Energy-Efficient Device-to-Device Communication
Overlying Cellular Networks with Cluster Relays

Chaowen Liu1, Chunlong He1,2, Xingquan Li1, Lei Huang1 and Ying Liu1

1 Shenzhen Key Lab of Multi-dimensional Signal Processing, College of Information Engineering, Shenzhen University, Shenzhen, 518060, China.
2 National Mobile Communication Research Laboratory, Southeast University, Nanjing, 210096, China.
Email: chunlonghe@163.com

Abstract. In this paper, we investigate the transmission capacity and energy efficiency (EE) of device-to-device (D2D) cluster assisted communication in co-located antenna system (CAS) with dedicated mode. We propose a novel cluster coalition algorithm (CCA) that first select appropriate cluster head (CH), then consider user equipments (UEs) cooperation which form coalitions of satisfying certain factors (channel quality and geometry distance) to improve EE and capacity. We compare EE and capacity of traditional CAS with adding cluster into CAS under different power consumption models. Simulation results verify that capacity and EE can be enhanced by developed CCA, which shows taking cluster multicast into CAS is a good way to improve the EE and capacity of CAS.

1. Introduction

Information and communication technology is playing an increasingly important role in global greenhouse gas emissions since the amount of energy consumption increasing dramatically with the exponential growth of service requirements [1]. Energy saving is very important in wireless communication because mobile devices have been limited by battery resources. Therefore, it’s more and more important to pursue high EE in wireless communication in the future. Meanwhile D2D cluster multicast technology [2, 3, 4, 5] has been proposed as a good way to enhance the capacity and EE. D2D cluster can be further improved by enabling cluster multicasting form group communication. In the literature, researchers usually only pay attention to the number of UEs versus the cluster numbers and average size of intra-cluster UEs, respectively. Lot of works have been verified that the effect of D2D cluster could reduce the average delay and the transmission power of the cluster members [6, 7, 8, 9]. What’s more, D2D cluster could extend the coverage [10] and increase the capacity [11]. However, there was few works find efficient ways to create appropriate clusters to improve the capacity and EE of system.

In this paper, we propose a novel cluster coalition algorithm (CCA) base on two different standards (distance and SINR) to form cluster coalition, then consider the comparison of EE and capacity of D2D cluster assist communication and direct link communication in idealistic and reality energy model, respectively. The novelty of this paper is aimed to investigate the performance of cluster multicast communication in the downlink (DL) of single cell, and the most important is the method of form coalition clusters. We also analysis the tendency concerning capacity and EE when cluster coalition factors change.

The rest of this paper is organized as follows. The system model and the total power consumption models are presented in the section 2. Section 3 propose a novel cluster coalition algorithm aim to
improve the EE and Capacity in a dedicated cellular system. In Section 4, simulation results are described to verify the effectiveness of the developed algorithms compared to the condition without D2D cluster communication. Section 5 concludes the paper.

2. System Model
Figure 1 shows a cellular system consisting of one omnidirectional BS located in the center of cell. There are K UEs randomly distributed in cell, for the convenience of analysis, we assume that the channels are orthogonal, so there is no interference among UEs. We also assume the BS has perfect channel state information (CSI) of all links and can schedule proper resource for users, including power, spectrum.

![System model](image)

Figure 1. System model.

In this paper, we assume the total system bandwidth as BW, so the transmission rate of UE $k$ for the downlink CAS can be expressed as [12]

$$R_k^c = \frac{BW}{K} \log_2 \left( 1 + \frac{P_k^c h_{B,k}}{\sigma_k^2} \right),$$

