Power Allocation Criteria for Distributed Antenna Systems with D2D Communication

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ABSTRACT

In this paper, we discuss two different optimization objective problems for distributed antenna systems (DAS) with D2D communication. The first objective problem is maximizing spectral efficiency (SE) of the DAS with D2D communication under the constraints of the minimum SE requirements of DAS and D2D pair, maximum transmit power of each remote access unit (RAU) and maximum transmit power of D2D transmitter. We use the sub-gradient iteration approach to obtain the optimal power allocation and summarize the algorithm. The second objective is maximizing energy efficiency (EE) of the DAS with D2D communication under the same constraints as the first problem. We firstly exploit fractional programming method to transform this difficult problem into an equivalent objective function with subtract form, and then we use the similar method like first problem to obtain the optimal power allocation for the equivalent problem. Simulation results are illustrated the SE and EE of the DAS by using D2D communication are much better than DAS without D2D communication. Keywords: Distributed antenna systems, Co-located antenna systems, D2D communication, Spectral Efficiency, Energy efficiency, Power allocation

INTRODUCTION

The rapid growth demands for data and multimedia services have posed huge challenges for the designers of the next generation wireless communication networks. To satisfy the growing requirements of users, the idea of the distributed antenna systems (DAS) have attractive enormous attention in recent years [1],[2],[3]. DAS is regarded as one of the promising

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system to provide high data transmit rate and multimedia services. Different from the traditional co-located antenna systems (CAS) where all the antennas of base stations (BS) are located in the center, remote access units (RAUs) in the DAS are geographically distributed in the cell and connected to a center unit (CU) via optical fiber or coaxial cable [4]. Since the access distances between RAUs and user equipments (UEs) are reduced, the DAS has many established benefits of increasing spectral efficiency (SE) [5],[6] and improving energy efficiency (EE) [7], [8].

Device-to-device (D2D) communication is also an effectively method to handle the local traffic demands among users [9],[10]. The concept of D2D communication in cellular networks was introduced from multihop relay technology in which idle mobile users operate as a relay node [11],[12]. It enable a user device to communicate with another nearby user device directly through D2D link without the extra help from BS, which reduces the burden of BSs. D2D communication has also been investigated to reduce the energy consumption of communication systems [13], [14].

Both of DAS and D2D communication are the good way to improve SE and EE of communication systems, but there is few works on the D2D communication in the DAS. So in this paper, we consider them together, which combine their own advantages. In the analysis, we assume that the traditional UE and D2D pair are using the orthogonal frequency, which is easily achieved by using some techniques like Frequency Division Multiple Access (FDMA). We investigate SE and EE of DAS by adding D2D communication, which are formulated as non-convex problems. By adopting the sub-gradient approach [15] and the fractional programming theory [16], we obtain the optimal power allocations of maximize SE and EE, respectively. Then optimal SE and EE power allocation algorithms are developed for the formulated problems.

The remainder of this paper is organized as follows. The DAS model with D2D communication is presented in Section II. In Section III, we formulate the maximum SE optimization problem of DAS with D2D communication and summarize optimal power allocation algorithm. In Section IV, after formulate the maximum EE optimization problem of DAS with D2D communication, we propose an optimal power allocation algorithm to maximize EE of the systems. Section V presents numerical results to verify the effectiveness of the developed algorithms. Section VI concludes the paper.
SYSTEM MODEL

We consider DAS in a single-cell scenario with $N$ RAUs. The CU can be regarded as a special RAU and is located in the center of the cell, which is denoted by RAU1 and all the other RAUs are physically connected to it via optical fiber. The RAUs are low-power and low-cost BSs, and only equipped with low-noise amplifiers (LNA) and up/down converters. UE1 and a pair of D2D user (UE2 and UE3) are randomly distributed in the cell. We take UE2 as the transmitter and UE3 as the receiver of D2D pair, which is shown in Fig.1. We assume that RAU and UE are equipped with single antenna and the channels are orthogonal, so there is no interference between UE and D2D users. We also assume that the perfect channel state information (CSI) is available at both the transmitter and receiver. We normalize the total system bandwidth into unit and the data transmission rate of UE can be expressed as

$$R_i^c = \log_2 \left( 1 + \frac{\sum_{n=1}^{N} p_{n,1}^c |h_{n,1}|^2}{\sigma_c^2} \right)$$

(1)

where $p_{n,1}^c$ denotes the transmit power of the $n$ th RAU to UE1 and $h_{n,1}$ is the composite fading channel between them. $\sigma_c^2$ denotes the power of complex additive white Gaussian noise (AWGN) of UE1.

