Resource Allocation Optimization for Device-to-Device Communication Underlaying Cellular Networks

Bin Wang, Li Chen, Xiaohang Chen, Xin Zhang, and Dacheng Yang
Wireless Theories and Technologies (WT&T)
Beijing University of Posts and Telecommunications (BUPT)
Beijing, 100876, China
Email: wangbinfgb@gmail.com, alibupt@gmail.com

***Abstract*—Device-to-Device (D2D) communication will become an important technology in future networks with the increase of the requirements of local communication services. The interference between cellular communication and D2D communication can be coordinated by proper power control and resource allocation. In this paper, we analyze the resource allocation methods for D2D communication underlaying cellular networks. A novel resource allocation method that D2D can reuse the resources of more than one cellular user is proposed. After that, we discuss the selection of the optimal resource allocation method from the proposed method and the conventional methods. Finally, the performance of different methods is evaluated through numerical simulation. The simulation results show that the proposed method is the optimal resource allocation method when the D2D pair locates at the most part of the cell area in both uplink and downlink. The proposed method can improve the sum throughput of cellular communication and D2D communication significantly.**

Keywords-Device-to-Device (D2D), resource allocation, cellular networks, spectral efficiency, energy efficiency.

I. INTRODUCTION

With the application of different kinds of multimedia services, such as mobile TV, video phone, etc. there is an increasing requirement for higher data rate transmission. But the spectrum below 5 GHz is already congested. The spectrum which is allocated to mobile communication systems must be used efficiently to meet the requirement of high data rate. 3GPP [1] proposes that the peak data rate will achieve downlink (DL) 100Mbps and uplink (UL) 50Mbps in Long Term Evolution (LTE) system. In order to fulfill the requirement of data rate, LTE adopts some advanced technology, e.g. MIMO, COMP, and relay, which can increase the spectral efficiency.

There is also an increasing requirement for local communication, such as games between mobile phones, video sharing, and information broadcast in hot point area like market. Machine to Machine [2] communication in small distance in the Internet of Things also becomes a hot topic, which is a local communication technology. The Device-to-Device (D2D) communication described in [3] can increase system throughput by reusing the resource of the cellular user. The interference between cellular communication and D2D communication can be coordinated by proper power control and resource allocation. The D2D communication reduces the transmit power of terminal, which increases the working time of terminal and improves the energy efficiency. The D2D communication can also decrease the load of base station (BS) via direct transportation. Besides, the D2D communication has the advantage that licensed spectrum is allocated to local communication. Licensed spectrum can guarantee a planned environment instead of an uncoordinated one. D2D needs new communication mechanisms, because of the difference with the conventional cellular communication. In [4], the mechanisms for D2D communication session setup and management involving procedures in the LTE System Architecture Evolution are proposed.

The BS is capable of coordinating the interference between cellular communication and D2D communication by proper power control and resource allocation with the channel state information (CSI) of all involved links. In [5], a resource allocation method that can minimize the system interference has been proposed, there were N cellular users and N D2D pairs, and one D2D pair reused the resource of only one cellular user in the system model. In [6] they discussed three D2D resource allocation methods and the power optimization when there was only one cellular user and one D2D pair. In [7] they discussed the mode selection method on the basis of [6]. Two mechanisms were proposed to coordinate the mutual interference between cellular communication and D2D sub-systems in [8]. In [9] time hopping (TH) based radio resource allocation schemes aiming to improve the robustness of the hybrid network were proposed. However, in all of these references, one D2D pair reused the resource of only one cellular user whenever there was one or more cellular user in the system.

In actual networks, cellular users are more than D2D pairs generally, so the spectrum is not used efficiently when one D2D pair reuses the resource of only one cellular user. In this paper, we propose a resource allocation method when there are more than one cellular user in the system. One D2D pair can reuse the resources of more than one cellular user. The proposed method can increase the data rate of D2D communication and the spectrum efficiency with giving priority to the cellular user. After that, we apply the proposed method to resource allocation optimization for D2D communication underlaying cellular networks. We present the improvement of sum throughput of cellular communication and D2D communication by using the proposed method compared with the method that one D2D pair reuses the resource of only one cellular user.

The rest of this paper is organized as follows. Section II describes the system model of D2D communication underlaying cellular networks. The algorithm used in the proposed resource allocation method is discussed in Section III. The algorithm for resource allocation optimization is also presented in this section. Section IV presents and discusses the numerical results. Finally, conclusion is drawn in Section V.

