A Resource Allocation Scheme for Distributed Antenna System with Device-to-Device Communication

Yejun He, Jiajia Yin, Chunlong He, Jian Qiao
Guangdong Engineering Research Center of Base Station Antennas and Propagation
Shenzhen Key Laboratory of Antennas and Propagation
College of Information Engineering, Shenzhen University, 518060, China
Email: heyejun@126.com, 824559201@qq.com, chunlonghe@163.com, 446941582@qq.com

***Abstract*—In this paper, we investigate a resource allocation scheme for fully loaded distributed antenna system (DAS) with Device-to-Device (D2D) communication. A framework of resource allocation for D2D communications under laying a fully loaded DAS is presented, where the objective is to maximize the throughput of shared spectrum channel. First, we set up DAS with D2D communication model. Then, a dual threshold power control scheme is studied for each D2D pair and its cellular user (CU) partner to maximize the throughput of shared spectrum channel. Finally, the optimal solution is obtained according to the convex optimization theory. Numerical results show that the proposed scheme can significantly improve the throughput and communication quality of communication network system compared to the co-located antenna system (CAS) with D2D communication.**

***Index Terms*—Distributed antenna system, D2D communication, power allocation, throughput.**

I. INTRODUCTION

Recently, mobile communication network system is developing rapidly. In order to meet the requirements of higher mobile data transmission rates, lower battery consumption, and higher quality of service (QoS) of all the user equipments (UEs), a variety of communication and transport technologies have been proposed. Distributed antenna technology and device-to-device (D2D) communication technology are hot topics. In 2005, China's FUTURE (Future Technology for Universal Radio Environment) plan first introduced the distributed antenna system [1]–[3] suitable for cellular mobile communications in the world. Unlike co-located antenna system (CAS), in distributed antenna system, a plurality of remote access units (RAUs) are placed in different positions in a certain region, they form a generalized cell (GC) by connecting optical fiber or hybrid fiber coaxial cable or wireless base station processing unit (BPU). Related theories [14] have proved that, compared with traditional co-located antenna system, distributed antenna system not only narrows the distance between mobile terminals and base station antenna, but also reduces transmission power, and makes the antennas of different RAUs become irrelevant, which brings a significant increase in spectrum efficiency and power efficiency. A good example is to build a small Femtocell cellular [4], [5]. Femtocell network has smaller cell size, which can efficiently use limited spectrum and bandwidth resources to reduce the load of the base station.

At the same time, in recent years, D2D communication has been widely used to increase throughput of the systems, improve the energy efficiency (EE) of communication systems and extend the battery using time of UEs [6]–[8]. D2D communication can easily build up a direct link between two user equipments without the involvement of base stations. In [9], the authors mainly investigated pattern selection based on spectrum sharing between D2D users and cellular users. In order to prevent excessive interference, the transmission power control algorithm of D2D communication has been proposed in [10]. In order to improve the scalability of D2D communication, the authors discussed the distributed resource allocation method in [11]. In [12] and [13], the authors investigated how to improve the reliability of interference management in co-located antenna systems. Both distributed antenna system and D2D communication technology are the key technologies of 5G. The combination of distributed antenna system and D2D communication will give further advantage of communication transmission. However, there are still many challenges when adding D2D pairs into the communication system, which is mainly caused by the interference between cellular and the D2D users. Therefore, interference management is one of the most important issues in DAS with D2D communication. In [14], the authors compared energy efficiency between co-located and distributed antenna systems with D2D communication. However the authors only considered single cellular and D2D pair in co-located and distributed antenna systems with D2D communication. Moreover, except for [14], the systems considered above only contain D2D communications for the co-located antenna systems. To the best of our knowledge, there is little investigation about D2D communications in the distributed antenna system, especially DAS with D2D communication in the multiuser scenario. In this paper, we mainly focus on the issue of interference management and resource allocation. The combination of distributed antenna system and D2D technology can greatly reduce the transmission distance between users and antennas to reduce transmission power consumption, which can improve the overall performance of the system.

The contributions of this paper are summarized as follows.

