Resource Allocation and Power Control for D2D Communication Underlaying LTE-Advanced Networks

Xu-ping ZHAI, Lei GONG and Nan ZHANG

Key Laboratory of Specialty Fiber Optics and Optical Access Networks, Joint International Research Laboratory of Specialty Fiber Optics and Advanced Communication, Shanghai Institute for Advanced Communication and Data Science, Shanghai University, Shanghai 200444, China

Keywords: Device-to-Device communication, Co-Channel interference, Resource allocation, Power control.

Abstract. Device-to-device (D2D) communications has proven to be efficient in improving the network performance and releasing the traffic load of base station. D2D user equipment(DUEs) can share the same LTE resources blocks with the cellular user equipment(CUEs), but it would cause severe co-channel interference. In this paper, a resource allocation and power control scheme is proposed to reduce the impact of co-channel interference. First, adopt a resource allocation scheme based on greedy algorithm on the premise of meeting the minimum rate requirements of devices, then the path loss compensation factor matrix could be calculated according to the distance between DUEs to the base station and CUEs and used to reduce the influence. Simulation results show that the proposed algorithm has better performance in D2D user access rate and system throughput.

Introduction

With the advent of 5G (the 5th generation) network, the number of mobile devices will exceed 50 billion by 2020. In a traditional cellular network, all communication must go through the base station. This centralized mode of work facilitates the management and control of resources and interferences, but the resource utilization efficiency is too low. D2D communication as an underlay to cellular networks have been introduced as a promising component to LTE-Advanced [1], it is defined as direct communication between two mobile users without traversing the base station or core network [2]. Therefore, D2D communication can greatly increase the spectrum efficiency and improve throughput, energy efficiency, delay and reduce the transmission power of the devices [3]. However, co-channel interference might occur between DUEs, CUEs and base station [4].

In order to reduce the impact of the co-channel interference caused by RBs reusing, several schemes have been proposed, including resource allocation, mode selection and power control. CHIA et al. [5] proposed a scheme that DUEs regulate power to enhance the signal-to-noise ratio of CUEs uplinks, but this scheme performs poorly when the distance between users is short. An interference aware resource allocation algorithm was proposed in [6], where base station allocates DUEs RBs that preassigned to CUEs least interfering with the DUEs, but the quality of service (QoS) of CUEs are not taken into consideration. Iliev et al. [7] adopt a simple power control algorithm to reduced influence by setting limited power threshold, this scheme is simple but does not take the distance between DUEs and CUEs into account. A three-step scheme has been proposed in [8], it allocates powers for each admissible D2D pair and its potential CUEs, then choses an appropriate CUE for each D2D pair.

However, all of the above works assume that at most one D2D pair can share the same RBs with one CUE, it will degrade the performance of the communication system and the utilization of spectrum resources undoubtedly. In view of this problem, a greedy resource allocation and adaptive power control (GRAAPC) algorithm was proposed, firstly adapting the number of user which will use the RB according to the communication model and the degree of interference among users, then calculate the path loss compensation factor matrix according to the distance between DUEs to the base station and CUEs to adjust users’ path loss compensation factor adaptively in order to improve monotony of path loss compensation factor in traditional power control.
System Model

This paper considers D2D communication by reusing the uplink resource of LTE-Advanced networks. As shown in Figure 1, there are two types of devices in this cell: CUE and DUE. CUEs communicate through the base station, while DUEs can communicate directly.