II. System Model

The system model includes a single cell environment as illustrated in Fig. 1, where *N* cellular users are *R* far away from the BS. We assume there is one D2D pair shares the available radio resources with those *N* cellular users. Similar analysis can be used for the scenario with more than one D2D pair. The distances between the BS and both of the D2D users are *D*. The distance between the two D2D users is *L*.

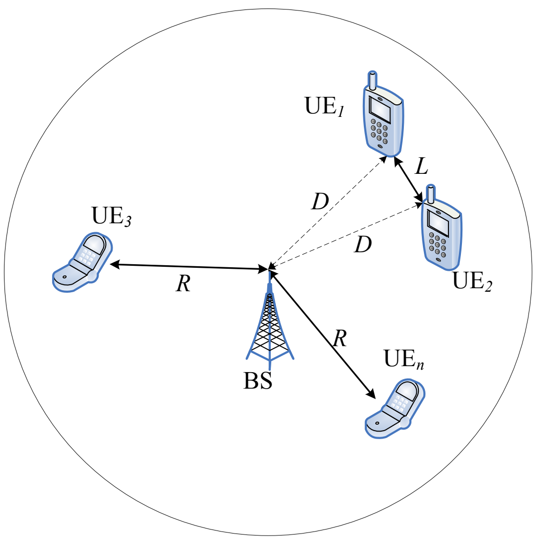


Figure 1. System model of D2D communication underlaying cellular networks.

We assume that the BS has the CSI of all involved links. The available resources are allocated to the cellular users and the D2D pair based on the CSI. We propose a novel resource allocation method that allows the D2D pair reuses the resources of more than one cellular user, which can increase the sum throughput of cellular communication and D2D communication. Thus, there are four resource allocation methods in D2D communication underlaying cellular networks, the first three methods are described in [6], and there are only one cellular user and one D2D pair in their system model. The last one is proposed by us.

- Cellular mode: The D2D users could not communicate directly. They communicate with each other through the BS like the cellular users. The resources which are shared by the D2D pair and cellular users are divided into *N*+2 parts uniformly, and every user uses one part of them in this mode.
- Dedicated resource mode: The D2D users communicate with each other with dedicated resource. There is no interference between cellular communication and D2D communication since their resources are orthogonal. There are *N*+1 orthogonal transmission links at this time. The resources which are shared by the D2D pair and cellular users are divided into *N*+1 parts uniformly, and the D2D pair uses one part of them in this mode.
- Reusing the resource of only one cellular user: The D2D pair reuses the resource of only one cellular user who incurs the smallest interference between them. The resources which are shared by the D2D pair and cellular users are divided into *N* parts uniformly, and every cellular user uses one part of them in this method. The D2D pair reuses the resource of one of the users.
- Reusing the resources of more than one cellular user: With guaranteeing a minimum transmission data rate of the cellular users, the D2D pair can reuse the resources of more than one cellular user. The resources which are shared by the D2D pair and cellular users are divided into *N* parts uniformly, and every cellular user uses one part of them in this method. The D2D pair reuses the resources of some of the users.

In the cellular and the dedicated mode, both the cellular users and the D2D pair can use the maximum transmit power to get the best system performance, because they do not interfere with each other with orthogonal resource. However, the BS should control the interference between cellular communication and D2D communication by proper power control and resource allocation when D2D reuses the resources of one or some cellular users. When D2D reuses the resources of cellular user, we give priority to the cellular user by guaranteeing a minimum transmission data rate, which can be achieved at an SINR of γ_{cl} . We also assume a minimum transmission data rate of D2D which is achieved at an SINR of γ_{dl} when D2D reuses the resource of one cellular user, otherwise D2D do not reuse the resource of this user. We assume an upper limit on the data rate based on the highest modulation and coding scheme (MCS), which can be achieved at an SINR higher than the target SINR γ_h .