1) The resource allocation scheme is proposed to investigate the distribution of signal to interference plus noise ratio (SINR) and throughput of different users for DAS with D2D communication and CAS with D2D communication. The algorithm includes the following three steps: a) establishing the system model, b) channel allocation for D2D communication, c) power allocation. In system model, we establish two models for performance comparison: co-located antenna system model and distributed antenna system model. In channel allocation, each D2D pair can reuse the channel resource which is the furthest from the cellular user communication channel. In order to ensure the QoS of cellular users, the number of D2D pairs is less than the number of cellular users, and one D2D pair can only reuse a channel of one cellular user, and D2D pair can not reuse the channel of cellular user that is on the edge of the system. In power allocation, we set up a power control factor for D2D user and its cellular user partner, respectively. According to the user's QoS requirements and maximum power limit for users, we use the dual threshold power allocation algorithm to maximize the channel throughput of the shared channel.

2) Also, the optimal solution is obtained according to the convex optimization theory. The proposed scheme can significantly improve the performance of communication network system compared to the co-located antenna system with D2D communication.

The rest of this paper is organized as follows. The system model is presented in section II, and power control method whose expression of different users are shown in section III . In Section IV, simulation results show that the performance of DAS with D2D communication is much better than CAS. In Section V, we conclude the paper and indicate future research directions.

II. SYSTEM MODEL

We consider a fully loaded uplink communication network with N cellular users and K D2D pairs, and all users are randomly distributed in the cellular network. Since the communication network system is fully loaded, the system has no excess spectrum resources allocated to D2D pairs. D2D pairs can only access the network communication system by reusing cellular user channel resources. The radius of cellular network is *R*. Base station antennas in the cellular network are distributed in two different scenarios. The location of the base station antenna is *M (M=1, 2, 3, 4, 5)*. The first scenario that all the base station antennas are co-located in the position 1 (CAS) and the other scenario that the base station antennas are distributed on the location *M* (DAS) are illustrated in the Fig. 1 and Fig. 2, respectively. Because the communication network system is fully loaded, the system has no excess spectrum resources allocated to D2D pairs. D2D pairs can only access the network communication system by reusing cellular user channel resources. For simplicity, we assume that each cellular user is equipped with single antenna and also assume that the total bandwidth is equally divided to each link between BS and cellular users, so each cellular user is allocated with an orthogonal channel. Each D2D pair user reuses a channel of cellular user, and each channel of cellular user can only be reused by one D2D pair. In order to reduce interference, cellular user which is selected to reuse channel is far away from D2D pair.

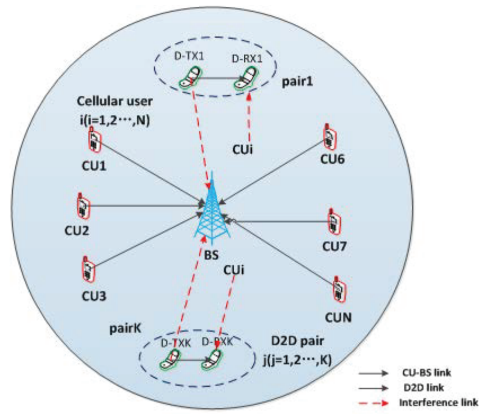

Fig. 1. CAS-D2D Communication system

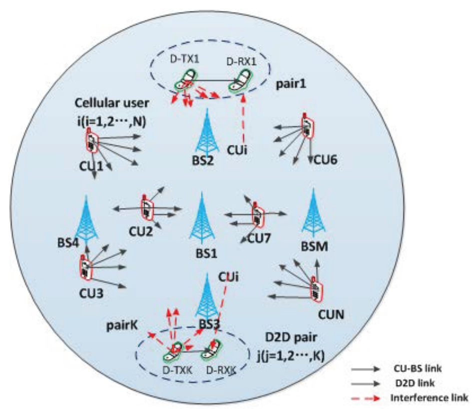

Fig. 2. DAS-D2D Communication system

III. PROBLEM DESCRIPTION AND POWER CONTROL

A. Problem description

In the uplink multiuser DAS with D2D communication, the total number of antennas is *S*, then the number of antennas for each base station is $\frac{S}{5}$. For the cellular user partner of D2D pair communication link, the received signal power of each base station antenna can be represented as

$$RX_{BSi}^{'} = \frac{1}{S} P_C . \left\| H_i^{'} \right\|^2 , \forall i \in C \quad (1)$$