where $P_k^c$ denotes the transmit power of UE $k$, and both fast fading and shadowing for the channels are considered [13], the channel power gain between the BS and user $k$ can be expressed as $h_{B,k}$ i.e. $c_0 \zeta_{B,k} \beta_{B,k} d_{B,k}^{-\alpha}$ and the channel power gain between CH $k$ and CM $j$ is calculated as $c_0 \zeta_{k,j} \beta_{k,j} d_{k,j}^{-\alpha}$, where $c_0$ and $\alpha$ are the pathloss constant and exponent, respectively. $\zeta_{k,j}$ and $\beta_{k,j}$ are the fast fading gain with exponential distribution and slow fading gain with log-normal distribution, respectively, and $d_{k,j}$ is the distance between the transmitter $k$ and the receiver $j$. $\sigma_k^2$ denotes the power of complex additive white Gaussian noise (AWGN). So the average sum transmit rate of CAS can be written as

$$R_{total}^c = \sum_{k=1}^{K} R_k^c.$$
While adding D2D cluster communication into the CAS, the total system capacity is the sum of three parts: The first part is the capacity of a single user using traditional cellular communications, the second part is the transmission capacity of the BS to the cluster heads, the transmit power of each cluster head is equal to the BS transmit power divided by the number of cluster heads, and the third part is the transmission capacity of the cluster heads to the cluster members. So the average capacity of the CAS that joins the D2D cluster can be expressed as following:

\[ R_{BS-CH} = \frac{BW}{K} \log_2 \left( 1 + \frac{P_i / n}{\sigma_k^2} \right), \]  
\[ R_{CH-CM} = \frac{BW}{K} \log_2 \left( 1 + \frac{P_i / n (D / n)}{\sigma_k^2} \right), \]
\[ R_{total-d2d} = \sum_{k=1}^{U} R_{k}^c + \sum_{i=1}^{n} R_{BS-CH(i)}^c + \sum_{j=1}^{D} R_{CH-CM(j)}^c. \]

where \( U \) is the number of remaining traditional communication users, \( n \) is the number of cluster heads, \( D \) is the total number of cluster members.

2.1. Total Power Consumption Model

We consider that EE from two different Power models, as the work discussed in [14, 15], the total power consumption \( P_{real} \) in the realistic condition of the CAS contains three parts which is written as

\[ P_{real} = \frac{P_{total}}{\eta} + \eta P_{dyn} + P_{sta}. \]

In the realistic scenario, Where in the first part \( \eta \) is the drain efficiency of the radio frequency (RF) power amplifier, then the transmit power \( P_{total} \) of traditional CAS can be expressed as

\[ P_{total} = \sum_{k=1}^{K} P_{k}^c. \]

After adding D2D cluster communication, the transmit power \( P_{total} \) can be expressed as

\[ P_{total} = \sum_{k=1}^{U} P_{k}^c + \sum_{j=1}^{D} P_{CM}^c. \]

Where \( P_{CM}^c \) is the transmit power of the \( j \)th D2D cluster member. i.e. D2D cluster member transmit power is equal to the sum transmit power of cluster heads. The second part \( P_{dyn} \) is the dynamic power consumption such as the frequency synthesizer, the mixer and the filters, etc. which is independent of the actual transmit power [16]. When the CAS adding D2D communication, the coefficient of \( P_{dyn} \) is equal to transmit terminal numbers i.e. \( \eta = n+1 \), otherwise it is equal to BS antenna number in CAS. i.e. \( \eta = 1 \). The last part \( P_{sta} \) is the static basic power consumption which is independent of the number of transmitter [17]. While in idealistic scenario, we just consider first part of the model items, i.e. the dynamic and static power consumption can be ignored, so the power consumption model can simplify be written as
\[ P_{\text{real}} = \frac{P_{\text{total}}}{\tau}. \] (9)

2.2. EE Model

In the many of literatures, the EE of a CAS is defined as the ratio of the sum transmit rate over the total power consumption, which can be written as [18, 19]

\[ \eta_{EE} = \frac{R_{\text{total}}}{P_{\text{total}}} . \] (10)

Where \( P_{\text{total}} \) is the sum transmit power of system. The total power consumption model is equation (6) under the realistic condition; otherwise ideal condition is equal to equation (9), respectively.

