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Distance-based resource allocation scheme for device-to-device communications underlaying cellular networks

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ABSTRACT

Recently, there has been growing interest in device-to-device (D2D) communications in a cellular network such as LTE-advanced. However, enabling D2D links in a cellular network presents a challenge in radio resource management due to the interference between cellular and D2D links. Some studies have considered cellular users as the primary and proposed methods to protect them from the additional interference from D2D links. However, considering that the D2D function is suitable for short-range and high-rate links, and local multimedia services, it is also important to guarantee these D2D links reliable. Thus, in this paper, we propose a method to properly choose a cellular user that shares radio resource with D2D users in the uplink to mitigate the interference from the cellular user to the D2D receivers. Numerical results show that by applying our method the reliability of D2D communication improves significantly without degrading the performance of the cellular connection. In addition, we derive a closed-form expression for the conditional outage probabilities of D2D links in the case when more than one D2D pair share the same resource with one cellular user, and discuss how the base station can choose a cellular user to optimize the performance of the D2D links.

1. Introduction

In the last few years, we have witnessed the emergence of new types of mobile devices, such as smart phones and tablets, and various new applications running on these devices. Those have led to a tremendous increase in mobile data traffic, which imposes the need for increasing network capacity. Device-to-device (D2D) communications are emerging as a promising technique to improve the user experience and resource utilization in cellular networks. Mobile devices in close proximity, with high signal-to-interference-plus-noise ratio (SINR) between them, may communicate directly instead of through the base station (BS). D2D communications underlaying a cellular network may be realized either in the network-controlled manner such that the cellular operator manages the D2D link configuration and resource allocation or in the autonomous manner without operator control [1]. The use of D2D communications is expected to bring a lot of advantages: improved energy efficiency, improved spectrum reuse and system throughput, improved user experience, cellular traffic offloading, extended coverage, enabling of new local services, such as video streaming, online gaming, media downloading, peer-to-peer (P2P) file sharing, etc. [2–4].

Although D2D communication accommodates large volume of traffic and provides better services to users, it also brings up two kinds of intra-cell interferences that were not present in the conventional cellular systems: the D2D-to-cellular (D2C) interference and the cellular-to-D2D (C2D) interference. The BS can mitigate these interferences using power control and resource allocation. In [2], a method to control the maximum transmit power of D2D transmitter has been proposed in order to suppress the D2C interference. A power optimization has been performed in [3] and [5] to maximize the sum rate of the cellular and D2D links considering the interference in both directions. In [6], a resource allocation method that can minimize the interference has been proposed. In [7], the authors discuss an algorithm to optimize the resource allocation, in which D2D links can reuse the resources of more than one cellular user. All of these works have focused on the D2C interference, and they are based on a channel-based resource allocation. In the channel-based resource allocation, the BS needs to know the channel state information (CSI) of all involved links, which increases the complexity and signaling overhead of the system. Recently, there have been some works that paid attention to the C2D interference and resource allocation based on the distance between nodes [8,9]. In [8], in particular, a distance-constrained resource-sharing criterion (DRC) was proposed for the BS to select a cellular resource to be

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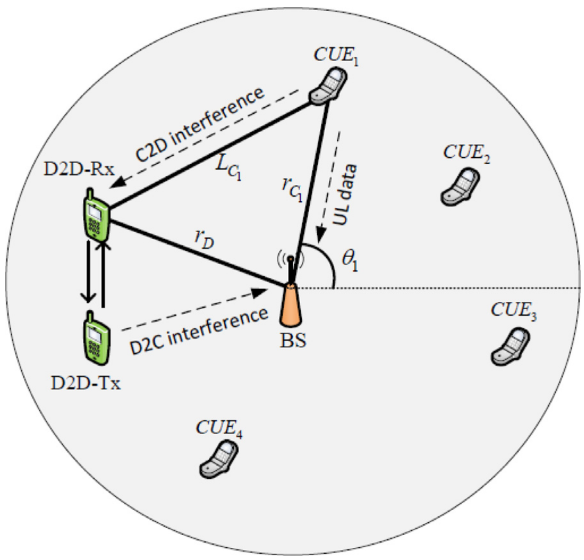

Fig. 1. System model of D2D communications underlaying a cellular network – an example with $N = 4$ active cellular users and one D2D pair.

shared with a D2D link, such that the C2D interference is controlled by keeping a minimum distance between them.

The distance-based resource allocation schemes are more simple and practical for D2D communications than the channel-based ones. Moreover, it is necessary to guarantee reliability of D2D communications by dealing with the C2D interference so that the D2D communication system underlaying a cellular network is advantageous. Therefore, we consider distance-based resource allocation to mitigate the C2D interference and focus on only the uplink interference from the cellular users to the D2D receivers. In a prior work [10], the authors have presented the outage probability analysis and proposed an improved distance-based resource allocation scheme, in the case when each D2D pair shares radio resource with one cellular user. In this paper, we elaborate the idea in [10] and extend the result to the case where three users share the same resource. In particular, we consider the case in which the BS supports two D2D pairs that could share resource with one cellular user simultaneously. In that case, one D2D receiver would experience interference from the cellular user and the other D2D transmitter. We derive closed-form expressions for the outage probability of these D2D links, and propose various criteria for the BS to choose the most appropriate cellular resource for them. We present the performance improvement of the proposed scheme over the previously proposed scheme in terms of the average outage probability of the D2D link.