where P_C is the power of a cellular user, $H_i^{'}$ is the channel matrix between the base station antennas and the cellular user, and $C = \{1, 2, 3, ..., N\}$ is a group of cellular users in the system. The received signal power of base station antennas on the location *M* can be represented as

$$RX_{BSMi} = \frac{S}{5} \cdot \frac{1}{S} P_C . \|H_{Mi}\|^2 = \frac{1}{5} P_C . \|H_{Mi}\|^2 \quad (2)$$

where H_{Mi} is the channel matrix between the base station antennas of the position *M* and the cellular user. The received signal power of all-location total base station antennas can be expressed as

$$RX_{BSi} = \frac{1}{5} \sum_{M=1}^{5} P_C . \|H_{Mi}\|^2 \quad (3)$$

The interference signal power received by a single base station antenna from the transmitter of D2D pair is given by

$$I'_{BSj} = \frac{1}{S} P_D . \left\|H'_j\right\|^2, \forall j \in D \quad (4)$$

where P_D is the power of D2D transmission, H'_j is the channel matrix between the base station antennas and the transmitter of D2D pair, and $D = \{1, 2, 3, ..., K\}$ is the group of D2D pairs in the system. The interference signal power received by base station antenna on the location *M* from the transmitter of D2D pair is given by

$$I_{BSMj} = \frac{S}{5} \cdot \frac{1}{S} P_D . \|H_{Mj}\|^2 = \frac{1}{5} P_D . \|H_{Mj}\|^2 \quad (5)$$

where H_{Mj} is the channel matrix between the base station antennas of the position *M* and the transmitter of D2D pair. The interference signal power received by all base station antennas from the transmitter of D2D pair can be written as

$$I_{BSj} = \frac{1}{5} \sum_{M=1}^{5} P_D . \|H_{Mj}\|^2 \quad (6)$$

In D2D communication, the received signal power at the receiver can be represented as

$$RX_{Dj} = P_D . \|H_{j_1 j_2}\|^2 \quad (7)$$

where $H_{j_1 j_2}$ is the channel matrix between the receiver of D2D pair j_2 and the transmitter of D2D pair j_1. The interference signal power received by the receiver of D2D pair from its cellular user partner can be represented as

$$I_{Di} = P_C . \|H_{ij_2}\|^2 \quad (8)$$

where H_{ij_2} is the channel matrix between the receiver of D2D pair and the cellular user. In order to reduce the interference among cellular users, D2D pair and base station antennas, we consider the throughput optimization for the uplink multiuser DAS with D2D communication under the constraints of satisfying the following requirements: the minimum SINR, the maximum transmit power of each cellular user, and D2D pair, respectively. The optimization goal is to maximize the throughput of the D2D pair and its cellular user partner. The optimization problem can be represented as

$$\max(\log_2 (1 + SINR_{Ci}) + \log_2 (1 + SINR_{Dj})) \quad (9)$$

s.t.

$$SINR_{Ci} = \frac{RX_{BSi}}{I_{BS_j} + {\delta_n}^2} \geq SINR_{C\min} \quad (10)$$

$$SINR_{Dj} = \frac{RX_{Dj}}{I_{Di} + {\delta_n}^2} \geq SINR_{D\min} \quad (11)$$

$$P_C \leq P_{C\max} \quad (12)$$

$$P_D \leq P_{D\max} \quad (13)$$

where $SINR_{Ci}$ is the SINR of the cellular user uplink communication, $SINR_{Di}$ is the SINR of D2D pair communication, ${\delta_n}^2$ is noise power, $SINR_{C\min}$ is minimum SINR of uplink cellular communication, $SINR_{D\min}$ is minimum SINR of D2D communication, and $P_{C\max}$ and $P_{D\max}$ denote the maximum transmission power of the cellular users and D2D users.