Consider a single cell in which M CUEs and N D2D pairs coexist, with the group of CUEs as $C=\{CUE_m | m=1,2,3,\ldots,M\}$, and the group of D2D pairs as $D=\{D2D_n | n=1,2,3,\ldots,N\}$. Each D2D pair includes a transmitter $DnT$ and a receiver $DnR$. There are L RBs in the cell in total. In order to ensure the QoS of CUEs, the number of RBs should be more than the number of CUEs, so $L>M$. Channel gain between user $K1$ and user $K2$ on the $l$-th RB is denoted by $g_{l,k_1,k_2}$, where $g_{l,k_1,k_2}$ represents the channel gain between $DnT$ and $DnR$ if $K2=BS$, it represents the channel gain between CUE $K1$ or DUE $K1$ and the base station. $P_c$, $c \in C$ denote the transmitting power if $c$-th CUE, $P_d$, $d \in D$ denote the transmitting power if $d$-th DUE. The usage of $l$-th RB is denoted by $\beta_l$, it equals to 1 if $l$-th RB has been used, unless it equals to 0, and if $v \in C$ or $v \in D$ the user is CUE or DUE respectively. Orthogonal RBs are used among CUEs, while DUEs select the RBs according to the usage of RBs. According to the Shannon formula, the throughput gain of CUE and DUE through $l$-th RB are denoted by $T_{c,T}$ and $T_{d,T}$ respectively:

$$T_{c,T} = B \log_2 \left( 1 + \frac{\beta_c P_c g_{c,l}^2}{\sum_{j \neq c} \beta_j P_j g_{j,l}^2 + \sigma^2} \right)$$  \hspace{1cm} (1)

$$T_{d,T} = B \log_2 \left( 1 + \frac{\sum_{j \neq d} \beta_j P_j g_{j,l}^2 + \sum_{j \neq d} \beta_j P_j g_{j,l}^2}{\beta_d P_d g_{d,l}^2 + \sigma^2} \right)$$  \hspace{1cm} (2)

The term $\sum_{j \neq d} \beta_j P_j g_{j,l}^2$ in (1) denotes the interference caused by D2D pairs which reuse the $l$-th RB of CUE $c$,$\sum_{j \neq c} \beta_j P_j g_{j,l}^2$ in (2) denote the interference caused by CUE which $l$-th RB has been reused by D2D $d$, the term $\sum_{j \neq d} \beta_j P_j g_{j,l}^2$ in (2) denote the interference caused by other D2D pairs which use the same $l$-th RB with D2D $d$, $B$ is the bandwidth of one RB, the terminal noise power $\sigma^2$ is assumed to be the same for base station and all the receivers.

The research goal of this paper is to maximize the system throughput of the network on the premise of QoS of CUEs and DUEs. To meet this goal, the minimum rate requirements for CUEs and DUEs are taken as constraints to ensure the effectiveness of resource allocation, and then use power control to limit transmitting power and reduce the interference. Based on the above analysis, the problem can be modeled as an optimization problem with constraints:

$$\max \sum_{j \in C} \sum_{l=1}^L T_{j,T} + \sum_{j \in D} \sum_{l=1}^L T_{j,T}$$  \hspace{1cm} (3)
Constraints in (4) and (5) ensure the QoS of CUEs and DUEs, the minimum communication rate of CUEs and DUEs are denoted by $\gamma_c$ and $\gamma_d$ respectively; Formula in (6) and (7) adopt closed-loop power control for CUEs and DUEs to adjust their transmitting power. Let $P_{\text{max}}^c$ and $P_{\text{max}}^d$ denote the maximum transmitting power of CUEs and DUEs, and $P_o$ is the nominal power, $\alpha^c$, and $\alpha^d$ are the path loss compensation factor of CUE and DUE when they use l-th RB, and the path loss of downlink reference signal of CUE and DUE when they use l-th RB are denoted by $PL^c_l$ and $PL^d_l$ respectively, $\Delta(c)$ and $\Delta(d)$ are closed-loop correction value of c-th CUE and d-th DUE, and the power control state is an accumulative or an absolute state are calculated by $f(\cdot)$. Constraints in (8) ensure one RB can be used by at most one CUE. It can be found this constrained optimization problem is a mixed nonlinear integer programming problem, and it is very difficult to solve directly. Therefore, the original optimization problem is divided into two sub problems, a resource allocation and a power control algorithm are proposed to improve the performance and reduce the complexity.

**Greedy Resource Allocation and Adaptive Power Control Algorithm**

In this section, in order to maximum the overall throughput of the system, we should assign D2D pairs to reuse the appropriate RBs with the corresponding CUEs under the restrictive conditions (4), (5), (8). Then adopt appropriate power control algorithm to upgrade the performance of the system furtherly.