III. Resource Allocation Algorithm

In this section, we study the sum throughput of cellular communication and D2D communication under different resource allocation methods, based on which, the optimal resource allocation method is analyzed. According to the system model and resource allocation methods described in Section II, by applying the Shannon capacity formula [10], the sum throughput of cellular communication and D2D communication of the four methods can be expressed as:

$$R_{cell}=\frac{1}{N+2}\sum_{i=1}^{N}\log_2(1+\frac{S_i}{N_0})+\frac{1}{N+2}\log_2(1+\frac{\min(S_m,S_n)}{N_0}) \quad (1)$$

$$R_{ded}=\frac{1}{N+1}\sum_{i=1}^{N}\log_2(1+\frac{S_i}{N_0})+\frac{1}{N+1}\log_2(1+\frac{S_{mn}}{N_0}) \quad (2)$$

$$R_{re\_1}=\frac{1}{N}\sum_{i=1,i\neq k}^{N}\log_2(1+\frac{S_i}{N_0})+\frac{1}{N}\log_2(1+\frac{S_k}{I_{dck}+N_0}) +\frac{1}{N}\log_2(1+\frac{S_{mn}}{I_{cdk}+N_0}) \quad (3)$$

$$\begin{aligned}R_{re\_n}=&\frac{1}{N}\sum_{i=1,i\neq j,...,k}^{N}\log_2(1+\frac{S_i}{N_0})\\&+\frac{1}{N}\log_2((1+\frac{S_j}{I_{dcj}+N_0})(1+\frac{S_{mn}}{I_{cdj}+N_0}))\\&+...+\frac{1}{N}\log_2((1+\frac{S_k}{I_{dck}+N_0})(1+\frac{S_{mn}}{I_{cdk}+N_0}))\end{aligned} \quad (4)$$

where S_i denotes the received power of the link between BS and UE$_i$, the receiver is BS in UL or UE$_i$ in DL. S_{mn} denotes the received power of the link between UE$_m$ and UE$_n$. I_{dcj} denotes the interference received by BS in UL or UE$_j$ in DL from the D2D communication when D2D reuses the resource of UE$_j$. I_{cdj} denotes the interference received by the D2D pair from cellular communication when D2D reuses the resource of UE$_j$. N_0 is the thermal noise power. The formulas are adapted for both UL and DL resource reusing.

A. Reusing the Resource of Only One Cellular User

By applying the Shannon capacity formula [10], the data rate of UE$_i$ without resource reusing is depicted as follows:

$$C(c)=\log_2(1+\frac{P_i \cdot g_i}{N_0}) \quad (5)$$

The sum throughput of cellular communication and D2D communication when they use the same resource is calculated as follows:

$$C(c,d)=\log_2(1+\frac{P_i \cdot g_i}{P_d \cdot g_{dc}+N_0})+\log_2(1+\frac{P_d \cdot g_d}{P_i \cdot g_{cd}+N_0}) \quad (6)$$

With giving priority to the cellular user, D2D will reuse the resource of one user, which can be determined by:

$$\begin{aligned}&k=\arg\max_j\{C(c,d)-C(c)\}\\&\text{where } j\in\{i:\gamma_{cl}\le\eta_c\le\gamma_h,\gamma_{dl}\le\eta_d\le\gamma_h\}\end{aligned} \quad (7)$$

where $\eta_c=\frac{P_i \cdot g_i}{P_d \cdot g_{dc}+N_0}$, $\eta_d=\frac{P_d \cdot g_d}{P_i \cdot g_{cd}+N_0}$, P_i and g_i denote the transmit power and channel gain of the link between BS and UE$_i$, respectively. P_d and g_d denote the transmit power and channel gain of the D2D link, respectively. g_{cd} and g_{dc} denote the channel gain of the interference link from the cellular communication to the D2D communication and that from the D2D communication to the cellular communication, respectively.

B. Reusing the Resources of More Than One Cellular User

With guaranteeing a minimum transmission data rate of cellular users, the D2D pair can reuse the resources of more than one cellular user to increase the data rate. With reusing the same resources, the SINR of the cellular communication should be higher than γ_{cl}, and the SINR of D2D communication should be higher than γ_{dl}. An SINR higher than γ_h does not increase the sum throughput because of the restriction of the highest MCS. D2D will reuse the resources of some users, which can be determined by:

$$k\in\{i:C(c,d)-C(c)>0,\ \gamma_{cl}\le\eta_c\le\gamma_h,\gamma_{dl}\le\eta_d\le\gamma_h\} \quad (8)$$

We can see that the resource reusing method will increase the sum throughput of cellular communication and D2D communication, because D2D reuse the resources of cellular users only if the sum throughput can be increased with resource reusing as shown in (8).