B. Power control

In this paper, we define λ_{cj} $(0 < \lambda_{cj} \leq 1)$ as a power control factor for uplink cellular user partner of D2D pair communication, and the transmitted power of the cellular user after the power control is $P_C = \lambda_{cj} P_{C\max}$. We define λ_{dj} $(0 < \lambda_{cj} \leq 1)$ as a power control factor for D2D communication, and the transmitted power of the D2D user after the power control is $P_D = \lambda_{dj} P_{D\max}$. The SINR of uplink cellular communication can be expressed as

$$SINR_{Ci} = \frac{\frac{1}{5} \sum\limits_{M=1}^{5} \lambda_{cj} P_{C\max} . \|H_{Mi}\|^2}{\frac{1}{5} \sum\limits_{M=1}^{5} \lambda_{dj} P_{D\max} . \|H_{Mj}\|^2 + {\delta_n}^2} \quad (14)$$

The SINR of D2D communication can be expressed as

$$SINR_{Dj} = \frac{\lambda_{dj} P_{D\max} . \|H_{j_1 j_2}\|^2}{\lambda_{cj} P_{C\max} . \|H_{ij_2}\|^2 + {\delta_n}^2} \quad (15)$$

In order to ensure the QoS of communication between the cellular user and the D2D pair, we present minimum SINR of uplink cellular communication and D2D communication respectively, which are as follows

$$SINR_{Ci} \geq SINR_{C\min} \quad (16)$$

$$SINR_{Dj} \geq SINR_{D\min} \quad (17)$$

According to equation (14) and (16), we can obtain the relationship between λ_{cj} and λ_{dj} as follows

$$\lambda_{cj} \geq \frac{SINR_{C\min} \cdot \frac{1}{5} P_{D\max} . \sum\limits_{M=1}^{5} \|H_{Mj}\|^2}{\frac{1}{5} P_{C\max} . \sum\limits_{M=1}^{5} \|H_{Mi}\|^2} \lambda_{dj} + \frac{SINR_{C\min} \cdot {\delta_n}^2}{\frac{1}{5} P_{C\max} . \sum\limits_{M=1}^{5} \|H_{Mi}\|^2}, \forall i \in C, \forall j \in D \quad (18)$$

To ensure the QoS of the cellular user partner of D2D pair communication, we should choose λ_{cj} and λ_{dj} to satisfy the inequality (18).

In the same way, according to equation (15) and (17), we can obtain the relationship between λ_{cj} and λ_{dj} as follows

$$\lambda_{dj} \geq \frac{SINR_{D\min} \cdot P_{C\max} \cdot \left\| H_{ij_2} \right\|^2}{P_{D\max} \cdot \left\| H_{j_1 j_2} \right\|^2} \lambda_{cj} + \frac{SINR_{D\min} \cdot {\delta_n}^2}{P_{D\max} \cdot \left\| H_{j_1 j_2} \right\|^2}, \forall i \in C, \forall j \in D \tag{19}$$

To ensure the QoS of the D2D communication, we should choose λ_{cj} and λ_{dj} to meet the inequality (19). After some mathematical simplification, we change the equation (18) and equation (19) into equation (20) and equation (21).

$$\lambda_{cj} \geq \frac{SINR_{C\min} \cdot \left(SINR_{D\min} \cdot \frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mj} \right\|^2 \cdot {\delta_n}^2 + \left\| H_{j_1 j_2} \right\|^2 \cdot {\delta_n}^2 \right)}{P_{C\max} \cdot \left(\frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mi} \right\|^2 \cdot \left\| H_{j_1 j_2} \right\|^2 - SINR_{C\min} \cdot SINR_{D\min} \cdot \frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mj} \right\|^2 \cdot \left\| H_{ij_2} \right\|^2 \right)} \tag{20}$$

$$\lambda_{dj} \geq \frac{SINR_{D\min} \cdot \left(SINR_{C\min} \cdot \left\| H_{ij_2} \right\|^2 \cdot {\delta_n}^2 + \frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mi} \right\|^2 \cdot {\delta_n}^2 \right)}{P_{D\max} \cdot \left(\frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mi} \right\|^2 \cdot \left\| H_{j_1 j_2} \right\|^2 - SINR_{C\min} \cdot SINR_{D\min} \cdot \frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mj_1} \right\|^2 \cdot \left\| H_{ij_2} \right\|^2 \right)} \tag{21}$$