**Greedy Resource Allocation**

In the stage of resource allocation, the transmitting power of CUEs and DUEs are set to the average power. With the increase number of RBs and users, the best allocation scheme can be obtained by exhaustive search method, but the computational complexity brought by it is exponentially increasing. In order to reduce the complexity, greedy algorithm can be used to do resource allocation.

Greedy algorithm is a method that choose the best one when the problem is under solving. Under the condition of guaranteeing the minimum communication rate of CUEs, select the optimal group with one CUE and one D2D pair to use same RB to gain maximum throughput. Then a pair of DUEs will be added to reuse the RB until the throughput can not be improved no matter which pair is added. When all the CUEs QoS guaranteed, in the remaining RBs, select the optimal group with one CUE and one D2D pair or two D2D pairs to use the same RB to increase overall throughput, then add D2D pair to use this RB until the overall throughput can not be improved no matter which pair is added.

We define $T_{ij}^c = \sum_{i=1}^{n} \gamma_i \cdot \sum_{j=1}^{m} \gamma_j$, as joint throughput matrix of users, $T_{ij}$ denote throughput gained by one CUE which use l-th RB or one CUE and a D2D pair which reuse l-th RB, when $d \in B$ users include c-th CUE and d-th D2D pair; When $d = B + 1$ user is c-th CUE, it can be formulated as follows:
Under the premise that two CUEs can not use the same RB, the term \( T = \{ T^1_d \}_{e,C,d,D} \) denote the joint throughput matrix of two users of any communication model. When \( e \in C \) or \( d \in D \), it refers to the throughput gained by e-th CUE and d-th D2D pair which reuse l-th RB; when \( e \in C \), \( d \in D \), the throughput only gained by e-th CUE which use l-th RB; when \( e, d \in D \) and \( e \neq d \), the throughput only gained by e-th D2D pair and d-th D2D pair which reuse l-th RB, this can be formulated as follows:

\[
T^e_d = \begin{cases}
B \log \left( 1 + \frac{P^e_d}{P^d_d + \sigma} \right) + B \log \left( 1 + \frac{P^e_d}{P^d_d + \sigma} \right) & e \in C \quad d \in D \\
B \log \left( 1 + \frac{P^e_d}{P^d_d + \sigma} \right) & e \in C \quad d \in D + 1
\end{cases}
\]

(9)

Firstly, select the appropriate RB and its CUE \( h \) and D2D pair \( h_i \) according to \( T = \{ T^1_d \}_{e,C,d,D} \):

\[
\{ l, h, h_i \} = \arg \max_{l, h, h_i} T^l_d
\]

(11)

When \( h_i = D + 1 \), the maximum throughput is gained by CUE which use RB independently, otherwise a pair of DUEs should be added to reuse this RB to improve throughput. When all the CUEs QoS guaranteed, in the remaining RBs, select the appropriate RB and its users \( h \) and \( h_i \) according to \( T = \{ T^1_d \}_{e,C,d,D} \):

\[
\{ l, h, h_i \} = \arg \max_{l, h, h_i} T^l_d
\]

(12)

When \( h_i = C \) and \( h_i = D + 1 \), the maximum throughput is gained by CUE \( h \) which use l-th RB independently; and when \( h_i = h_i \), the maximum throughput is gained by DUE \( h_i \) which use l-th RB independently; otherwise a pair of DUEs should be added to reuse this RB to improve throughput. The added value of throughput brought by one D2D pair which reuse l-th RB shown as follows:

\[
\Delta T^i_d = T^i (e, l) - T^i (e, l - 1)
\]

(13)

The group of users which use l-th RB denoted by \( V^l = V^l \cup V^l \), and the access rules for DUEs should meet the following requirement:

\[
h_i(e) = \arg \max_{h_i} \Delta T^i_d
\]

(14)

Follow this rule, D2D pairs are constantly added until the overall throughput is no longer increased and \( |l| = \emptyset \), then output the final result of resource allocation.