C. Resource Allocation Optimization

The BS allocates the resources to the cellular users and the D2D pair with the CSI of all involved links. With giving priority to the cellular user, the optimal resource allocation method is the one that can lead to the highest sum throughput of cellular communication and D2D communication, which can be expressed as follows:

$$R_{\max}=\max(R_{cell},R_{ded},R_{re\_1},R_{re\_n}) \quad (9)$$

This is the optimal resource allocation method in D2D communication underlaying cellular networks. The optimal resource allocation method is adapted for both UL and DL resource reusing. With the CSI of all involved links, the BS can maximize the sum system throughput by using the optimal resource allocation method whenever how many cellular users there are and how they are distributed in the cell.

IV. NUMERICAL SIMULATION

In this section, we resort to the numerical simulation to evaluate the performance of the optimal resource allocation method selection and the sum throughput performance of the proposed resource allocation method presented in Section III. We consider a normalized circular cell (Radius = 1). The single-slope path loss model $P(d)=P(d_0)d^{-\alpha}$ is used in the simulation, where $P(d)$ is the received power at the distance d from the transmitter, $P(d_0)$ is the received power at reference distance of d_0, and α is the path loss exponent. We assume $\alpha=4$ for all the links. $P(d_0)$ is normalized to the transmit power since we consider a normalized cellular cell. The transmit power and N_0 are both normalized so that the SINR of cellular communication is 0 dB at the cell edge without resource reusing.

We assume γ_{cl}=0dB, γ_{dl}=-10dB, γ_h=20dB [6] in both UL and DL. The sum of transmit power and antenna gain of BS is

25dB higher than that of the cellular user. We assume that the number of cellular users N is 6. The distance between BS and all the cellular users are R. The distance between BS and both D2D users are D. The D2D users are L far away from each other.

D2D can reuse UL resources or DL resources of the cellular network. We will discuss both DL and UL separately, which means that D2D reuses DL and UL resources, respectively. We consider the relationship between the optimal resource allocation method selection and the location of the transmitter of D2D in DL or the location of the receiver of D2D in UL in the following simulation. The transmit power of D2D communication when DL resources are reused is larger than the transmit power when UL resources are reused because the transmitter is the BS in DL, which has higher transmit power.

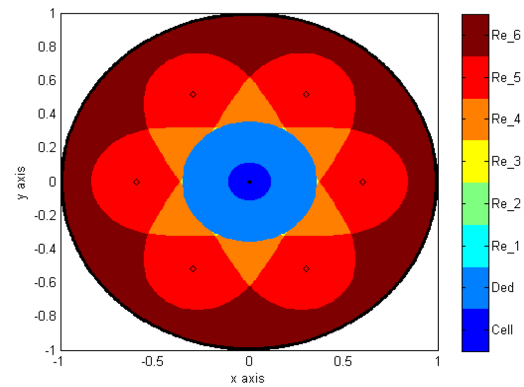
A. DL Simulation

The maximal transmit power of D2D communication is the same as cellular users when D2D reuses DL resources. The BS can reduce the interference between cellular communication and D2D communication by resource allocation and power control. We consider two scenarios: the one is that the cellular users are uniformly distributed in the cell; the other is that the cellular users congregate in some area of the cell. The performance of the optimal resource allocation method selection and the sum throughput performance of the proposed resource allocation method will be evaluated. We assume R=0.6, L=0.2. The transmitter of D2D is D far away from the BS, the receiver of D2D is D far away from the BS if $D>L/2$ or $L-D$ far away from the BS if $D<L/2$.

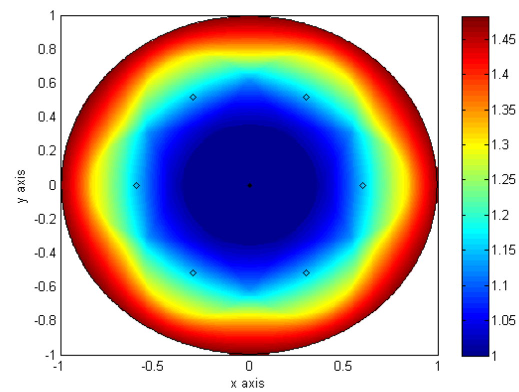
Fig. 2(a) illustrates the selection results of the optimal resource allocation method when the transmitter of D2D is distributed in different place in the cell. The color indicates the optimal resource allocation method when the transmitter of D2D is in the corresponding location. Re_n in the figure represents that D2D reuses the resources of n cellular users. The N(=6) cellular users are distributed uniformly in the cell indicated by diamonds.

