Energy Efficient Channel Sharing and Power Optimization for Device-to-Device Networks

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Abstract. In device-to-device (D2D) networks, the system performance can be significantly improved with a well resource allocation scheme. In this paper, the issue of channel sharing and power allocation for device-to-device (D2D) communications underlaying cellular networks is considered. The users with the same service content are categorized into clusters, with clusters sharing the frequency of the uplink users. With this non-orthogonal frequency sharing, the energy efficiency of different type of users, i.e., the uplink users or the D2D users, is analysed. The energy-efficient resource sharing problem is further formulated into a non-transferable coalition formation game, and several related factors of the game is described. A distributed coalition formation game algorithm based on the merge and split rule is proposed. With numerical results, the effectiveness of the game model and the algorithm is demonstrated.

Keywords: Energy efficiency (EE) · Device-to-device (D2D) communication · Coalition formation game · Resource sharing

1 Introduction

The substantial increase of network elements and users explosive data traffic requirements is the inevitable trend of todays wireless network, which brings a serious challenge for network management and business delivery. In order to improve the service efficiency and satisfy the users' service quality, resource allocation in heterogeneous network has been fully studied. [1] describes a network architecture which combines cloud radio access network with small cells, while [2] maximize the total capacity of all femtocell users without ignoring the fairness and the spectrum sensing errors. [3] proposes a novel semidynamic clustering scheme based on affinity propagation for picocell to maximize users spectrum efficiency and throughput, and [4] introduces a network architecture where small cells use the same unlicensed spectrum that Wi-Fi systems operate in without affecting the performance of Wi-Fi systems. However, the energy efficiency of the network is ignored in most of the existing studies. The energy consumption

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is tightly coupled with the scale of users, and the diversity of user distribution not only leads to the heterogeneity of radio channel and the poor communication conditions for some users, but also seriously affects the energy efficiency on the network side and the battery life. Note that the convergence of service and content is one of the salient features of wireless networks. [5,6] have shown that users in the same access point often have the similar service content request, and geographically adjacent users may have a similar content request. With such similarity in service content, user collaboration based on D2D transmission can take the advantage of the heterogeneity of multi-user channels and improve the energy efficiency.

In such D2D transmission underlaying cellular networks, interference need to be carefully considered. Frequency allocation between the potential D2D clusters and uplink users is an crucial issue. Distributed resource allocation algorithms which are based on the reverse iterative combinatorial auction (ICA) game and the bisection method were proposed in [7,8]. However, the quality of service (QoS) provisioning issue is not considered and no close-form solution has been derived. Centralized resource allocation algorithms for optimizing the energy efficiency in the device-to-multidevice (D2MD) and D2D-cluster scenarios were explored in [9,10]. However the computational complexity is high and the signalling is increasing significantly with the number of user equipments (UEs), it's hardly for the base station to deliver the information to the user equipments within the channel coherent time in practical. In [11] an auction-based resource allocation algorithm was proposed to maximize the battery lifetime, but the energy efficiency of cellular UEs were neglected.

In this paper, a coalition formation game model is proposed for resource sharing in mobile D2D communications underlaying cellular networks. As a useful tool to model the complex interactions among users while accounting for the inherent benefit-cost trade-off in [12], coalition formation game theory can be well qualified to design the resource sharing scheme for D2D communications [13]. In particular, the proposed resource sharing scheme is more practical than the previous works.

The main contributions of this paper are as follows: (1) Different from previous works aim at one potential D2D pair or cluster [14,15], the proposed scheme is suitable for multiple potential D2D clusters and multiple uplink users, which is more general. (2) An novel energy efficiency equation for nonorthogonal D2D communications is proposed, both the spectrum utilization and QoS constraints are considered. (3) The resource sharing problem is modeled as a non-transferable coalition formation game. With the process of coalition formation and the resulting partition, the joint optimization of channel sharing and power optimization is addressed. Compared with [16,17], our coalition formation algorithm is distributed, which allows the users to adapt to the environmental changes. And the proposed scheme is more flexible for the data-requesting users than other schemes such as in [18].