Thus, the optimization problem equation (9) can be written as

$$\max(\log_2 \left(1 + \frac{\frac{1}{5} \lambda_{cj} P_{C\max} \cdot \sum_{M=1}^{5} \left\| H_{Mi} \right\|^2}{\frac{1}{5} \lambda_{dj} P_{D\max} \cdot \sum_{M=1}^{5} \left\| H_{Mj} \right\|^2 + {\delta_n}^2} \right) + \log_2 \left(1 + \frac{\lambda_{dj} P_{D\max} \cdot \left\| H_{j_1 j_2} \right\|^2}{\lambda_{cj} P_{C\max} \cdot \left\| H_{ij_2} \right\|^2 + {\delta_n}^2} \right)) \tag{22}$$

$$s.t. \quad \frac{SINR_{C\min} \cdot \left(SINR_{D\min} \cdot \frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mj} \right\|^2 \cdot {\delta_n}^2 + \left\| H_{j_1 j_2} \right\|^2 \cdot {\delta_n}^2 \right)}{P_{C\max} \cdot \left(\frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mi} \right\|^2 \cdot \left\| H_{j_1 j_2} \right\|^2 - SINR_{C\min} \cdot SINR_{D\min} \cdot \frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mj} \right\|^2 \cdot \left\| H_{ij_2} \right\|^2 \right)} \leq \lambda_{cj} \leq 1 \tag{23}$$

$$\frac{SINR_{D\min} \cdot \left(SINR_{C\min} \cdot \left\| H_{ij_2} \right\|^2 \cdot {\delta_n}^2 + \frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mi} \right\|^2 \cdot {\delta_n}^2 \right)}{P_{D\max} \cdot \left(\frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mi} \right\|^2 \cdot \left\| H_{j_1 j_2} \right\|^2 - SINR_{C\min} \cdot SINR_{D\min} \cdot \frac{1}{5} \sum_{M=1}^{5} \left\| H_{Mj_1} \right\|^2 \cdot \left\| H_{ij_2} \right\|^2 \right)} \leq \lambda_{dj} \leq 1 \tag{24}$$

The equation (22) is the optimization objective, equation (23) and (24) are the constraint conditions, and the optimization variables are λ_{cj} and λ_{dj}. The equation (22) is derived second times with respect to variable λ_{cj} and λ_{dj} respectively, and it is calculated that their second derivative is greater than 0. Therefore, the optimization problem can be transformed into a convex optimization problem. We can use Quasi-Newton Method to calculate the optimal solution of λ_{cj} and λ_{dj}.

TABLE I
SOLVING PROCESS OF QUASI NEWTON METHOD

Solving process of Quasi-Newton Method
1: Initialization $x^k = x_0$, *a=0.01*, $D_0 = I$ and *k=0*.
2: Calculate the search direction: $d_k = -D_k g_k$, $D_k = B_k^{-1}$, Set the equation (22) to be $f(x)$, $B_k = f''(x_k)$, $g_k = f'(x_k)$.
3: Search step size μ_k, $f(x_k + \mu_k d_k) = \min_{\mu > 0} f(x_k + \mu d_k)$, $s_k = \mu_k d_k$, $x_{k+1} = x_k + s_k$.
4: Calculate $g_{k+1} = g(x_{k+1})$, if $\|g_{k+1}\| < a$, stop calculation, get the approximate solution: $[x = x_{k+1}$.
5: Calculate $y_k = g_{k+1} - g_k$, then calculate $D_{k+1} = D_k + \frac{s_k s_k^T}{s_k^T y_k} \frac{D_k y_k y_k^T D_k^T}{y_k^T D_k y_k}$
6: *k=k+1*, then go to step 2.

IV. SIMULATION RESULTS

In this section, we present the different simulation results by comparing different scenarios. The scenario 1 is all the base station antennas are co-located in the center of the cellular network (CAS) and the scenario 2 is the base station antennas are distributed on the location *M* (DAS). In each scenario, the cellular users and D2D pairs are distributed uniformly, where there are fifty cellular users and ten D2D pairs. The system parameters in the simulation are listed in the Table 1.

