future works in Section 7.

2. Related works

There has been considerable interest in interference managements for cellular networks with D2D communications. The most popular interference management methods include mode selection [21,22], channel allocation [23] and power control [24]. Some authors jointly consider these methods to explore the potentials to improve the network throughput. For instance, the authors in [10,13,15,25–27] have focused on the joint mode selection and power control problems in cellular networks with D2D communications. The joint channel allocation and power control problems are studied in [11,12,14,28,29]. In [30], opportunistic resource scheduling strategies supporting mode selection, power control, sub-channel assignment and channel reuse have been proposed. Although the paper supports multiple D2D users reusing the channels adopted by CUs, it puts restrictions on the number of users sharing the same channel (reusing group in the paper).

The above studies haven't adopted the bio-inspired idea. Some researchers have adopted the PSO algorithm into cellular networks with D2D communications. Authors in [31] have proposed the PSO based mode selection and resource allocation scheme to maximize the overall network throughput. However, it allows at most one D2D pair sharing the same channel with one CU. In [32], the hybrid PSO-GA algorithm has been adopted to assign channels for the CUs and D2D pairs. However, it allows at most two D2D pairs sharing the same frequency with one CU, and the powers of all the mobile users are fixed which limits the ability to alleviate the interference and improve the network performance. In [33,34], the power allocation schemes of D2D multicast communication have been studied. Although the application scenarios are different from this paper, they imply that the PSO based algorithms have great potential in improving the network throughput. In [35], the QPSO algorithm (which is also adopted in [34]) is used to obtain the joint spectral allocation and power allocation solutions. Due to the constraint that each resource block (frequency) can only be shared by at most one D2D pair which is the same as in [13–15,31], the strategy in [35] is not applicable in this study.

3. System model and problem formulation

3.1. Network model

We consider a network with one base station (BS), N CUs and M D2D pairs. All the CUs send packets to the BS. The sources of D2D pairs send packets to the corresponding D2D destinations directly without the help of the BS. The D2D pairs could reuse the uplink frequency of the CUs. The typical structure of a cellular network with D2D communications is illustrated in Fig. 1. The CUs and the sources of D2D pairs locate randomly in the circle of the BS with a radius of R, and the destinations of D2D pairs locate within the circle of the corresponding sources of D2D pairs with a radius of r.

In the cellular networks with D2D communications, the packets being transmitted to the BS by the CU suffer from the interference from the sources of D2D pairs which share the same channel. Considering that we allow arbitrary number of D2D pairs sharing the same channel with one CU, the destination of a D2D pair will be interfered by one CU and the sources of some D2D pairs sharing the same channel.

The whole network is provided with C orthogonal channels. The CU i is assigned with a dedicated channel c_u^i, the set $\mathbf{C_u} = \{c_u^1, \ldots, c_u^N\}$ represents the channels assigned to all the CUs. The D2D pair j reuses one channel which is already assigned to one CU, the channel is denoted by c_d^j, the set $\mathbf{C_d} = \{c_d^1, \ldots, c_d^M\}$ represents the channels assigned to all the D2D pairs. In order to ex-