Research on the Cellular User's available Communication Radius in Overlaid Device to Device Systems*

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Abstract - D2D technology is introduced as IMT-Advanced system. D2D communication and cellular communication may be orthogonally or multiplexed shared by the authorization band of the IMT-advanced system, and sharing resource will cause interference. In this paper, we analyse the scenario that D2D UEs reuse the resource allocated to cellular UEs in the uplink period, which will be interfered by D2D UEs at the BS. In addition，when more than one D2D users reuse the same resource, it will cause aggregate interference. Based on the established scenario and using the random geometric and the information theory, we obtain mutual quantitative restriction correlation of the cellular user successful communication radius,D2D user density and throughput of cellular user under the condition of lowest throughput and communication interruption probability of cellular user.

Index Terms - Device-to-Device; Cellular Communications; Aggregate Interference.

1. Introduction

Recently, the D2D(device-to-device)technology has been proposed, it means the neighbouring terminal in close range can be directly connected to the link for data transmission, without the need for the central node (i.e., the base station) forwarding. The benefits of D2D networks include increased data rates, reduced power transmission, enhanced network capacity, better load balancing and extended coverage . D2D link exists in the cellular network, reusing the cell's spectrum resources, transmitting data through a direct link . The base station can control the allocation of resources of the UE and D2D Users [1].

Now D2D technology is introduced into IMT-Advanced system, D2D communication and cellular communication may be orthogonally or multiplexed shared the authorization band of the IMT-advanced system, sharing resource will cause interference, especially, when the D2D communication reusing the resources of the cellular network, it will cause more complex interference. In this paper, we research the situation that there is only one cellular user in the single cell, D2D UEs reuse the resource allocated to cellular UEs in the uplink period, which will be interfered by D2D UEs at the BS. In addition，when more than one D2D users reuse the same resource, it will cause aggregate interference. Based on the established scenario and using the random geometric and the information theory, we obtain mutual quantitative restriction correlation of the cellular user successful communication radius,D2D user density and throughput of cellular user under the condition of lowest throughput and communication interruption probability of cellular user.

2. System model and analysis

we design the D2D coexistence scene shown in Figure 1, The base station (eNB) is located in the centre of the circle, in a circle domain with a eNB as the centre, there are some pairs of D2D UEs in a random distribution, which are the D2D transmitter $D2D_{Ti}$ and receiver $D2D_{Ti}$, In the figure $r_i\left(i=1,2,3...\right)$ represents the distance between the D2D transmitter $D2D_{Ti}$ and the eNB, the radius R of the circle which means that the distance between the CU and the base station, i.e. the communication radius of CU. Within the circle, several $D2D_T$ randomly scattered around the base station multiplexing the cellular uplink resource , the $D2D_{Ti}$ will cause interference to eNB when the eNB is receiving signals.

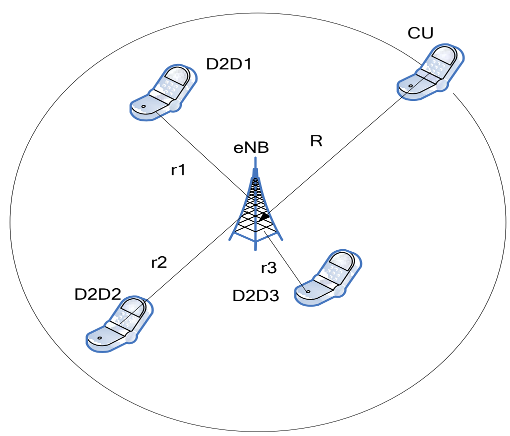

Figure1 D2D coexistence system model

Under the condition of fixed transmission power of CU and D2D UE, if there only a few D2D UEs in the cell, it will cause smaller interference to eNB, in this case the eNB can receive signals which are far away from eNB, therefore the CU's communication radius becomes bigger. On the other

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hand, if there are many D2D UEs in the cell, it will cause serious interference to eNB receiving and the CU's successful communication radius will decrease. As a result ,the CU's successful communication radius changes with the number of D2D UEs.

