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Performance Improvement of Device-to-Device (D2D) Communications Underlaying Uplink Cellular Networks

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Abstract

Device-to-Device (D2D) communications underlaying cellular networks is a viable network technology that can potentially increase spectral utilization and improve power efficiency for proximity based wireless applications and services. However, a major challenge in such deployment scenarios is the interference caused by D2D links when sharing the same resources with cellular users. This work deals with the performance improvement of Device-to-Device (D2D) communications underlaying uplink cellular networks, where we aim to optimize the sum-rate of D2D communications

Keywords: Power control, device-to-device communication, cellular networks, Poisson point process, sum-rate.

1. Introduction

Device-to-Device (D2D) communication is a technology component for Long Term Evolution Advanced (LTE-A) of the Third Generation Partnership Project (3GPP) [1]. In D2D communication, cellular users (CUs) in close proximity can exchange information over a direct link rather than transmitting and receiving signals through a cellular base station (BS). D2D users communicate directly while remaining controlled under the BS. Compared to routing through a BS, CUs at close proximity can save energy and resources when communicating directly with each other. Moreover, D2D users may experience high data rate and low transmission delay due to the short-range direct communication [1]. Reducing the network load by offloading cellular traffic from the BS and other network components to a direct path between users is another benefit of D2D communication reduce the network load and increase its effective capacity. Other benefits and usage cases are discussed in [2].

1.1 Related Work

There has been considerable interest in power control techniques for D2D underlaid cellular networks. A simple power control scheme was proposed in [3] for a single-cell scenario and deterministic network model, which regulates D2D transmit power to protect the existing cellular links. To maximize the sum rate of the network, a D2D transmit power allocation method was proposed in [4] for the deterministic network model. A dynamic power control mechanism for a single D2D link communication was proposed in [5], which targets improving the cellular system performance by mitigating the interference generated by D2D communication. The main idea was to adjust the D2D transmit power via base station (BS) to protect cellular users. In [6], a power minimization solution with joint subcarrier allocation, adaptive modulation, and mode selection was proposed to guarantee the quality-of-service demand of D2D and cellular users.

In this paper, we improve power control method along with channel allocation and analyze their performance assuming a random D2D underlaid cellular network model. In our work, we study a general scenario by randomly modeling the distance between the D2D pairs, each D2D transmitter selects its transmit power based on the channel conditions, namely the distance-based path-loss between d2d pairs, so as to maximize its own D2D link rate, varying the SINR targets, and consider one cellular users sharing the resources with the D2D links.

The remainder of this paper is organized as follows. In Section II, the proposed model for D2D underlaying cellular networks is described. In Section III ,the D2D distributed power control scheme. In Section IV, the simulation results, which are followed by our conclusions in Section V.

2. System model

In this section, we present the system model and describe network metrics that will be used in this paper.

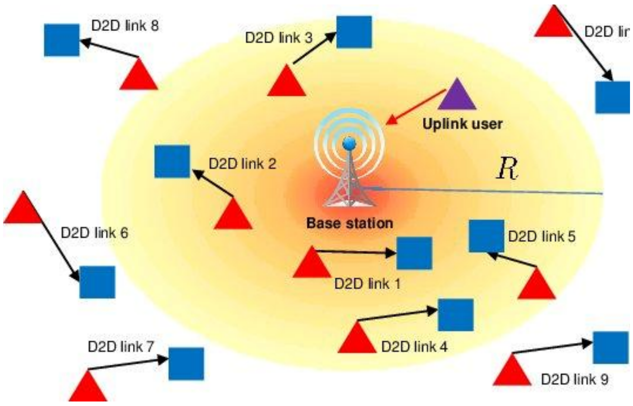

Fig. 1. A single-cell D2D underlaid cellular system

We consider a D2D underlaid cellular network, as shown in Fig. 1. In this model, let the circular disk C with radius R denotes the coverage region of a BS centered at the origin. $\mathcal{M}$ is the number of cellular uplink user is uniformly located in this region. Further, $\mathcal{k}$ is the number of D2D users, we assume its locations are distributed in the whole $\mathbb{R}^2$ plane according to a homogeneous PPP Φ with density λ. The associated receiver with a D2D transmitter is located at a variable distance away with isotropic direction. We assume all nodes have one antenna.

Under the given assumptions, the number of D2D transmitters in C is a Poisson random variable with mean E[K] = λπR2.Given a particular realization of the PPP Φ.

3. D2D distributed power control schemes

In this PC scheme, each D2D transmitter selects its transmit power based on the channel conditions, namely the distance-based path-loss $d_{k,k}^{-\alpha}$ so as to maximize its own D2D link rate.