The rest of this paper is organized as follows. Section 2 describes the system model of D2D communications underlaying a cellular network. In Section 3, a resource allocation algorithm is proposed first for the case of one D2D pair, and then it is extended to the case of two D2D pairs. Moreover, we will discuss how to further extend the algorithm for two D2D pairs to the general case of the arbitrary number of D2D pairs. The resource allocation algorithm is developed based on the derivation of the outage probability of each D2D link, conditioned on the location of a cellular user. Section 4 presents and discusses numerical results. Finally, conclusion is drawn in Section 5.

2. System and channel models

We first consider the scenario as illustrated in Fig. 1, where the BS is located in the cell center and cellular user equipments (CUEs) are uniformly distributed over the cell area. We assume that there is one D2D pair and N cellular users, though the scenario where there are more than one D2D pair will be discussed in Section 3.2. For any cellular user, the probability density function (PDF) of its distance r_C from the BS is $f(r_C) = \frac{2r_C}{R^2}(r_C \in (0, R])$, while the angle θ between the x-axis and the line from the BS to the cellular user is uniformly distributed over $[0, 2\pi)$. D2D communications underlaying a cellular network will be limited to local traffic, and application utilizing D2D communications should be designed accordingly [2]. Thus, we assume that D2D transmitter (D2D-Tx) and D2D receiver (D2D-Rx) are close to each other. In addition, we assume that the D2D link uses the uplink resource of the cellular system, since it is accepted to be more practical than the downlink resource [11]. Then, the D2D pair should be near the cell edge [12]. The BS will choose radio resource of a particular CUE_i among the N cellular users randomly distributed over the cell for sharing with the D2D pair. For example, in Fig. 1, D2D-Rx is receiving data from D2D-Tx under the interference from CUE_1's uplink transmission. L_{C_1} denotes the distance corresponding to the C2D interference link between CUE_1 and D2D-Rx. In general, the distance L_{C_i} between the CUE_i and D2D-Rx is given as

$$L_{C_i} = \sqrt{r_{C_i}^2 + r_D^2 - 2r_{C_i}r_D\cos\theta_i}. \tag{1}$$

It should be noted that the distance ρ between the D2D-Tx and D2D-Rx should be kept small so as to lower the power consumption of user equipments, which is one of primary reasons of enabling D2D links in cellular systems. For instance, the authors in [2] suggest 50 m of D2D transmission range in a macro-cell with the radius of 500 m, according to which the D2D transmitter and receiver are assumed to be in proximity if the distance between them is less than 10% of the cell radius. We focus to deal with the C2D interference rather than the D2C interference. The reason is that the victim of D2C interference is the base station when the uplink resources are shared. Since the range of D2D links is usually small, the power level required for a D2D link will be much lower than that for the cellular uplink which uses the same resources. Moreover, the BS will have more capability of managing the D2C interference. Therefore, the D2C interference can be negligible, whereas the C2D interference is crucial.

When CUE_i share the same resource with the D2D pair, the received signal at the D2D-Rx can be expressed as

$$y_i = h_D\sqrt{P_D\rho^{-\alpha}}x_D + h_{C_i}\sqrt{P_{C_i}L_{C_i}^{-\alpha}}x_{C_i} + n_0, \tag{2}$$

where x_D denotes signal transmitted from D2D-Tx, x_{C_i} is the uplink signal that CUE_i transmits to the BS, h_D and h_{C_i} stand for fading coefficients in the D2D link and the CUE_i to D2D-Rx link, respectively, both following the independent complex Gaussian distribution, P_D and P_{C_i} are the transmit power of the D2D-Tx and CUE_i, respectively, α is the path-loss exponent, and n_0 represents the additive white Gaussian noise (AWGN). Therefore, depending on which CUE_i is selected, the SINR at the D2D-Rx is given as [8]

$$\gamma_{D_i} = \frac{|h_D|^2 P_D\rho^{-\alpha}}{\left|h_{C_i}\right|^2 P_{C_i}L_{C_i}^{-\alpha} + N_0}. \tag{3}$$

where N_0 denotes the variance of the AWGN. A fixed signal-to-noise ratio (SNR) target η/N_0 is assumed to be adopted for the D2D link, where $\eta = P_D\rho^{-\alpha}$ denotes the received signal power at the D2D-Rx. We also assume that a target SNR power control scheme is employed for the uplink transmission of a cellular user [6]: the uplink transmit power of CUE_i is adjusted to provide a fixed SNR target ξ at the BS as [8]

$$\xi = \frac{P_{C_i}}{N_0 r_{C_i}^{\alpha}}. \tag{4}$$