The rest of this paper is organized as follows: Sect. 2 introduces the system model of the D2D communication underlaying cellular networks. In Sect. 3, the resource sharing problem is formulated as a non-transferable coalition formation game, and an algorithm is proposed for the game to obtain the stable coalition structure. In Sect. 4, the algorithm is validated with numerous simulations. Section 5 gives the conclusion.

2 Network Model

We consider a single-cell network, the radius of which is R and a base station (BS) is located at the center. There are N users distributed randomly in the network, communicating with the BS through the uplink channel, they called uplink users. Moreover, there are M users requesting the same business content, the popular content could be a live show or a hot video. The M users called data-requesting users. Since they all need the same data, the data could be relayed from one user to another. These users could be composed into several collaboration clusters, and every cluster has one cluster head which receives traffic data from the BS through long-range communication, and then distributes the data to the other users within the cluster by short-range communications. Note that the short-range communications are operated in the form of broadcast. Especially, the relay in the cluster will reuse the uplink of some uplink users. Several clusters may be built, and there will always be some data-requesting users not in any cluster. The BS will regard the independent data-requesting users as normal downlink users.

The clusters are constructed basing on the distance relationship, and not every data-requesting users can be in a cluster. Let d be the maximum distance of D2D link, if the distance between two data-requesting users is less than d, then each of them has one neighbor. The user with the most neighbors is selected as the cluster head, and it will form a cluster with its neighbors being the corresponding cluster tails. The next cluster will be formed from the rest data-requesting users, and the cluster formation process will continue until the leaving data-requesting users have no neighbor.

As illustrated in Fig. 1, uplink users U_1, U_2, U_3, U_4 are communicating with the BS using different frequency band with a bandwidth normalized to one. There are seven data-requesting users requesting the same service content, and they are divided into three parts CL_1, CL_2, S_1. Note that CL_1, CL_2 are clusters. The cluster head in CL_1 transmits the data to its tails using the uplink of U_1 and U_3, while the cluster head in CL_2 reuses the uplink of U_2 for the short-range communications. There is only one user in S_1, which means the user has no neighbor within d, so it communicate with the BS directly.

From the aspect of green communication, we take the EE of each transmission link as the performance metric for the users. For every user in the network, including the uplink users and the data-requesting users, the EE of them is defined as the ratio of the throughput and the total power of the user's link. More precisely, the EE of the uplink user is the energy efficiency of data sending, while the EE of the data-requesting user is the energy efficiency of data receiving. And the total power of one link is consisted of two parts: the power of the power

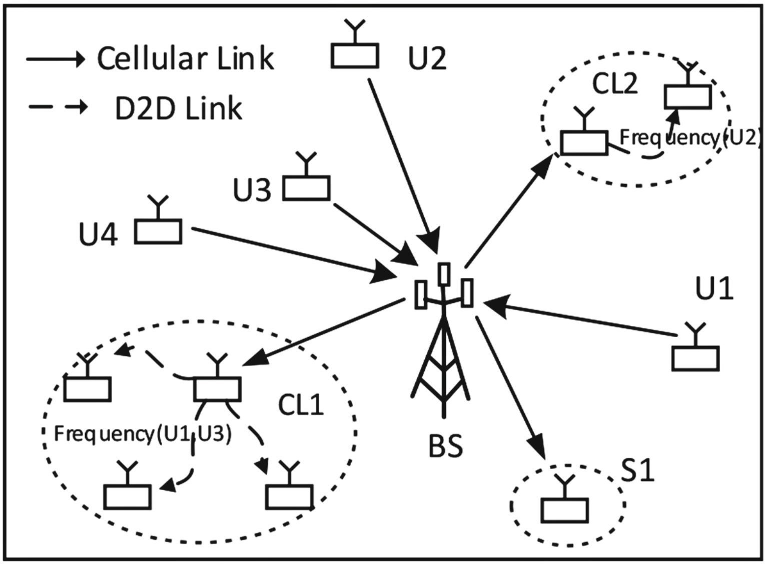

Fig. 1. A single-cell D2D underlaid cellular system

amplifier (PA) and the power consumed by circuit blocks of both the transmitter and the receiver. The corresponding functions are as follows:

$$EE = T/P_{link} \tag{1}$$

$$P_{link} = P_{pa} + P_{ct} + P_{cr} \tag{2}$$

$$P_{pa} = KP_t \tag{3}$$

T is the throughput of one user, while P_{link} is the total power of the link. P_{pa} is the power of the PA, and P_t is the transmit power. The ratio of them is K, which is a value related to the modulation scheme. P_{ct}, P_{cr} respectively represents the power of the circuit blocks of the transmitter and the receiver, which remains the most basic function.