TABLE II
SIMULATION PARAMETERS

Parameter	Value
The cellular radius	500 m, 1000 m
Total bandwidth of uplink in a cell	9 MHz
The maximum distance of D2D communication	25 m, 50 m, 75 m,100 m
Total number of position M of base station antennas	5
The noise power	-174 dBm
Path loss model between D2D users	Free space model
Path loss model between other users	COST231 Hata model
Shadow fading model	8 dB
multipath fading	1
Reception noise coefficient of base station	5 dB
User acceptance of noise coefficient	9 dB
Maximum transmission power of cellular users	24 dBm
D2D user maximum transmission power	24 dBm
Number of cellular users	50
Number of D2D pairs	10
Minimum SINR of cellular communication	10 dB
Minimum SINR of D2D communication	3 dB

Fig. 3 and Fig. 4 illustrate the CDF curve of the D2D users and the cellular users' SINR and throughput distribution in the DAS with different radius of a cell. Simulation results show that the performance of cellular users in the cell of the radius *R*=500 m is better than that in the cell of the radius *R*=1000 m. However, D2D users are almost unaffected by cell radius. The reason is that cellular users need to rely on the base station antennas to transmit the data signal. The expansion of the cell radius will increase the distance between the cellular users and the base station antennas, which will increase the channel loss and reduce the user communication performance. D2D users exchange data without the help of base station antennas, and the communication between the D2D users is only related to the distance between the D2D users. Simulation results also show that D2D communication can be applied to the larger network communication system to improve communication performance. For the overall performance of the system, we set the *R*=500 m as the default simulation parameter.

Fig. 5 and Fig. 6 show that the CDF curve of D2D users' SINR and throughput distribution in the DAS with different maximum distances of D2D communication, respectively. As we can see, with the increase of the maximum distance between D2D communication, the number of D2D users in the lower number of SINR and throughput is increased. The reason is that the expansion of maximum distance of D2D communication will increase the channel loss and reduce the

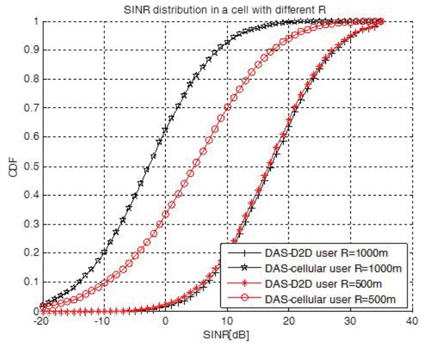

Fig. 3. The CDF curve of the D2D users and the cellular users' SINR distribution in the DAS with different radius of a cell

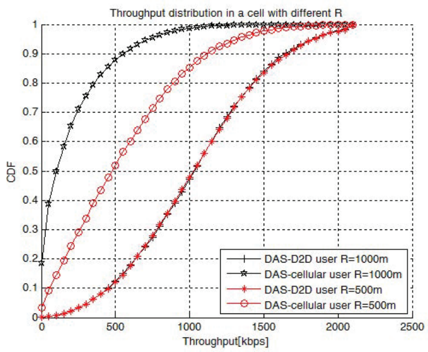

Fig. 4. the CDF curve of the D2D users and the cellular users' throughput distribution in the DAS with different radius of a cell

user communication performance. However, we can also see that the results of *DLmax*=25 m and *DLmax*=50 m are almost identical. So we can know the maximum distance to maintain the best performance of D2D communication is about 50 m. Therefore, we set *DLmax*=50 m as the default simulation parameter.

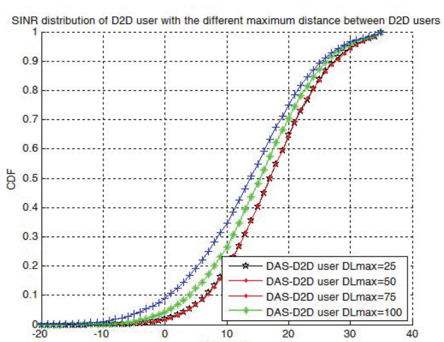

Fig. 5. The CDF curve of D2D users' SINR distribution in the DAS with different maximum distance of D2D communication

Fig. 7 presents the CDF curve of the D2D users and the cellular users' SINR and Fig. 8 describes the CDF curve of the D2D users and cellular users' throughput distribution in different scenarios. Fig. 7 and Fig. 8 show that the performance of D2D users is better than that of cellular users in the CAS or in the DAS, which means using D2D communication is helpful to increase the system's throughput in the CAS or in the DAS. What's more, it also shows that the performance of the cellular and D2D users in the DAS is much better than that in the CAS. The reasons are as follows, for the cellular users communication link, the distributed antenna system reduces the communication transmission distance, which reduces the channel loss, improves the quality of the user communication, and enhances the user communication performance, especially