The data transmission rate of D2D pair can be written as
\[
R_{23}^d = \log_2 \left( 1 + \frac{p_d^d |h_{2,3}|^2}{\sigma_d^2} \right)
\]  \hspace{1cm} (2)

where \(p_d^d\) is the transmit power of the transmitter (UE2) D2D pair and \(h_{2,3}\) is the composite fading channel between UE2 and UE3. \(\sigma_d^2\) denotes the power of complex additive white Gaussian noise (AWGN) of D2D transmitter. The composite fading channel includes a small and a large scale fading [7], which is modeled as

\[
h_{n,1} = g_{n,1} w_{n,1}
\]  \hspace{1cm} (3)

where \(g_{n,1}\) represents the small scale fading that can be modeled as independent and identically distributed complex Gaussian random variables for different RAUs with zero mean and unit variance, and \(w_{n,1}\) represents the large scale fading and is independent of \(g_{n,1}\). In this model, we ignore the shadowing effect. The large scale fading coefficient can be written as [17]

\[
w_{n,1} = \sqrt{\frac{cs_{n,1}}{d_{n,1}^\alpha}}
\]  \hspace{1cm} (4)

where \(c\) is the median of the mean path gain at a reference distance of \(d_{n,1} = 1\) km, \(d_{n,1}\) is the distance between the \(n\) th RAU and UE1, \(\alpha\) is the path loss factor and is typically between 3 and 5, and \(s_{n,1}\) is log-normal shadow fading variable, i.e., \(10\log_{10} s_{n,1}\) is a zero mean Gaussian random variable with standard deviation \(\sigma_{sh}\) [7], which are similar to the D2D pair.

**MAXIMUM SE OPTIMIZATION**

We consider the maximizing SE optimization of the downlink DAS with D2D communication under the constrain of satisfying the system's minimum SE requirements and overall transmit power of UE and D2D pair, which can be modeled as

\[
\max_{P_1^c, P_{23}^d} R_{D2D}^c = R_1^c + R_{23}^d \hspace{1cm} \text{s.t.} \hspace{0.5cm} R_1^c \geq R_{\text{min}}^c
\]
\[ 0 \leq p_{n,1}^c \leq p_{\text{max}}^c, \forall n \in [1, 2, \ldots, N] \]

\[ R_{23}^d \geq R_{\text{min}}^d \]

\[ 0 \leq p^d \leq p^d_{\text{max}} \quad (5) \]

where \( P^c = \{ p_{n,1}, n = 1, 2, \ldots, N \} \), \( p_{\text{max}}^c \) and \( R_{\text{min}}^c \) denote the maximum transmit power of RAUs and the requirement of the UE’s minimum data transmission rate, respectively. \( p^d_{\text{max}} \) and \( R_{\text{min}}^d \) denote the maximum transmit power and the requirement of the minimum data transmission rate of transmitter in D2D pair, respectively.

Adopting the sub-gradient iteration approach [15], we can obtain the optimal SE allocation solutions of (5) as following.

\[
p_{n,1}^{opt} = \left[ \frac{1 + \lambda}{\alpha_n \ln 2} - \frac{\sigma_c^2}{|h_{n,1}|^2} - \frac{\sum_{j=1,j\neq n}^N p_{j,1}^c |h_{j,1}|^2}{|h_{n,1}|^2} \right]^+ \quad (6)
\]

\[
p_d^{opt} = \left[ \frac{1 + \mu}{\gamma \ln 2} - \frac{\sigma_d^2}{|h_{2,3}|^2} \right]^+ \quad (7)
\]

where \( \lambda, \alpha_n, \mu \) and \( \gamma \) are the multipliers, which can be solved by using the following Lagrange multipliers update equations:

\[
\lambda^{(i+1)} = \left\{ \lambda^{(i)} - \nu^{(i)} \left[ \log_2 \left( 1 + \frac{\sum_{n=1}^N p_{n,1}^c |h_{n,1}|^2}{\sigma_c^2} \right) - R_{\text{min}}^c \right] \right\}^+ \quad (8)
\]

\[
\mu^{(i+1)} = \left\{ \mu^{(i)} - \varepsilon^{(i)} \left[ \log_2 \left( 1 + \frac{p^d |h_{2,3}|^2}{\sigma_d^2} \right) - R_{\text{min}}^d \right] \right\}^+ \quad (9)
\]