3. Cluster Coalition Algorithm Formulation

Due to the D2D cluster communication is a useful method to improve the performance of CAS; we propose two algorithms to find appropriate UEs to form appropriate D2D clusters. The CCA can be implemented following two phases: the first is to select the appropriate CH from UEs; the second step is to identify the appropriate cluster members (CM) and associate them with cluster heads. We propose these two algorithms base on different standards and the details are shown as following:

3.1. D2D Cluster Choosing Algorithm Base on Distance Selection

Base on distance, we first calculate the distance indicator between UEs and the BS, and the distance among UEs. We considering that the UEs distance is far away from BS more than \( R/2 \) as to potential CH, and then if the distance between CH \( (k) \) and other UEs is less than the \( 1/20, 1/10, 1/4 \) of cell radius, we will put satisfied UEs into the same virtual cluster. The specific selection algorithm as following:

Table 1. D2D cluster choosing algorithm base on distance selection.

| Algorithm 1 Cluster Coalition algorithm (Distance) |
|-----------------------------------------------|
| 1: Initialization K UEs randomly located in the cell, user number \( s = 0 \), cluster number \( n = 0 \), user label tag \( l = 1 \). |
| 2: Calculate Euclidean distances of overall UEs to BS \( dis(k) \) and inter-user distances \( dis(k, j) \), \( k=1,2...,K, j=1,2...,K \). |
| 3: Repeat |
| 4: for \( k=1:K \) |
| 5: if \( dis(k) > R/2 \) , take \( k \) as the Prime UEs, set tag \( l(k) = 1, s = s+1, n = n+1 \), for \( j=1:K \) |
| if \( dis(k, j) \leq \text{threshold value} \) & \( tag(j) != 1 \), take the UEs \( j \) as cluster member add to CH \( k \), \( s = s+1 \). |
| end if |
| end for each |
| end if |
| end for each |
| 6: Until \( s = K \). |
| 7: Return cluster number \( n \). |
3.2. D2D Cluster Choosing Algorithm Base on SINR Selection

In this part, our algorithm is base on SINR, which is similar to the former. The channel quality is represented as the SINR value of UEs to BS. We choose the above average value of UEs SINR from CAS as the potential D2D CHs. Then the SINR among the UEs $\text{CM}(k, j)$ is more than threshold value (3dB,10dB,15dB) will be added into the same virtual cluster.

| Algorithm 2. D2D cluster choosing algorithm base on SINR selection. |
|---------------------------------------------------------------|
| 1: **Initialization** K UEs randomly located in the cell,      |
| user number $s = 0$, cluster number $n=0$, user label tag $2 = 0$. |
| 2: Calculate SINR of overall UEs to BS $CH(k)$ and     |
|     Between inter-user SINR $CM(k, j)$,     |
|     $k=1,2,...,K$, $j=1,2,...,K$.             |
| 3: **Repeat**                                    |
| 4: **for** $k=1:K$                                |
|     if $CH(k) \geq$ average SINR value of the CAS,     |
|     take $k$ as the Prime UEs, set tag2$(k) = 1$, $n=n+1$, $s=s+1$. |
|     **for** $j=1:K$                                |
|     if $CM(k, j) \geq$ threshold value & tag2$(j) \neq 1$ |
|     take the UE $j$ add to CH $k$ to form D2D cluster sets, $s=s+1$. |
|     **end if**                                     |
|     **end for each**                              |
| **end if**                                        |
| **end for each**                                  |
| **5: Until** $s = K$.                             |
| **6: Return** cluster number $n$.                 |

4. Numerical Results

We present numerical results to demonstrate the effectiveness of the CCA proposed in the paper. The system parameters in the simulations are listed in the Table 3, and the simulation results were calculated through 1000 iterations.