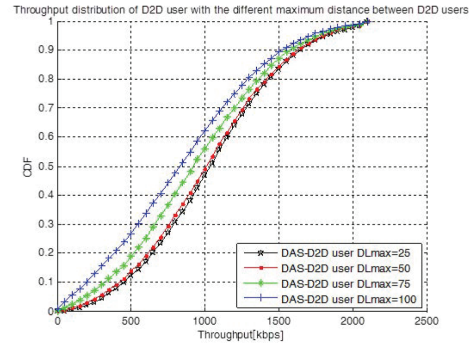

Fig. 6. The CDF curve of D2D users' throughput distribution in the DAS with different maximum distance of D2D communication

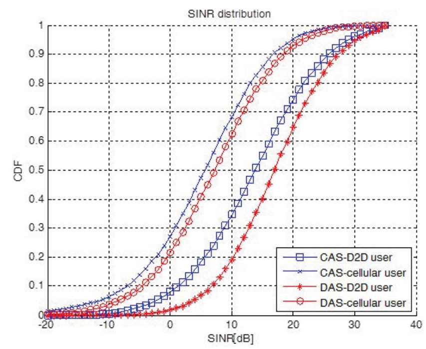

Fig. 7. The CDF curve of the D2D users and the cellular users' SINR distribution in different scenarios

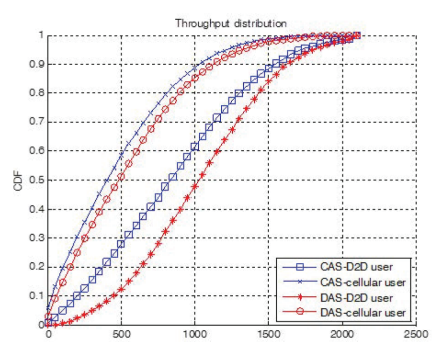

Fig. 8. The CDF curve of the D2D users and the cellular users' throughput distribution in different scenarios

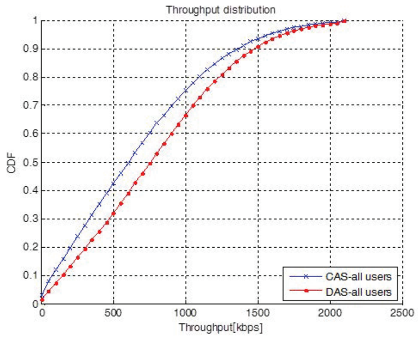

Fig. 9. The CDF curve of all users' throughput distribution in different scenarios

improves the communication performance of the edge cellular users. On the other hand, when the base station antennas are uniformly distributed in the cell, the interference signal power received by base station antennas from the transmitter of D2D pair is also increased. For the D2D communication link, we adopt a dual threshold power allocation method to control each D2D pair and its CU partner to maximize the throughput of shared spectrum channel, which reduces the interference between the D2D users and the cellular users and improves the communication quality of the D2D communication. So the performance enhancement of D2D users is more obvious.

From Fig. 9, we compare the CDF curve of all users' throughput distribution in different scenarios and conclude that the throughput of all users in the DAS is much better than that in the CAS, which means the distributed antenna system with D2D communication is a better way to increase the systems' total throughput. Simulation results show that the distributed antenna system with D2D communication improves the overall throughput of the system to demonstrate the effectiveness of the algorithm.

V. Conclusion

In this paper, we investigated resource allocation for fully loaded DAS with D2D communication. we considered distribution of signal to interference plus noise ratio and throughput of different users in the DAS with D2D communication and in the CAS with D2D communication. We found that the overall throughput of the system remarkably increased in the DAS with D2D communication. Aiming at the problem of interference between the D2D users and the cellular users, we adopt a dual threshold power allocation method to control each D2D pair and its CU partners to maximize the throughput of shared spectrum channel, which reduces their mutual interference. Simulation results show that the SINR and throughput of the cellular users and D2D users both increase in the DAS with D2D communication to demonstrate the effectiveness of the algorithm.