In order to obtain the EE of one user, two parameters must be ensured, the throughput of the user and the total power of the link. Generally, the first parameter can be set as the minimum required throughput, which also represents the QoS of the user. So the requirement of the user is satisfied. Once the throughput is setted, using Shannon's theorem the value of the received signal-to-interference-plus-noise ratio (SINR) can be calculated. After that, using the information of the interference and the noise, the transmit power of the link could be computed. Since the power of the circuit blocks of the transmitter and the receiver are known, the second parameter can be acquired.

The parameters of the uplink users, the cluster head users, and the data-requesting users with no neighbor are obtained using the following equations:

$$T = Blog_2(1 + SINR) \tag{4}$$

$$SINR = P_t H/N \tag{5}$$

B is the bandwidth of the link, P_t is the transmit power of the link. H is the channel gain from the transmitter to the receiver, and N is the noise. Since no user occupy the other users' resource, no interference considered.

For the tail users in the clusters and the uplink users who share their resource with the clusters, the calculation is complicated because of the mutual interference. The analysis is as follows.

First of all, the most remote tail user is studied. Assuming there is only one tail user in each cluster, and the user is the most remote one for the cluster head. Establish the equations of SINR and throughput of the single tail user and the resource-sharing uplink users, the corresponding transmit power can be calculated.

$$T_{tail} = B_t log_2(1 + SINR_{tail}) \tag{6}$$

$$SINR_{tail} = P_{t,ch} H_{ch,tail} / (\sum_{i=1}^{M} P_{t,u} H_{u,tail} + N) \tag{7}$$

$$T_{uplink} = B_u log_2(1 + SINR_{uplink}) \tag{8}$$

$$SINR_{uplink} = P_{t,u} H_{u,B} / (P_{t,ch} H_{ch,B} + N) \tag{9}$$

For the sake of simplicity, the most remote tail user is called single tail. T_{tail} is the throughput of the single tail, while the SINR of the single tail is $SINR_{tail}$. B_t is the bandwidth of the link of the single tail. $P_{t,ch}$ is the transmit power of the cluster head, and $H_{ch,tail}$ is the channel gain from the cluster head to the single tail. Similarly, the transmit power of the resource-sharing uplink user is $P_{t,u}$, and the channel gain from the uplink user to the single tail is $H_{u,tail}$, the product of the two value is the interference for the single user. There may be several uplink users sharing the resource with one cluster, so the interference is additive. For each resource-sharing uplink user, the throughput, bandwidth, and SINR are respectively denoted by T_{uplink}, B_u, and $SINR_{uplink}$. $H_{u,B}$ is the channel gain from the uplink user to the BS, and $H_{ch,B}$ is the channel gain from the cluster head to the BS. Using the equations, the value of $P_{t,ch}$ and $P_{t,u}$ can be ensured with the value of T_{tail} and T_{uplink}.

Secondly, the remaining cluster tails are discussed. As for the data-requesting user who is a tail user of one cluster but not the most remote one, both the two parameters depend on the most remote tail user. The transmit power of the link of the data-requesting user equals the transmit power from the cluster head to the most remote tail user. And then the throughput is obtained according to this power and the corresponding interference and noise. While the most remote tail user just meet the minimal throughput requirement, the throughput of the other tail users are higher.

$$SINR_{rt} = P_{t,ch} H_{ch,rt} / (\sum_{i=1}^{M} P_{t,u} H_{u,rt} + N) \tag{10}$$

$$T_{rt} = B_{rt} log_2(1 + SINR_{rt}) \tag{11}$$

$P_{t,ch}$ and $P_{t,u}$ have been calculated above. These data-requesting users are called the rest tails. And for each rest tail, the SINR and the channel gain from the cluster head to it are respectively denoted by $SINR_{rt}$ and $H_{ch,rt}$. $H_{u,rt}$ is the channel gain from the resource-sharing uplink user to the rest tail. The interference come from the same uplink users who share the resource with the most remote tail user, and the interference is additive. When $SINR_{rt}$ is obtained, we can use the bandwidth B_{rt} to get the throughput of this tail user T_{rt}.