The $\mathcal{k}$th D2D TX can only use transmit power p_k with transmit probability $\mathcal{P}_{\text{tx}}$, if the channel quality of the $\mathcal{k}$th D2D link is favorable, the transmit probability is given by :

$$\mathcal{P}_{\text{tx}} \triangleq \mathbb{P}\left[\left|h_{k,k}\right|^2 d_{k,k}^{-\alpha} \geq \beta_{min}\right] \approx exp\left(-\beta_{min}\, \mathbb{E}\left[d_{k,k}^{\alpha}\right]\right) \qquad (1)$$

Furthermore, an estimation error margin ε is introduced to compensate for the error in estimating the distance between the D2D pairs. Hence, the proposed power allocation, based on the channel inversion for the D2D link, is given by

$$p_k = \begin{cases} p_{rx} d_{k,k}^{\alpha}(1+\varepsilon) & with\ \mathcal{P}_{\text{tx}} \\ 0 & with\ 1-\mathcal{P}_{\text{tx}} \end{cases} \qquad (2)$$

where $d_{k,k}$ is the distance between the $\mathcal{k}$th D2D pairs, α is the path-loss exponent, and ε is the estimation error margin of $d_{k,k}^{\alpha}$, such that 0 ≤ ε ≤ 1.

The D2D coverage probability in the interference-limited regime (where noise variance $\sigma_2 = 0$, and $SINR_k$ reduces to SIR_k) is given by

$$\rho_{con,D}(\beta_k) = \mathbb{E}_{d_{k,k}^{\alpha} p_k^{-1}}\left[\exp\left(-\theta_k\left(d_{k,k}^{\alpha} p_k{}^{-1}\right)^{2/\alpha}\right) \times \mathbb{E}_{k,cm}\left[exp\left(-\beta_k\left(d_{k,k}^{\alpha} p_k{}^{-1}\right)\left|h_{k,c_m}\right|^2 d_{k,c_m}^{-\alpha} p_0\right)\right]\right] \qquad (3)$$

$$= \mathbb{E}_{d_{k,k}^{\alpha} p_k^{-1}}\left[\exp\left(-\theta_k\left(d_{k,k}^{\alpha} p_k{}^{-1}\right)^{2/\alpha}\right) \times \mathbb{E}_{k,cm}\left[\frac{1}{1+\beta_k \frac{p_0}{p_k} d_{k,k}^{\alpha} d_{k,c_m}^{-\alpha}}\right]\right]$$

From the SIR distribution of the D2D link given in (3) with $\sigma_2 = 0$, the ergodic rate of the typical D2D link is generally expressed as

$$\Re_{D2D} = \int_0^{\infty} log(1+x)\frac{\partial}{\partial x}\left[\mathbb{P}[SIR_k \geq x]\right]d_x \approx \int_0^{\infty} \frac{1}{1+x}\rho_{con,D(x)}\, d_x$$

$$\approx \int_0^{\infty} \frac{exp\left(-\frac{\pi\lambda x^{2/\alpha}\,\mathbb{E}\left[p_k{}^{2/\alpha}\right]\left(\left(d_{k,k}^{\alpha} p_k{}^{-1}\right)\right)^{2/\alpha}}{sinc(2/\alpha)}\right)}{(1+x)\times\left(1+\left(\frac{p_0}{d_{k,k}^{-\alpha} p_k}\right)^{2/\alpha} \mathbb{E}\left[d_{k,c}\right]^{-2}\right)} dx \qquad (4)$$

From the ergodic sum rate of D2D links, we optimize the D2D PC threshold β_{min} by maximizing the derived transmission capacity of D2D links, which is given as

$$\mathcal{R}_s^D(\beta_k) = \frac{q\pi\gamma\mathcal{P}_{\text{tx}}R_C^2 log2(1+\beta)}{1+\left(\beta_k \frac{p_0}{\mathfrak{p}_{rx}(1+\varepsilon)}\right)^{2/\alpha}\left(\frac{5\ 12R}{4\ 5\pi^2}\right)^{-2}} \times exp\left(-\frac{\pi\lambda{\beta_k}^{2/\alpha}}{sinc(2/\alpha)}\mathbb{E}\left[{p_k}^{2/\alpha}\right]\left(\mathfrak{p}_{rx}(1+\ \varepsilon)\right)^{-2/\alpha}\right) \approx \frac{q\pi\lambda R_C^2 log2(1+\beta)}{1+\kappa{\beta_k}^{2/\alpha}} \times exp\left(-\frac{\pi\lambda{\beta_k}^{2/\alpha}}{sinc(2/\alpha)}\frac{R_D^2}{2}\right) \quad (5)$$

where $\kappa = \left(\frac{p_0}{\mathfrak{p}_{rx}(1+\varepsilon)}\right)^{2/\alpha}\left(\frac{5\ 12R}{4\ 5\pi^2}\right)^{-2}$ and $\lambda = q\gamma\mathcal{P}_{\text{tx}}$

4. Simulation Results and Discussion

In this section, we provide numerical results for the D2D underlaid cellular network. First, in the fig 2 we show how the Path-loss exponent (α) and the Target SINR threshold (β) affect on the transmission capacity of the D2D links. where we vary the control parameter (α) ,As (α) creases from 16 to 64, the transmission capacity of the D2D links increases So as to diminished interference from users D2D Others and cellular users, thus the interference at the cellular users and at the other D2D users will be even more diminished.

in the fig 3 we show how the estimation error margin ε and the distance between the D2D pairs affect on the power transmission of the D2D links. where we vary the the estimation error margin ε ,As (ε) creases from 0 to 1, the power transmission of the D2D links increases .