For convenience of discussion, we only consider the path loss between the transmitter and receiver, the path loss function is

$$L(d) = \frac{1}{d^{\alpha/2}} \quad (1)$$

d is the distance between the transmitter and receiver, α is the path loss factor. We assume that P_{CU} is the transmission power of cellular users and all D2D UE's transmission power is P_D .And the noise is additive white Gaussian noise ,its power is σ^2 .

From the above analysis, the D2D user will cause interference to base station receiving, in order to ensure the quality of cellular communication, it must satisfy the following formula

$$P\left[C_{CU} \le C_0\right] \le \Theta \quad (2)$$

Where Θ and C_0 is predetermined constant, Θ is upper limit of cellular communication system outage and C_0 is lower limit of system throughout. To ensure the quality of cellular communication, it must satisfy the following formula (2). The interference power of all D2D transmitters in the cell to base station is:

$$I = \sum_{i=1}^{n} I_i = \sum_{i=1}^{n} P_D \left|h_{D_i 2BS}\right|^2 \quad (3)$$

And

$$I_i = P_D \left|h_{D_i 2BS}\right|^2 = P_D \frac{1}{r_i^{\alpha}} \quad (4)$$

h_{C2BS} is the channel gain between CU and eNB, h_{D2BS} is the channel gain between $D2D_{T_i}$ and eNB, according to the classic Shannon formula we can calculate the throughput of CU as follows：

$$C_{CU} = lb\left(1 + \frac{P_{CU}\left|h_{C2BS}\right|^2}{I + \sigma^2}\right) \quad (5)$$

Take (5) into (2) we can know

$$\varepsilon = \mathrm{P}\left[lb\left(1 + \frac{P_{CU}\left|h_{C2BS}\right|^2}{I + \sigma^2}\right) \le C_0\right] \le \Theta \quad (6)$$

Where ε is the probability that the cellular communication interrupt when its throughout is less than C_0 caused by interference.

3. Analysis of the interference to the eNB receiving caused by D2D users inside the cell

3.1 The scenario with a single D2D user

Firstly, we take a simple scenario as show in figure 2 into consideration. The base station is located in the center of the circle, the distance between CU and eNB is R. There is only a pair of D2D users in the cell with the radius of R:a D2D transmitter($D2D_T$)and a D2D receiver($D2D_R$).Next, we discuss the interference to the uplink throughput of base station caused by D2D users in different location.

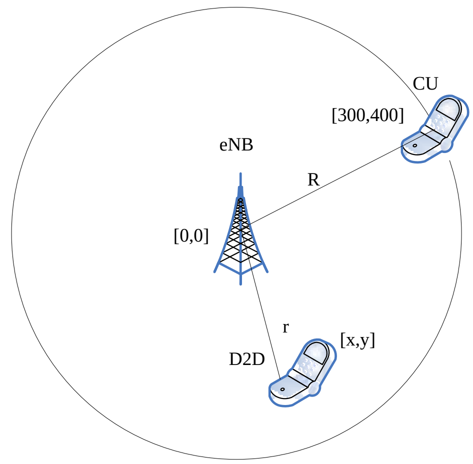

Figure 2 the scenario with a single D2D user

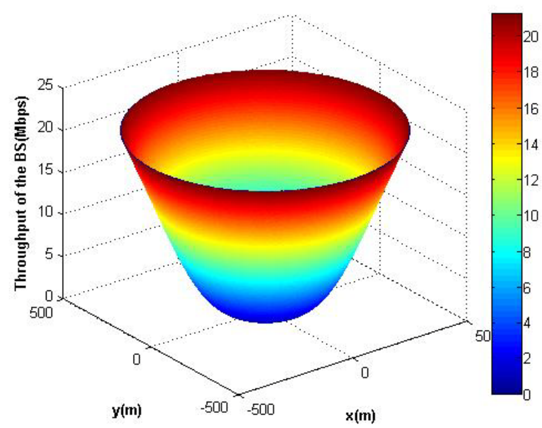

figure 3 the performance curve of the throughput of the cellular system as D2D users located in different locations.