The value of EE depends on the resource sharing result, so the problem of D2D resource allocation can be described as a process of the match between the uplink users and the D2D clusters.

3 Coalition Formation Game and the Solution

In order to solve the joint problem of uplink resource allocation and power management, the energy-efficient uplink resource sharing problem is modelled as a non-transferable coalition formation game. After weighing the benefits of the improvement of EE and the loss caused by mutual interference, the final match relationship will be obtained.

In the coalition formation game, several related factors are defined as:

Player: The set of game players is defined as X, which includes all of the uplink users and the data-requesting users. And they all attempt to merge with others to get the collection of coalitions more stable, and get all the EE improved.

Strategy: The collection of coalitions is defined as L, which describes the match relationship of the uplink users and the data-requesting users.

Utility: The characteristic function of a coalition is defined as CF, the value of which is based on the EE of the users in this coalition. Take coalition L_i as an example:

$$CF(L_i) = \{u_1(L_i), u_2(L_i), ..., u_r(L_i), ..., u_{|L_i|}(L_i)\} \tag{12}$$

$CF(L_i)$ is a vector, and $u_r(L_i)$ is the utility of player $r \in L_i$.

Since coalition L_i is obtained from the resource reused relationship between clusters and uplink users, the users in L_i have the following cases. In the first case, coalition L_i has only one user, which could either be an uplink user or a data-requesting user. None uplink resource will be reused and $u_r(L_i) = EE_r$. In the second case, coalition L_i contains one D2D cluster, which means no uplink users will share resource with this cluster. In this paper, D2D cluster is treated as an inseparable entity. The users in the D2D cluster will directly receive data from the BS and $u_r(L_i) = EE_r$. In the third case, coalition L_i consists of one D2D cluster and several uplink users who share their resource with the cluster. For an arbitrary user in the cluster, the utility is expressed as $u_r(L_i) = EE_r$. However, the utility expression of the uplink users can not be as simple as that. On the one hand they suffer from the interference from the D2D cluster, the energy efficiency would surely be reduced. On the other hand, they are inspired to share their resource. Therefore the utility must be adjusted. So the utility of the uplink users are defined as $u_r(L_i) = EE_r + \mu(u_{CL_i}(L_i) - u_{CL_i})$, where μ is a positive constant and CL_i is the cluster in coalition L_i. The second part of the utility is a compensate function, which indicates that the improvement of the utility of CL_i will be rewarded to the uplink users. Here the utility of CL_i is defined as the utility of the most remote tail user.

The case one uplink user share the resource with more than one cluster is not concerned, because the interference is too much. And the probability of a coalitions formation decrease with the increase in the number of uplink users in the coalition, for the costs limit the advantage. By well performing the uplink users' resource sharing, the utility of all users can be improved at the same time, and the new coalition structure are more beneficial.

The utility obtained by every user is related to the rest users in its coalition, and the coalition value cannot be arbitrarily apportioned among them, so the coalition formation game has non-transferable utility (NTU). Because of that, the Pareto Optimality can be used to judge the merits of collections of coalitions, which will be mentioned later. The increase in the cost depends on many factors, so the proposed coalition formation game is non-superadditive. Given one grand coalition which consists all users, there would be only one cluster reusing all the uplink resource. Not to mention the difficulty that all data-requesting users are distributed closely, the case all uplink users involve in the resource sharing is rarely seen. When the number of uplink users and data-requesting users are very small, the grand coalition could probably be formed, but in this case it makes no sense to improve the spectrum efficiency. So the grand coalition would never form.

Generally, the solving process of coalition formation game is too complicated, and not applicable in practice. Confronted with this problem, we propose a distributed algorithm making the process took place in a low-complexity manner. In the algorithm, merge and split rule is used for forming or breaking coalitions, while Pareto Optimality is used to compare the collections of coalitions.