| Table 3. Simulation Parameters.                  |
|------------------------------------------------|
| Parameters          | Value   |
| The cellular radius $R$          | 1000m   |
| The UE number $K$                | 100     |
| The bandwidth Size BW           | 1.25MHz |
| Constant of the pathloss $c_0$   | 0.01    |
| The noise power $\sigma_0^2$     | $114\text{dBm}$ |
| The dynamic power consumption $P_{\text{dyn}}$ | 20dBm |
| The static power consumption $P_{\text{sta}}$ | 30dBm |
| The maximum transmit power $P_t$  | 5~45dBm |
| Path loss exponent $\alpha$      | 4       |
| Drain efficiency $\tau$          | 38%     |
4.1. The Analysis of System Capacity

**Figure 2.** Capacity versus the BS transmits power in Distance cluster coalition algorithm.

**Figure 3.** Capacity versus the BS transmits power in SINR cluster coalition algorithm.

Figure 2 and figure 3 show the total achievable capacity of the DL cellular networks. The proposed D2D CCA used in CAS can lead to considerable performance compared to the traditional cellular communications. And along with relief the constraint of cluster coalition factor (distance and SINR), we could see that loosen CCA performance is better than the strict selection condition. Meanwhile we can derive that the little BS transmit power have not apparently effect on cluster coalition factor.
4.2. The Analysis of System EE

Figure 4. EE versus the BS transmit power in idealistic energy model of distance factor.

Figure 5. EE versus the BS transmit power in realistic energy model of distance factor.

Figure 6. EE versus the BS transmit power in idealistic energy model of SINR factor.
Figure 7. EE versus the BS transmit power in realistic energy model of SINR factor.

Figure 4–figure 7 show the DL average EE versus maximum transmit power results. Huge gains are achieved by CCA compared to the CAS scenarios. From figure 4 and figure 6, it's easy to find that the systems EE decreases with the growth of transmit power in the idealistic power consumption model of two different CCA. No matter which algorithm we use, the CAS with D2D cluster is better than traditional CAS. EE of the systems will slightly increase when loosen restrict condition in the same model.

Figure 5 and figure 7 show that EE in the realistic power model of these two different cluster coalition algorithms under the same condition. In these figures, the tendency of EE increases at first and then decreases with the growth of the BS transmit power. We can find a preferable transmit power (interval of 27–30dBm) that can approach the peak of EE. And relaxed the cluster form standard, i.e. the distance or SINR of UEs to the BS, there will be more appropriate UEs added to virtual cluster and corresponds to EE increase gradually.

5. Conclusion

In this paper, we proposed two different algorithms to form clusters from UEs base on SINR and distance standards to reduce data traffic and energy consumption from CAS. Numerical results demonstrate that the effectiveness of using properly cluster coalition algorithms in CAS. For future research, we will plan to investigate a scenario with multiple cells.

6. Acknowledgments

This work was supported by the Natural Science Foundation of China under grants 61601300, the Natural Science Funding of Guangdong Province No. 2017A030313336, the Open Research Fund through the National Mobile Communications Research Laboratory, Southeast University, Nanjing, China, under Grant 2017D10, the Science and Technology Innovation Commission of Shenzhen under Grants JCYJ20160331114526190, New teacher natural science research project of Shenzhen University, Shenzhen University start-up funding No.2016053, Tencent “Rhinoceros Birds” Scientific Research Foundation for Young Teachers of Shenzhen University.

7. References

[1] Arnold O, Richter F, Fettweis G and Blume O 2011 Proc. Int. Conf. on Future Network and Mobile Summit Power consumption modeling of different base station types in heterogeneous cellular networks (Florence, Italy) pp1-8
[2] Zhao P, Feng L, Yu P, Li W, and Qiu X 2017 J. IEEE Access A social-aware resource allocation for 5g device-to-device multicast communication pp 99
[3] Zhang G, Yang K and Chen H H 2016. Socially aware cluster formation and radio resource allocation in d2d networks. IEEE Wireless Communications 23(4) pp 68-73.

[4] Liang L, Wang W, Jia Y and Fu S 2016 J. IEEE Access A cluster-based energy-efficient resource allocation management scheme for ultra-dense networks 4 (99) pp 6823-6832.