We can see that the cellular mode is the optimal method when the D2D pair locates at the cell center, because the links between the BS and the D2D users are in good condition. The dedicated resource mode becomes the optimal method when the D2D pair gets farther away from the BS. D2D will reuse the resources of more than one cellular user, and the number of users whose resources are reused by D2D increases with the distance between the D2D transmitter and the BS. D2D will reuse the resources of 6 users at the cell edge. The conventional resource allocation method that D2D reuses the resource of only one cellular user never becomes the optimal method wherever the D2D pair locates. We can see that reusing the resources of more than one cellular user is the optimal resource allocation method in the most part of the cell area. We can also utilize the resource reusing method by reusing the resources of other users when D2D transmitter is very close to one of the cellular user.

Fig. 2(b) illustrates the sum throughput gain of cellular communication and D2D communication by using the proposed resource allocation method compared with the method that D2D reuses the resource of only one cellular user. The sum throughput gain is 1 when the D2D pair locates at the cell center, because D2D do not take the resource reusing mode. The sum throughput gain increases when the D2D transmitter becomes farther away from the BS. Moreover, the sum throughput of cellular communication and D2D communication by reusing the resources of more than one cellular user is 0.5 times larger than that by reusing the resource of only one cellular user. We can see that the proposed resource allocation method that D2D reuses the resources of more than one cellular user can use spectrum more efficiently.



(a)

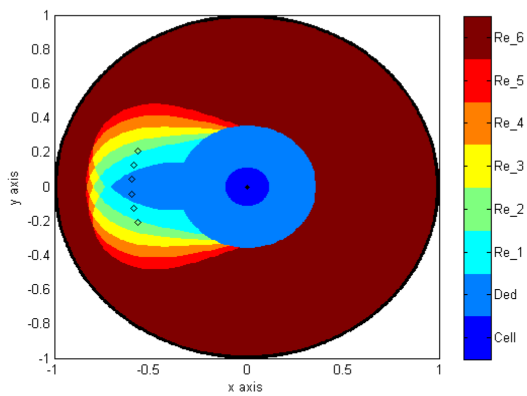


(b)

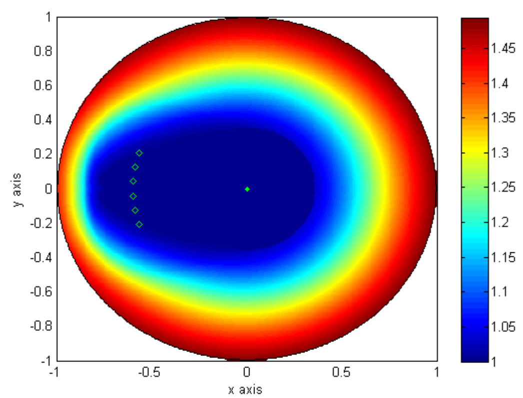
Figure 2. The N(=6) cellular users are uniformly distributed in the cell: (a) the optimal resource allocation method vs. the location of the D2D transmitter. (b) the throughput gain vs. the location of the D2D transmitter.

In the following, we study the sum throughput performance in the scenario that the cellular users congregate in some area of the cell. Fig. 3(a) illustrates the selection results of the optimal resource allocation method when the transmitter of D2D is distributed in different place in the cell when DL resources are reused. The color indicates the optimal resource allocation method when the transmitter of D2D is in the corresponding location. The N(=6) users congregate in some area of the cell indicated by diamonds. We can see that the dedicated resource mode is the optimal method when the D2D transmitter is close to the BS or the cellular users. The number of users whose resources are reused by D2D increases gradually when the D2D transmitter becomes farther away from the cellular users. The method that D2D reuses the resources of 6 users is the optimal resource allocation method in the most part in the cell.

Fig. 3(b) illustrates the sum throughput gain of cellular communication and D2D communication by using the proposed resource allocation method compared with the method that D2D reuses the resource of only one user when cellular users congregate in some area of the cell. The throughput gain increases gradually with the increase of the distance between D2D transmitter and the BS or the cellular users, and achieves almost up to 1.5 at the cell edge.