Figure 3 shows the performance curve of the throughput of the cellular system, xy axis indicate the location of the D2D users, z axis shows the throughput of the system. The coordinate of the base station and the uplink cellular user are [0,0]and [300,400](m).We assume that the transmission power of cellular users and D2D users are 20dbm and 17dbm.We can infer from the figure that more interference there will be and the throughput of the system will be lower if the D2D user is closer to the base station.

3.1 The scenario with multiple D2D users

In the scenario researched by this paper, the location of the D2D transmitter is random in the cell and the number of the D2D transmitter (N_D) has relationship with the radius of the cell(R).Assumes that the base station eNB is only interfered by the transmitters($D2D_T$) of D2D users inside the cell. N_D , the number of the $D2D_{T_i}$ can be represented as:

$$N_D = \lambda \pi R^2 \tag{7}$$

λ is the density of the transmitters of D2D users, the distance between $D2D_{T_i}$ and the base station is d_i ,and its pdf is:

$$f_d(d) = 2d/R^2 \quad 0 < d < R \tag{8}$$

The expectation value of d_i is :

$$E[d] = \int_0^R d\, f_d(d) = \frac{2}{3}R \tag{9}$$

Considering equation (1) and λ, we can get the expectation value of interference to the receivers in the cell caused by D2D transmitters:

$$E[I] = \lambda \frac{P_D}{\left\{\left[\int_0^R d\, f_d(d)\right]^{\alpha/2}\right\}^2} = \frac{\lambda P_D}{\left(\frac{2}{3}R\right)^{\alpha}} \tag{10}$$

Based on equation (10), we can analyse the relationship between $E[I]$ and R, λ .Assumes that $P_D = 1, \alpha = 4$,the relationship between $E[I]$ and R is showed in Figure 4 as λ takes a series of different values.

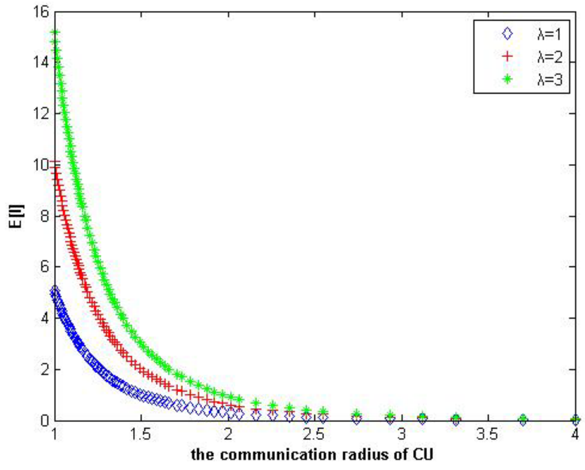

Figure 4 the relationship between interference power and the density of D2D users λ ,the communication radius of CU

In figure 4, we can see that when the interfering power $E[I]$ is reduced gradually, the radius of cellular communication, R, will increase. In other words, the smaller the interfering power from the D2D transmitter to the BS is, the larger the radius of available cellular communication is. When $E[I]$ tends to zero, R will reach the maximum limit. As there exists AWGNs in the channel, R will reach a certain value not infinite. In the figure, we can also see that the interfering power is larger if the density of D2D user nodes is higher.

4. The Analysis of the Radius of Available Cellular Communication

Under the condition of no D2D users exist, there is only the interference of AWGN between cellular user and BS. At this moment, if the transmission power of D2D transmitter is assumed to be a fixed value P_D , the radius of available cellular communication R will reach the maximum value. From Equation (6) we know,

$$R \le \left(\frac{P_D}{\sigma^2\left(2^{C_0}-1\right)}\right)^{1/\alpha} \tag{11}$$

Under the condition of D2D user existing, due to the interference from D2D transmitter, the radius of available cellular communication will decrease somewhat. If C_0 is set to a fixed value by the system, Equation (2) can be rewritten as

$$\begin{aligned}\varepsilon &= \mathrm{P}\left[lb\left(1+\frac{P_{CU}|H|^2}{I+\sigma^2}\right) \le C_0\right] \\ &= \mathrm{P}\left[I \ge \frac{P_{CU}/R^{\alpha}}{2^{C_0}-1} - \sigma^2\right]\end{aligned} \tag{12}$$