Table I. Simulation Parameters

Parameter	Value
Cell radius (RC)	500m
Max. D2D link range (RD)	50m
Min. D2D link range (Rmin,D)	5m
D2D link density (λ)	20/(pi*1500^2)
Average # D2D links (K)	$E[K] = \pi\lambda R^2$
Path-loss exponent (α)	Varies from 16 to 64
Target SINR threshold (β)	varies from 0 dB to 10 dB
Max. TX power of cellular user	$P_{max,C}$= 100 mW
Max. TX power of D2D user [13]	$P_{max,D}$= 0.1 mW
Estimation margin ε	Varies from 0 to 1
sensitivity $\mathfrak{p}_{rx}$	$\mathfrak{p}_{rx} = P_{max,D}R_D^{-\alpha}$

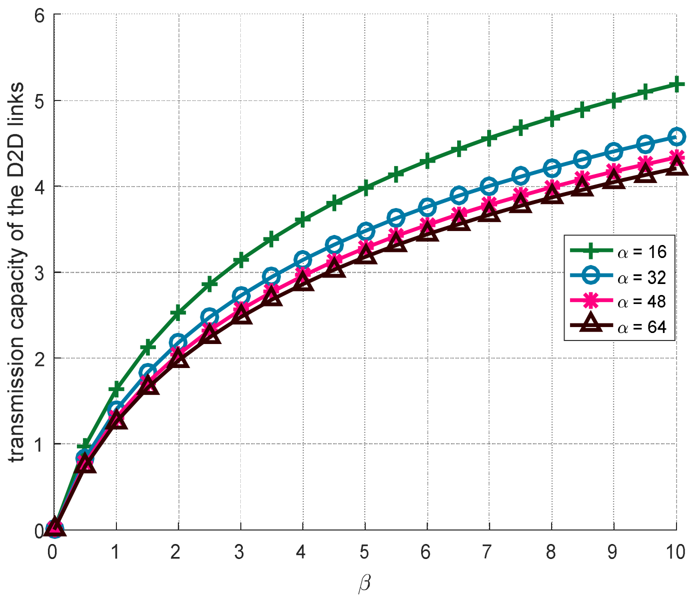

Fig. 2. Transmission capacity of D2D links versus the Target SINR threshold (β) for different Path-loss exponent (α)

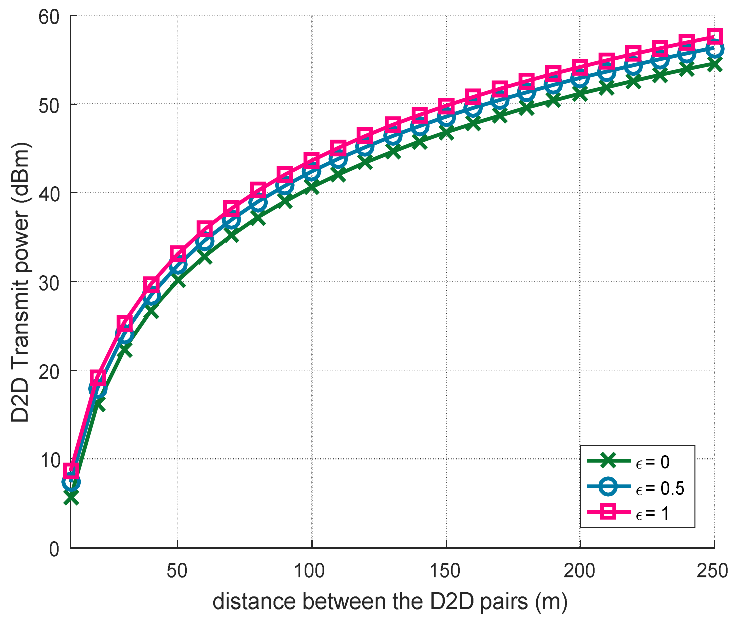

Fig. 3. D2D transmit power versus distance between the D2D pairs for different estimation error margin (ε).

5. Conclusions

In this article, we have studied the transmission capacity of D2D links and the distributed transmission power D2D. From the results that we have concluded, the approach of path loss exponents leads to improving the transmission capacity of the performance of D2D links due to the proven control of the interference levels of the additional underlying D2D links. Meanwhile, the approach to the estimation margin of error based on distance, it also improves the control of the distributed power.

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