(a)



(b)

Figure 3. The N(=6) cellular users congregate in some area of the cell : (a) the optimal resource allocation method vs. the location of the D2D transmitter. (b) the throughput gain vs. the location of the D2D transmitter

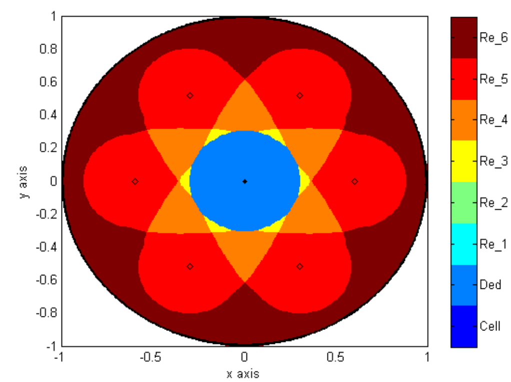
We can see that the resource allocation method that we proposed is the optimal method in the most part of the cell area whenever the cellular users are distributed uniformly or not when DL resources are reused. The proposed method will increase the sum throughput of cellular communication and D2D communication significantly.

B. UL Simulation

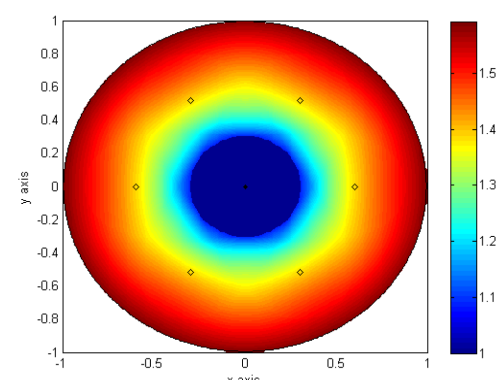
In this subsection, we simulate the performance of the optimal resource allocation method selection and the sum throughput performance of the proposed resource allocation method when the UL resources are reused by D2D pair. The transmit power of D2D communication is lower than that of the cellular users by 16dB to reduce the interference from D2D to cellular communication when D2D reuses UL resources. We assume R=0.6, L=0.2. The receiver of D2D is D far away from the BS, the transmitter of D2D is D far away from the BS if $D>L/2$ or $L-D$ far away from the BS if $D<L/2$.

Fig. 4(a) illustrates the selection results of the optimal resource allocation method when the receiver of D2D is distributed in different place in the cell. The color indicates the optimal resource allocation method when the receiver of D2D is in the corresponding location. The N(=6) users distributed uniformly in the cell indicated by diamonds. We can see that the dedicated resource mode is the optimal method when the D2D pair locates at the cell center. The number of users whose resources are reused by D2D increases gradually when the D2D receiver becomes farther away from the BS. The proposed method that D2D reuses the resources of more than one cellular user is the optimal method when the D2D pair locates at the most part of the cell area.

Fig. 4(b) illustrates the sum throughput gain of cellular communication and D2D communication by using the proposed resource allocation method compared with the method that D2D reuses the resource of only one cellular user. The sum throughput gain is 1 when the D2D pair locates at the cell center. The throughput gain increases gradually when the D2D receiver becomes farther away from the BS, and achieves more than 1.5 at the cell edge. The sum throughput gain is significantly in the most part of the cell area.



(a)



(b)

Figure 4. The N(=6) cellular users are uniformly distributed in the cell: (a) the optimal resource allocation method vs. the location of the D2D receiver. (b) the throughput gain vs. the location of the D2D receiver.

The results when the cellular users congregate in some area of the cell are similar with the results of reusing DL resources, so we do not discuss them here. We can see that the proposed resource allocation method that D2D reuses the resources of more than one cellular user is the optimal method in the most part of the cell area which is the same as the DL. The proposed method can increase the sum throughput of cellular communication and D2D communication significantly.

