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Multi-hop routing for energy-efficiency enhancement in relay-assisted device-to-device communication

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Abstract

Financial and environment considerations present new trends in wireless network known as green communication. As one of the most promising network architectures, the device-to-device (D2D) communication should take seriously account to the energy-efficiency. Most of the existing work in the area of D2D communication only focus on the direct communication, however, the direct link D2D communication has to be limited in practice because of long distance, poor propagation medium and cellular interference, etc. A new energy-efficient multi-hop routing algorithm was investigated for multi-hop D2D system by jointly optimizing channel reusing and power allocation. Firstly, the energy-efficient multi-hop routing problem was formulated as a combinatorial optimization problem. Secondly, to obtain a desirable solution with reasonable computation cost, a heuristic multi-hop routing algorithm was presented to solve the formulated problem and to achieve a satisfactory energy-efficiency performance. Simulation shows the effectiveness of the proposed routing algorithm.

Keywords device-to-device (D2D) communication, energy-efficiency, multi-hop, relay-assisted transmission, routing algorithm

1 Introduction

With explosive growth of wireless communication and strong expansion of mobile Internet, the exponential surge of energy consuming in wireless communication industry has already been reported in Ref. [1]. Based on financial and environmental considerations, the green communication has become more and more important. Moreover, D2D communication has been regarded as one of the most promising network architectures, and it has a lot of advantages. Therefore, it is vital to study and improve the energy-efficiency of D2D network.

However, most of the previous work only considered the direct link situation of D2D communication. In practice, the advantages of D2D communication may be limited in the direct transmission for the following reasons.

1) Long distance: the potential D2D users may be far away from the D2D transmitter [2].

2) Poor propagation medium: the link condition between two D2D users may be intolerable [3].

3) Interference to and from cellular users [4].

As relay-assisted transmission can enhance the performance of D2D communication when D2D users are far away from each other, so more attentions are given to D2D communication with relay-assisted, i.e. multi-hop D2D communication.

Some researches dealt with the relay-assisted D2D communication. The spatial density and transmission power were focused to maximize transmission capacity of multi-hop D2D system in Ref. [5], which only stated in theory without specific routing method. In Ref. [6], a multi-hop routing method for minimizing hop-count was proposed. However the multi-hop routing method took minimizing hop-count as the only objective, then it may increase the distance of each link. Since the energy-efficiency was not considered in previous relay-assisted D2D communication, it is urgent to develop the multi-hop routing algorithm with energy-efficiency guarantee. Furthermore, some research improved the energy-efficiency of D2D communication [7–8], but they only considered the direct communication.

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An energy-efficient multi-hop routing algorithm was proposed for multi-hop D2D system. Both channel reusing and power allocation policies are jointly considered to maximize the energy-efficiency of D2D system. The energy-efficient multi-hop routing problem was formulated as a combinatorial optimization problem, which is a NP-hard problem with prohibitive computation complexity. To obtain a desirable solution with reasonable computation cost, a heuristic multi-hop routing algorithm was presented to solve the formulated problem and achieve a satisfactory energy-efficiency performance. Simulation shows that the proposed routing algorithm can significantly improve the energy-efficiency of multi-hop D2D communication system.

The remainder of this article is organized as follows. In Sect. 2, the relay-assisted system model for multi-hop D2D network is described. Sect. 3 formulates the energy-efficient multi-hop routing problem. The heuristic multi-hop routing algorithm is proposed in Sect. 4. In Sect. 5, the performance of multi-hop D2D system is analyzed by several simulations. Finally, conclusions are drawn in Sect. 6.

2 System model

In this section, a spectrum sharing model for D2D and cellular hybrid network was built. Also, channel model and D2D relay model were described.

2.1 Spectrum sharing model

A single cell scenario with interference was considered here, including M cellular user equipment (CUE) and N D2D nodes. Assuming the D2D nodes share the uplink spectrum with cellular users. In this scenario, we assume D2D transmitter (D2D Tx) and D2D receiver (D2D Rx) are too far away to communicate directly, and they communicate with each other with the help of one or more other existing D2D nodes, as illustrated in Fig. 1. According to classical assumption, we assume that M CUEs communicate with base station (BS) on M different channels, and the channel allocated to each CUE is fixed. Moreover, each D2D user can only reuse one channel.

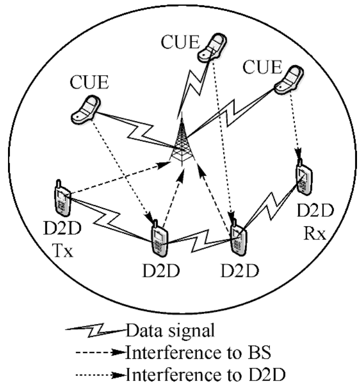

Fig. 1 System model of the relay-assisted D2D communication underlay cellular network

From Fig. 1 we can find that BS suffers interference signal from all the D2D transmitters. Thus the transmission power of D2D users must be controlled to decrease the interference to the cellular link. On the other hand, D2D receivers also suffer from the interference of cellular users.

2.2 Channel model

The transmission power used by the cellular user is denoted by P_0, and the distance between the cellular user and BS is denoted by d_m ($m = 1, 2, ..., M$). Then the channel model is defined as

$$G_m = A\vartheta P_0 d_m^{-\alpha} \tag{1}$$

where G_m is the received signal power of BS, A is the constant power gain introduced by other factors, such as amplifier and antenna gain, and ϑ is the small-scale fading constant, α is the path-loss exponent.

The distance between D2D node i and node j is described by $d_{i,j}$ $(i, j = 1, 2, ..., N)$. Moreover the distance between node i and the cellular user, whose channel is reused by node i, is denoted as Δ_i. The distance between node i and BS is represented by D_i. The transmission power of node i is denoted as P_i. Then, the interference of cellular link is expressed as

$$S_{BS} = \frac{A\vartheta P_0 d_m^{-\alpha}}{A\vartheta P_i D_i^{-\alpha}} \tag{2}$$

2.3 D2D relay model

Assuming the decode and forward (DF) relaying protocol is applied to the relay-assisted D2D system. The set of D2D nodes except D2D Tx and D2D Rx is considered as idle relay nodes.

We assume that each cellular channel can only be reused