**Adaptive Power Control**

Average transmitting power is used for all users in the stage of resource allocation, but the path loss compensation factor in the traditional closed-loop power control is not set flexibly, the same value are used for all users. The interference is strong when distance between two users is close, serious interference and more resource consumption will be caused if the users adopt high \( \alpha \). Therefore, if \( \alpha \) can be adjusted adaptively according to the distance between users and base stations, the impact caused by overcompensation or undercompensation will be reduced. When l-th RB belonging to \( c \)-th CUE is reused by d-th D2D pair, steps of adaptive closed-loop power control are shown as follows:
Step 1 d-th D2D pair starts to reuse l-th uplink RB of c-th CUE, calculate the distance matrix of DT and base station, then select the maximum $r_{DL}^{c}$ and minimum $r_{DR}^{c}$;

Step 2 Calculate the added value of path loss compensation factor $a_{DL}^{c}$ of d-th D2D pair, the closer the DT is to the base station, the lower its added value;

Step 3 $a_{DL}^{c}=a_{DL}^{c}+\alpha DL/10$;

Step 4 Calculate the distance matrix $L_{c,DL}$ of c-th CUE and the DR of all the D2D pairs, then select the maximum $r_{DL}^{c}$ and minimum $r_{DR}^{c}$;

Step 5 Calculate the added value of path loss compensation factor $a_{DL}^{c}$ of c-th CUE, the closer the c-th CUE is to the DR which resource its uplink RB, the lower its added value;

Step 6 $a_{DL}^{c}=a_{DL}^{c}+\alpha DL/10$;

Step 7 Stop the calculation of added value of path loss compensation factor when all the added value has been done, otherwise back to step 3.

The final adaptive path loss compensation factor of CUE and DUE when l-th uplink RB of c-th CUE reused by d-th D2D pair can be formulated as (15),(16):

$$a_{DL}^{c} = \left[ \frac{r_{DL}^{c} - r_{DL}^{c}}{r_{DL}^{c} - r_{DL}^{c}} / 0.33 \right] / 10 + a_{DL}^{c}$$ (15)

$$a_{DL}^{c} = \left[ \frac{r_{DL}^{c} - r_{DL}^{c}}{r_{DL}^{c} - r_{DL}^{c}} / 0.33 \right] / 10 + a_{DL}^{c}$$ (16)

The $a_{DL}^{c}$ and $a_{DL}^{c}$ in (6),(7) can be replaced by (15),(16), and then the final adaptive power control expression (17),(18) can be obtained. In this way, the transmitting power of the CUEs and DUEs is adjusted to further improve the system throughput.

$$P_{i}^{c} = \min \left\{ P_{i}^{c}, P_{i}^{c} + \left[ \frac{r_{DL}^{c} - r_{DL}^{c}}{r_{DL}^{c} - r_{DL}^{c}} / 0.33 \right] / 10 + a_{DL}^{c} \right\} + f(c) \quad \forall c \in C$$ (17)

$$P_{i}^{d} = \min \left\{ P_{i}^{d}, P_{i}^{d} + \left[ \frac{r_{DL}^{c} - r_{DL}^{c}}{r_{DL}^{c} - r_{DL}^{c}} / 0.33 \right] / 10 + a_{DL}^{c} \right\} + f(c) \quad \forall d \in D$$ (18)

Simulation Results

| Parameters                        | Values                  |
|-----------------------------------|-------------------------|
| RBs Bandwidth                     | 180[KHZ]                |
| Number of RBs                     | 15                      |
| Number of CUE/DUE                 | 10/2~20                 |
| maximum transmitting power of CUE/DUE | 24[dBm]/ 21[dBm]      |
| Noise spectral density            | -174[dBm/Hz]           |
| Path loss model for CUE link      | 37.6lg[d(km)]+128.1     |
| Path loss model for D2D pair      | 40/lg[d(km)]+148        |
| minimum rate of CUE/DUE           | 0.8[Mbit/s]             |