There are still a lot of problems to be solved in the DAS with D2D communication. In this paper, we only put forward some own methods from the point of view of power allocation. We will develop communication models that are much better in line with the actual situation and mode selection in the DAS with D2D communication in the near future.

Acknowledgment

This work was supported in part by NSFC under Grant 61372077, in part by the Shenzhen Science and Technology Programs under Grant ZDSYS 201507031550105, Grant JCYJ20170302150411789, Grant JCYJ20170302142515949 and Grant GCZX2017040715180580, the Guangzhou Science and Technology Program under Grant 201707010490, as well as in part by the Guangdong Provincial Science and Technology Programs under Grant 2013B090200011 and Grant 2016B090918080.

References

[1] Xiaohu You, Dongming Wang, Bin Sheng, Xiqi Gao, Xin-Sheng Zhao, Ming Chen, "Cooperative distributed antenna systems for mobile communications [Coordinated and Distributed MIMO]," *IEEE Wireless Communications*, vol. 17, no. 3, pp. 35-43, Jun. 2010.

[2] Huling Zhu, "Performance Comparison Between Distributed Antenna and Microcellular Systems," *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 6, pp. 1151-1163, May 2011.

[3] H. Kim, S. Lee, K. Lee, and I. Lee, "Transmission Schemes Based on Sum Rate Analysis in Distributed Antenna Systems," *IEEE Transactions on Wireless Communications*, vol. 11, no. 3, pp. 1201-1209, Mar. 2012.

[4] Brett Kaufman, "Spectrum Sharing Techniques for Next Generation Cellular Networks," Dissertations Theses - Gradworks, 2009.

[5] Pekka Janis et al, "Device-to-Device Communication Underlaying Cellular Communications Systems," *International Journal of Communications Network System Sciences*, vol. 2, no. 3, pp. 169-247, 2009.

[6] Klaus Doppler et al, "Device-to-device communication as an underlay to LTE-advanced networks," *IEEE Communications Magazine*, vol. 47, no. 12, pp. 42-49, Dec. 2009.

[7] Gabor Fodor et al, "Design aspects of network assisted device-to-device communications," *IEEE Communications Magazine*, vol. 50, no. 3, pp. 170-177, Mar. 2012.

[8] Chiahao Yu, Klaus Doppler, Cassio B. Ribeiro, and Olav Tirkkonen, "Resource Sharing Optimization for Device-to-Device Communication Underlaying Cellular Networks," *IEEE Transactions on Wireless Communications*, vol. 10, no. 8, pp. 2752-2763, Aug. 2011.

[9] Mohammad Zulhasnine, Changcheng Huang, and Anand Srinivasan, "Efficient resource allocation for device-to-device communication underlaying LTE network," in *Proc. IEEE 6th International Conference on Wireless and Mobile Computing, Networking and Communications*, Oct. 2010, pp. 368-375.

[10] C. Yu, O. Tirkkonen, K. Doppler, C. Ribeiro, "On the Performance of Device-to-Device Underlay Communication with Simple Power Control," in *Proc. IEEE 69th Vehicular Technology Conference Spring*, 2009, pp. 1-5.

[11] Norbert Reider and Gabor Fodor, "A distributed power control and mode selection algorithm for D2D communications," *EURASIP Journal on Wireless Communications and Networking*, vol. 2012, no. 1, pp. 266, 2012.

[12] Hyunkee Min, Woohyun Seo, and Jemin Lee, "Reliability Improvement Using Receive Mode Selection in the Device-to-Device Uplink Period Underlaying Cellular Networks," *IEEE Transactions on Wireless Communications*, vol. 10, no. 2, pp. 413-418, Dec. 2010.

[13] Zhenyu Zhou, Mianxiong Dong, Kaoru Ota, Jun Wu, Takuro Sato, "Distributed interference-aware energy-efficient resource allocation for device-to-device communications underlaying cellular networks," in *Proc. IEEE Global Communications Conference*, Dec. 2014, pp. 4454-4459.

[14] Xingquan Li, Chunlong He, Ce Zhang, and Zihao Li, "Energy Efficiency Comparison between Co-located and Distributed Antenna Systems with D2D Communication," in *Proc. ITM Web of Conferences: 2017 International Conference on Information Science and Technology*, May 2017, pp. 1-8.