\[
\alpha^{(i+1)}_n = \left\{ \alpha^{(i)}_n - \delta^{(i)} \left[ p_{n,1}^c - p_{\text{max}}^c \right] \right\}^+ \quad (10)
\]
\[ \gamma^{(i+1)} = \{ \gamma^{(i)} - \zeta^{(i)} \left[ P_d - P_{\text{max}}^d \right] \}^+ \quad (11) \]

where \( [x]^+ = \max\{x, 0\} \), \( i \geq 0 \) is the iteration index, \( \nu, \varepsilon, \delta \) and \( \zeta \) are small positive step sizes. The Lagrange multipliers update equations are guaranteed to converge to the optimal \( \lambda, \alpha_n, \mu \) and \( \gamma \) as long as these step sizes are chosen to be sufficiently small. The detailed procedures of optimal sum rate power allocation algorithm are show in Table I.

**Table I. Optimal SE power allocation algorithm for DAS with D2D communication.**

| Algorithm 1 Optimal SE power allocation algorithm for DAS with D2D communication |
|---|
| 1. Initialization \( i = 0, \lambda = 0.01, \mu = 1, \gamma = 1, p^d = 0, p^e_{n,1} = 0 \) and \( \alpha_n = 0.01 \) for \( n = 1, 2, \ldots, N \). |
| 2. Calculate \( p^e_{n,1} \) and \( p^d \) according to equations (6) and (7). |
| 3. \( i = i + 1 \), according to (8), (9), (10) and (11), update \( \lambda^{(i+1)}, \mu^{(i+1)}, \alpha_n^{(i+1)}, \gamma^{(i+1)} \). |
| 4. If the multipliers \( \lambda, \mu, \alpha_n \) and \( \gamma \) are convergent, return \( p^e_{n,1}^* \) and \( p^d^* \), and stop the algorithm, otherwise, return to step 2. |

**MAXIMUM EE OPTIMIZATION MODEL**

**Total Power Consumption**

As the work discussed in [17], the total power consumption \( P_{\text{total}} \) contains three parts which is written as

\[ P_{\text{total}} = \frac{P}{\tau} + (N + 1)P_{dy} + P_{st} + P_0 \quad (12) \]
where in the first part $\tau$ is the drain efficiency of the radio frequency (RF) power amplifier. When DAS with D2D communication, the transmit power $P_t$ can be expressed as

$$P_t^{D2D} = \sum_{n=1}^{N} p_{n,1}^{c} + p_{n,1}^{d}$$  (13)

The second part $P_{dy}$ is the dynamic power consumption such as the frequency synthesizer, the mixer, the filters, etc., which is independent of the actual transmit power[18]. The third part $P_{st}$ is the static basic power consumption which is independent of the number of transmitter. The last part $P_0$ is the dissipated power by the optical fiber transmission.

EE Model

As in the most of literatures, the EE of a DAS can be defined as the ratio of the sum transmit rate over the total power consumption, which can be written as [7]

$$\eta_{EE} = \frac{R_{total}}{P_{total}}$$  (14)

Maximum EE optimization

We will discuss the maximum EE optimization and develop the corresponding optimal power allocation algorithms for DAS with D2D communication.

The objective of maximizing EE optimization for the downlink DAS under the constraints of satisfying the system’s minimum requirements of transmit rate of UE1 and D2D pair and the maximum transmit power of RAUs and the transmitter of D2D pair, which can be modeled as

$$\max_{v_c, p^d} \frac{R_{D2D}}{\frac{1}{\tau} \frac{P_{D2D}}{P_{t}^{D2D}} + (N + 1) P_{dy} + P_{st} + P_0}$$
\[ R_i^c \geq R_{\text{min}}^c \]
\[ 0 \leq P_{n,1}^c \leq P_{\text{max}}^c, \forall n \in [1, 2, \ldots, N], R_{23}^d \geq R_{\text{min}}^d \]
\[ 0 \leq P^d \leq P_{\text{max}}^d \] \hspace{1cm} (15)

where \( P_1^c = \{ p_{n,1}, \forall n \in [1, 2, \ldots, N] \} \).

Since the EE optimization problem in (15) is a non-convex and non-linear function, we cannot obtain the optimal solutions directly by adopting the traditional convex methods. By exploiting the fractional programming theory [16], we transform it into a subtract optimization problem, which can be expressed as

\[
\max_{P_1^c, P^d} h_1(P_1^c, P^d, \omega_1) \\
\text{s.t. all constrains in (15)} \] \hspace{1cm} (16)

where

\[
h_1(P_1^c, P^d, \omega_1) = R_{D2D} - \frac{\alpha_1}{\tau} P_{D2D} - \omega_1 (N + 1) P_{dy} - \omega_1 P_{st} - \omega_1 P_0 \]

We introduce the following Theorem to show the relationship between the optimization problems (15) and (16), which has been proved in [16].