At this moment, we introduce the Markov inequality [5], if X is a nonnegative random variable, there is

$$P_r\left(|X| \ge a\right) \le \frac{E\left(|X|\right)}{a} \tag{13}$$

According to the Markov inequality, Equation (12) can be rewritten as

$$\varepsilon \le \frac{E[I]}{\frac{P_{CU}/R^{\alpha}}{2^{C_0}-1} - \sigma^2} \tag{14}$$

Synthesize Equation (6) and Equation (14) and then we can achieve

$$\frac{E[I]}{\frac{P_{CU}/R^{\alpha}}{2^{C_0}-1} - \sigma^2} \le \beta \tag{15}$$

Substitute Equation (10) into Equation (5) and after simplification, we can reach

$$R \le \left\{ \frac{1}{\sigma^2} \left[\frac{P_{CU}}{2^{C_0} - 1} - \frac{\lambda P_D}{\left(\frac{2}{3}\right)^{\alpha} \beta} \right] \right\}^{1/\alpha} \quad (16)$$

According to Equation (16), we can derive the relationship among the radius of available cellular communication, the transmission power of cellular user and the density of D2D user nodes, as shown in figure 5.

From figure5, with the increase of cellular user communication radius, the transmission power of cellular user P_{CU} increases, under the same communication radius, when the density of D2D user becomes larger, the transmission power of CU also can become big, because when the interfering signal increases, the cellular users require higher transmit power to ensure that cellular communication quality, and in the case of the same transmission power, communication will become smaller with the increase of the radius.

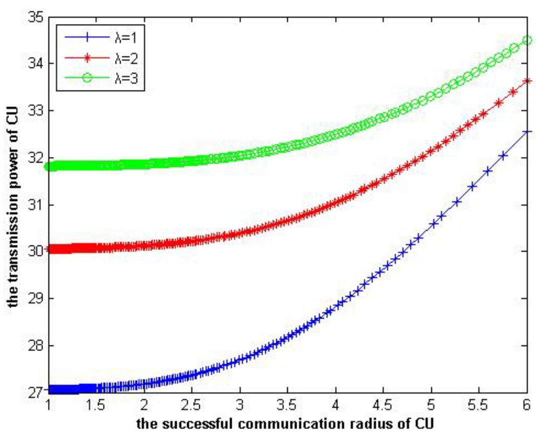

Figure 5 the relationship between the transmission power of CU and the successful communication radius of CU, the density of D2D user,

From the formula (15) and the analysis above we can find that: the interaction relation between CU communication radius R、the density of D2D user and throughput of cellular system is shown in Fig 6.

From Fig6,when the λ is fixed, with the increase of cellular user communication radius, C_0 would decrease, as the SIR of the base station decrease, and it is shown that the throughput of cellular system decrease from formula (5)、（6）.

5. Summarize

D2D technology is introduced into IMT-Advanced system, when D2D users multiplex cellular uplink resources, D2D transmitters can cause interference to eNB receiving, when more than one D2D users to reuse the same resources, it can produce aggregate interference and cause serious interference to cellular and affect cellular communication. Based on the established scenario and using the random geometric and the information theory, we obtain mutual quantitative restriction correlation of the cellular user successful communication radius,D2D user density and throughput of cellular user under the condition of lowest throughput and communication interruption probability of cellular user.

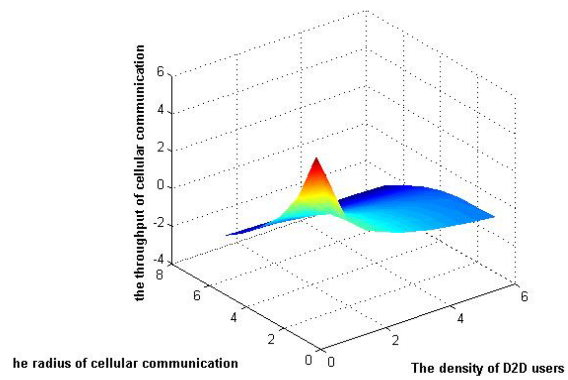

Figure 6 the relationship between R, λ and the throughput of CU

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