[5] Liu X, Li J, Dong Z and Xiong F 2017 J. IEEE Access Joint design of energy-efficient clustering and data recovery for wireless sensor networks 5(99) pp 3646-3656.

[6] Seppälä J, Koskela T, Chen T and Hakola S 2011 IEEE Wireless Com. and Net. Conf. on Network controlled Device-to-Device (D2D) and cluster multicast concept for LTE and LTE-A networks (Cancun, Mexico) vol 34 pp 986-991

[7] Militano L, Orsino A, Araniti G, Molinaro A and Iera A 2016 J. IEEE Trans. on Wireless Communications A constrained coalition formation game for multihop d2d content uploading 15(3) pp 2012-2024

[8] Shen Y, Jiang C, Quek T Q S and Ren Y 2016 J. IEEE Trans. on Wireless Communications Device-to-device-assisted communications in cellular networks: an energy efficient approach in downlink video sharing scenario 15(2) pp 1575-1587

[9] Narottama B, Fahmi A and Syihabuddin B 2016 IEEE Asia Pacific Conf. on Wireless and Mobile (Bandung, Indonesia) Impact of number of devices and data rate variation in clustering method on device-to-device communication pp 233-238

[10] Afshang M, Dhillon H S and Chong P H J 2015 Proc. Int. Conf. on Global Communications (San Diego, USA) Coverage and Area Spectral Efficiency of Clustered Device-to-Device Networks pp1-6

[11] Zhou Y 2013 J. auto control Performance evaluation of a weighted clustering algorithm in nsps scenarios

[12] He C 2016 J. AEU Electro. Commu. Comparison of three different optimization objectives for distributed antenna systems 70(4) pp 442-448

[13] Feng D, Yu G, Xiong C, Yi Y W, Li G Y and Feng G et al. 2015 J. IEEE Trans. on Wireless Communications Mode switching for energy-efficient device-to-device communications in cellular networks 14(12) pp 6993-7003

[14] Ng D W K, Lo E S and Schober R 2012 J. IEEE Trans. on Wireless Communications Energy-efficient resource allocation in ofdma systems with large numbers of base station antennas 11(9) pp 3292-3304

[15] He C, Li G Y, Zheng F C and You, X 2015 Proc. Int. Conf. on Signal and Information(Chengdu ,China) Energy efficiency of distributed MIMO systems pp 218-222

[16] Arnold O, Richter F, Fettweis G and Blume O 2011 Proc. Int. Conf. on Future Network and Mobile Summit Power consumption modeling of different base station types in heterogeneous cellular networks (Florence, Italy) pp1-8

[17] Nagayama K, Kakui M, Matsui M, Saitoh T and Chigusa Y 2002 (OSA Publishing:optics express) Ultra-low-loss (0.1484 db/km) pure silica core fibre and extension of transmission distance 38(20) pp 1168-1169

[18] Xu J and Qiu L 2013 J. IEEE Trans. on Wireless Communications Energy efficiency optimization for mimo broadcast channels 12 (2) pp 690-701

[19] Rui Y, Zhang Q T, Deng L, Cheng P and Li M 2013 J. Selec. Area. Commu. Mode selection and power optimization for energy efficiency in uplink virtual mimo systems 31(5) pp 926-936

[20] Li X, He C, Huang L, Zhang C and Zhang J 2017 AEU J. Electro. Commu. Energy efficient power allocation for co-located antenna systems with d2d communication 11 p 03003.

[21] Yaacoub E and Kubbar O 2013 Proc. Conf. GLOBECOM Workshops (Atlanta, Georgia) Energy-efficient Device-to-Device communications in LTE public safety networks pp 391- 395

[22] Doumiati S, Artail H and Kabalan K 2017 Proc. Int. Conf. on Information and Communication Systems (Irbid, Jordan) A framework for clustering LTE devices for implementing group D2D communication and multicast capability pp 216-221