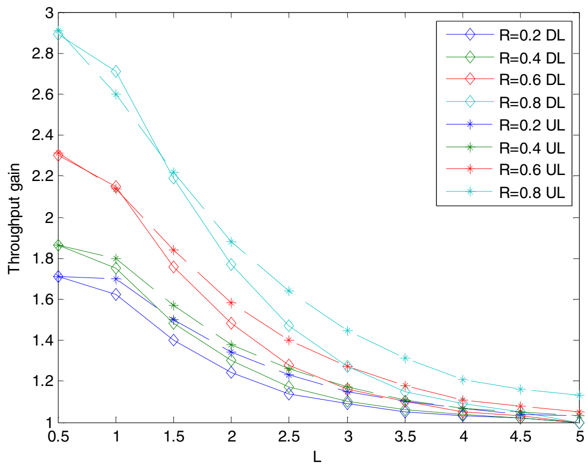


Figure 5. The throughput gain of the proposed method compared with reusing the resource of only one cellular user under different *R* and *L*.

In the following, we study the sum throughput gain performance when the D2D pair locates at the cell edge. Fig. 5 illustrates the sum throughput gain of cellular communication and D2D communication by using the proposed resource allocation method compared with the method that D2D reuses the resource of only one cellular user when D2D pair locates at the cell edge under different *R* and *L*. We can learn that the sum throughput gain decreases with the increasing of *L*, because the link of D2D becomes worse with larger *L*. D2D will not reuse DL resources if $L>0.5$. The sum throughput gain increases with *R*. The interference between D2D and the user whose resources are reused by D2D decreases with the increasing of *R,* because the distance between the D2D pair and the user becomes larger with *R*. We can see that the proposed method that D2D reuses the resources of more than one cellular user will increase the sum throughput significantly whenever D2D reuses the resources of DL or UL. The proposed resource allocation method can use spectrum more efficiently.

V. CONCLUSION

D2D is an advanced technology that can increase the spectral efficiency and energy efficiency by reusing the resource of cellular user. In this paper, we studied the resource allocation optimization for D2D communication underlaying cellular networks. We proposed a resource allocation method that D2D can reuse the resources of more than one cellular user. We assumed the BS can select the optimal resource allocation method with the CSI of all involved links. The results show that the proposed method is the optimal method when D2D locates at the most part of the cell area. The sum throughput improvement by using the proposed method is significant in both UL and DL whenever the cellular users are distributed uniformly in the cell or not. The proposed method achieves better performance when the D2D pair becomes closer to the cell edge. The sum throughput improvement is also more significant with smaller *L* and bigger *R*.

REFERENCES

[1] 3GPP TS 36.300, v9.1.0, "E-UTRA and E-UTRAN; Overall description," September 2009.

[2] R1-082813, "M2M Communications," Alcatel-Lucent, 3GPP RAN1#54, 18-22 August 2008.

[3] K. Doppler, M. Rinne, P. Jänis, C. Ribeiro, and K. Hugl, "Device-to-Device Communications; Functional Prospects for LTE-Advanced Networks," in *IEEE International Conference on Communications (ICC)*, Dresden, Germany, June 2009.

[4] K. Doppler, M. Rinne, C. Wijting, C. Ribeiro, and K. Hugl, "Device-to-device communication as an underlay to LTE-advanced networks" *IEEE Communications Magazine*, vol. 47, no. 12, pp. 42-49.

[5] P. Jänis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler, and K. Hugl, "Interference-aware resource allocation for device-to-device radio underlaying cellular networks," in *IEEE Vehicular Technologies Conference 2009 Spring*, Barcelona, Spain, April 2009.

[6] C.-H. Yu, O. Tirkkonen, K. Doppler, and C. Ribeiro, "Power optimization of device-to-device communication underlaying cellular communication," in *IEEE International Conference on Communication Technology*, Dresden, Germany, June 2009.

[7] K. Doppler, C.-H. Yu, C. Ribeiro, and P. Jänis, "Mode selection for Device-to-Device Communication underlaying an LTE-Advanced Network," in *IEEE Wireless Communications and Networking Conference (WCNC)*, Sydney, Australia, April 2010.

[8] T. Peng, Q. Lu, H. Wang, S. Xu, and W. Wang, "Interference Avoidance Mechanisms in the Hybrid Cellular and Device-to-Device Systems," in *IEEE 20th International S ymposium on*, Personal, Indoor and Mobile Radio Communicaitons, Tokyo, September 2009.

[9] T. Chen, G. Charbit, and S. Hakola, "Time Hopping for Device-to-device Communication in LTE Cellular System," in *IEEE Wireless Communications and Networking Conference (WCNC)*, Sydney, Australia, April 2010.

[10] T. M. Cover and J. A. Thomas, *Elements of information theory*. New York: Wiley, 1991.