The simulation experiments are carried out on the Matlab platform and the main simulation parameters are shown in table 1. The single cell radius is 500 meters, all the CUEs and DUEs are randomly distributed in the same single cell with a eNB at the center, and the maximum distance between D2D pairs is 50 meters. Exhaustive search(ES) algorithm, GRAAPC algorithm proposed in the paper and two compared algorithms are used to doing the comparison simulation of system throughput and access rate of DUEs. The compared algorithm 1 is the three step resource allocation(TSRA) algorithm in[8], the compared algorithm 2 is the greedy resource allocation(GRA) algorithm in[4], 5000 times simulation have been carried out.
Figure 2 give the access rate of DUEs, the access under GRAAPC which proposed in this paper is closest to the ES, and the overall performance under GRAAPC remains at a high level. With the increase of the number of DUEs, the access rate of DUEs is decreasing under TSRA, the reason is TSRA does not allow multiple DUE to reuse the same RBs. The DUEs access rate also decreases with the increase of the number of DUEs under GRA, but it allows multiple DUE to reuse the same RBs so it’s rate of decrease less than TSRA. However, the transmission power is invariable, so with the increasing number of DUEs, the interference becomes more and more serious.

Figure 3 give the system throughput curve. The system throughput under GRAAPC which proposed in this paper is closest to the ES algorithm, and compared to the GRA and TSRA, its achieved throughput gain is as much as 124% and 150% respectively. This is because GRAAPC optimize the allocation scheme of RBs by greedy algorithm under the premise of guaranteeing the minimum communication rate of all the users. And meanwhile using adaptive closed-loop power control to reduce the co-channel interference which caused by the increase number of DUEs.

Summary

D2D communication plays an important role in spectrum utilization improvement, base station load reduction, and transfer efficiency promotion of 5G network. In this paper, an algorithm of resource allocation and power control is proposed, this algorithm meets the constraint of the need of minimum communication rate of users, while achieving the need of total throughput promotion. The simulation of the experiments show that the algorithm could improve the system throughput and access rate of DUEs with high service quality, and reduce the effect of co-channel interference.

Acknowledgement

This research was financially supported by the National Natural Science Foundation of China [grant no. 61171085 and 61401266].

References

[1] K. Doppler, M. Rinne, C.Wijting, C. Ribeiro, K.Hugl. Device-to-device communication as an underlay to lte-advanced networks [J].IEEE Commun. Mag, 2009: 47 (12): 42-49.
[2] Asadi A, Wang Q, Mancuso V. A Survey on Device-to-Device Communication in Cellular Networks[J]. Communications Surveys & Tutorials IEEE, 2014, 16(4):1801-1819.
[3] DOPPLER K, RINNE M, WIJT ING C. Device-to-Device Communication as an Underlay to LTE- Advanced Networks [J]. IEEE Communications Magazine, 2009: 47(12): 42-49.
[4] Sun H, Sheng M, Wang X, et al. Resource allocation for maximizing the device-to-device communications underlaying LTE-Advanced networks[C]// IEEE International Conference on Communications in China - Workshops. IEEE, 2013:60-64.
[5] CHIA H Y, O TIRKKONEN, DOPPLER K, C B RBEIRO. On the Performance of Device-to-Device Underlay Communication with Simple Power Control [C]//IEEE 69th Vehicular Technology Conference, Barcelona, 2009: 1-5.

[6] Janis P, Koivunen V, Ribeiro C, et al. Interference-Aware Resource Allocation for Device-to-Device Radio Underlaying Cellular Networks[C]// Vehicular Technology Conference, 2009. Vtc Spring 2009. IEEE. IEEE, 2009:1-5.

[7] Iliev T B, Mihaylov G Y, Ivanova E P, et al. Power control schemes for device-to-device communications in 5G mobile network[C]// International Convention on Information and Communication Technology, Electronics and Microelectronic. IEEE, 2017:416-419.

[8] Feng D, Lu L, Yi Y W, et al. Device-to-Device Communications Underlaying Cellular Networks[J]. IEEE Transactions on Communications, 2013, 61(8):3541-3551.