**Theorem** Let \( G_1(\omega_1) = \max_{P_1^c, P^d} h_1(P_1^c, P^d, \omega_1) \) and \( g_1(\omega_1) = \arg \max_{P_1^c, P^d} h_1(P_1^c, P^d, \omega_1) \).

The optimal power allocation \([P_1^{c*}, P^{d*}]\) can achieve the maximum EE in (15) if and only if \( G_1(\omega_1^*) = 0 \) and \( g_1(\omega_1^*) = [P_1^{c*}, P^{d*}] \).

According to the theorem, there always exists an equivalent objective problem in (16) with subtractive form for the optimization problem in (15) with fractional form. We can focus on the equivalent objective problem with subtractive form and design optimal energy efficient power allocation algorithm to solve it. We can obtain the optimal solutions for problem (16) as follow.
where the multipliers $\lambda$, $\alpha$, $\mu$ and $\gamma$ can be solved by using sub-gradient method through the iteration equations of (8), (9), (10) and (11).

From the analysis above, we can obtain the optimal energy efficient power allocation algorithm of DAS with D2D communication, which shows in Table II.

| Algorithm 2: Optimal EE power allocation algorithm for DAS with D2D communication |
|-------------------------------------------------|
| 1. Initialization $\alpha_i = 0.01$, $G_i(\omega_i) = 1000$ and $\xi > 0$. |
| 2. While $G_i(\omega_i) > \xi$ |
| 3. Initialization $i = 0$, $\lambda = 0.01$, $\mu = 1$, $\gamma = 1$, $p^d = 0$, $p^c_{n,1} = 0$ and $\alpha_n = 0.01$ for $n = 1,2,\ldots,N$. |
| 4. Calculate $p^c_{n,1}$ and $p^d$ accroding to equations (17) and (18). |
| 5. $i = i + 1$, accroding to (8), (9), (10) and (11), update $\lambda^{(i+1)}$, $\mu^{(i+1)}$, $\alpha^{(i+1)}_n$, $\gamma^{(i+1)}$. |
| 6. If the multipliers $\lambda$, $\mu$, $\alpha_n$ and $\gamma$ are convergent, save $P^*_i$ and $p^d*$, then go to step 7. |
| 7. Calculate $G_i(\omega_i) = h_i(P^*_i, p^d, \omega_i)$ and update |
\[
\log_2 \left( 1 + \frac{\sum_{n=1}^{N} p_{n,1}^c |h_{n,1}|^2}{\sigma_c^2} \right) + \log_2 \left( 1 + \frac{p_{3}^d |h_{3,1}|^2}{\sigma_d^2} \right)
\]

\[
\omega_i = \frac{1}{\tau} \left( \sum_{n=1}^{N} p_{n,1}^c + p_{d}^d \right) + (N + 1) p_{d}^d + p_{st} + P_0
\]

8. End While

9. Return \( P_i^c \), \( P_i^d \) and \( \omega_i \).

SIMULATION RESULTS

In this section, we present numerical results to demonstrate the effectiveness of the combination of DAS and D2D communication. In the simulation, The cellular radius is 1000m. The D2D pair distance between 10m and 100m. The maximum transmit power of UE and D2D are 30dBm and 10dBm.

Fig.2 shows the change of average SE with respect to different maximum transmit power for different power allocation methods. It's easily obtain that the average SE of DAS with D2D communication is much better than DAS without D2D communication [18]. From Fig.2, when the maximum transmit power is 20 dBm, the average SE of using maximize system SE algorithm in DAS with D2D communication is approximately 54% higher than the same algorithm used in DAS without D2D communication, and the average SE of using maximize the system EE in DAS with D2D communication is 96% higher than the same algorithm used in DAS without D2D communication, which means D2D communication is a good way to save the system SE. Moreover, the maximum SE power allocation algorithm is better than the maximum EE power allocation algorithm in terms of average SE, especially when the maximum transmit power is large.

Fig.3 compares the average EE versus the maximum transmit power for different power allocation methods in different systems. It shows that the average EE of DAS by adding D2D communication is much better than the DAS without D2D communication [18]. When the maximum transmit power is 20dBm, the average EE of using maximize the system EE algorithm of DAS with D2D communication is about 170% higher than traditional DAS,
and the average EE of using maximize the SE algorithm of DAS with D2D communication is approximately 200\% higher than the average EE of using maximize SE algorithm in DAS without D2D communication. The average EE performance of the EE power allocation algorithm outperforms the other scheme, especially when the the maximum transmit power is large.

CONCLUSION

In this paper, we investigated two different optimization objectives for the downlink DAS with D2D communication. Through the sub-gradient iteration approach, the corresponding power allocation algorithm proposed to maximize SE. By exploiting fractional programming method, an effectively EE power allocation algorithm developed to maximize EE in DAS with D2D communication. Simulation results demonstrated the effectiveness of the proposed algorithms and we conclude that the average SE and EE of DAS with D2D communication are much better than the DAS without D2D communication.

![Figure 2. Average SE versus the maximum transmit power.](image-url)
Figure 3. Average EE versus the maximum transmit power.

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REFERENCES

1. You X. H. and Wang D. M., “Cooperative distributed antenna systems for mobile communications [coordinated and distributed MIMO],” IEEE Commun. Mag., vol. 17, no. 3, 2010.
2. Dai L., “An uplink capacity analysis of the distributed antenna system (DAS): From cellular DAS to DAS with virtual cells,” IEEE Trans.Wireless Commun., vol. 13, no. 5, pp. 2717–2731, 2014.
3. Roh W. and A. Paulraj, “Outage performance of the distributed antenna systems in a composite fading channel,” Proc. IEEE VTC, vol. 3, pp. 1520–1524, 2002.
4. Heath R., Peters S., Wang Y., and Zhang J., “A current perspective on distributed antenna systems for the downlink of cellular systems,” IEEE Commun. Mag., vol. 51, no. 4, pp. 161–167, 2013.
5. Choi W. and Andrews J. G., “Downlink performance and capacity of distributed antenna systems in a multicell environment,” IEEE Trans. Wireless Commun., vol. 6, no. 1, 2007.
6. Wang J., Zhu H., and Gomes N. J., “Distributed antenna systems for mobile communications in high speed trains,” IEEE J. Sel. Areas Commun., vol. 30, no. 4, pp. 675–683, 2012.
7. He C. L., Sheng B., Zhu P., You X., and G. Li, “Energy-and spectral efficiency tradeoff for distributed antenna systems with proportional fairness,” IEEE J. Sel. Areas Commun., vol. 31, no. 5, pp. 894–902, 2013.
8. Pan C., Xu W., Wang J., Ren H., Zhang W., Huang N., and Chen M., “Pricing-based distributed energy-efficient beamforming for MISO interference channels,” IEEE J. Sel. Areas Commun., vol. 34, no. 4, pp. 710–722, 2016.
9. Cho Karakus C. and Diggavi S., “Enhancing multiuser MIMO through opportunistic D2D cooperation,” IEEE Trans. Wireless Commun., 2017.
10. Chen X. and Zhang J., “When D2D meets cloud: Hybrid mobile task off loadings in fog computing,” IEEE ICC, pp. 1–6, 2017.
11. Jo M., Maksymyuk T., Strykhalyuk B., and Cho C. H., “Device-to-device based heterogeneous radio access network architecture for mobile cloud computing,” IEEE Trans. Wireless Commun., vol. 22, no. 3, pp. 50–58, 2015.
12. Zhu D., Wang J., Swindlehurst A. L., and Zhao C., “Downlink resource reuse for device-to-device communications underlaying cellular networks,” IEEE Signal Process. Lett., vol. 21, no. 5, pp. 531–534, 2014.
13. Xu H., Xu W., Pan Z. Y., Shi J., and Chen M., “Energy-efficient resource allocation in D2D underlaid cellular uplinks,” IEEE Commun. Lett., vol. 21, no. 3, pp. 560–563, 2017.
14. Hu J., Heng W., and Li X., “Energy-efficient resource reuse scheme for D2D communications underlaying cellular networks,” IEEE Commun. Lett., 2017.
15. Palomar D. P. and Chiang M., “A tutorial on decomposition methods for network utility maximization,” IEEE J. Sel. Areas Commun., vol. 24, no. 8, pp. 1439–1451, 2006.
16. Dinkelbach W., “On nonlinear fractional programming,” Management science, vol. 13, no. 7, pp. 492–498, 1967.
17. You X. H., Wang D. M., Zhu P., and Sheng B., “Cell edge performance of cellular mobile systems,” IEEE J. Sel. Areas Commun., vol. 29, no. 6, pp. 1139–1150, 2011.
18. He C., “Comparison of three different optimization objectives for distributed antenna systems,” AEU-INT J ELECTRON C, vol. 70, no. 4, pp. 442–448, 2016.