A collection of coalitions is defined as a set of mutually disjoint coalitions which is denoted as $L = \{L_1, L_2, ..., L_i\}$. The collection in this paper also the partition of X. Given another collection $\overline{L} = \{\overline{L}_1, \overline{L}_2, ..., \overline{L}_{\bar{i}}\}$, the utility of player r in coalition $L_i \in L, 1 \leq i \leq I$ and coalition $\overline{L}_{\bar{i}} \in \overline{L}, 1 \leq \bar{i} \leq \bar{I}$ are $u_r(L) = u_r(L_i)$ and $u_r(\overline{L}) = u_r(\overline{L}_{\bar{i}})$, respectively. For all of the user, when $u_r(L) \geq u_r(\overline{L})$ happens with at least one strict inequality, then we define L is preferred over $\overline{L}$ by the Pareto Optimality. And the relationship is denoted as $L \sqsupset \overline{L}$. In order to find the stable collection, merge and split rule will be used [19]. When disjoint coalitions $\{L_1, L_2, ..., L_G\}$ in one collection have $\bigcup_{g=1}^{G} L_g \sqsupset \{L_1, L_2, ..., L_G\}$, while the utilities of the rest coalitions remain the same, these coalitions merge into one coalition $\{\bigcup_{g=1}^{G} L_g\}$. Otherwise when one coalition $\{\bigcup_{g=1}^{G} L_g\}$ has $\{L_1, L_2, ..., L_G\} \sqsupset \bigcup_{g=1}^{G} L_g$, the coalition is split into several coalitions $\{L_1, L_2, ..., L_G\}$. When merge or split operation happens, new collection is formed.

Use these rules, the energy-efficient uplink resource sharing algorithm can be described as follows:

1: The set of players is denoted as X, which includes all the users. Some data-requesting users can form clusters. Each cluster and single data-requesting users is a coalition.
2: The uplink user coalitions form a small collection $L_{0,U}$, while the cluster coalitions form a small collection $L_{0,CL}$. And the rest coalitions form a small collection L_R. So the initial collection of coalitions is $L_0 = L_{0,U} \cup L_{0,CL} \cup L_R$. According to (12), using the formulas mentioned above to get the coalition value set of each coalition. Note that the users in $L_{0,CL}$ and L_R is treated as normal downlink users.
3: Repeat the merge operation until all the coalitions have made their local merge decisions, then the resulting collection $\widetilde{L}$ is obtained.
4: The collection $\widetilde{L}$ accepts some split operations until it converge to a final collection L.

Starting from the collection L_0, we can always obtain the final collection using the algorithm. Every time one uplink user attempts to merge with a coalition which contains a cluster, the value set of the merged coalition will be calculated. Compare the utilities before and after the merge using Pareto Optimality, we can determine whether the merge is successful or not. According to the result of the merge operation, the collection of coalitions is obtained, remain the same or be different. Based on the fact that the number of coalitions in $L_{0,U}$ and $L_{0,CL}$ is finite, the process of the algorithm will end after several operations, and the final collection is obtained.

4 Numerical Results

In this section, the proposed algorithm is verified through computer simulations. Inspired by [20,21], the values of simulation parameters are summarized in Table 1. For each simulation, the location of the uplink users are generated randomly within the cell. The data-requesting users are distributed in a small area of the cell, which is easy to form D2D clusters. The data-requesting users distributed somewhere else work the same with these users. The channel gains $H_{i,j}$ between the transmitter i and the receiver j is calculated as:

$$\begin{aligned} H_{i,j} &= 10lg(-h_{i,j}/10) \\ h_{i,j} &= 32.4 + 20log10(d) + 20log10(f) \end{aligned} \tag{13}$$

where $h_{i,j}$ follows the free space transmission loss formula, d is the distance between the two nodes, and f denotes the transmission frequency. For simplicity, the power consumption of circuit blocks for the transmitters and the receivers are set the same value. For comparison, two cases are considered: the first case is that all the users are in cellular mode, with no uplink resource reused; in the second case, every D2D cluster reuse one cellular user's uplink resource at most, and the relationship is one-to-one optimal according to exhaustive searches.

Figure 2 shows the uplink resource reusing relationships. The small hollow circle represents the data-requesting users, and the cross represents the uplink

Table 1. Simulation parameters

Cell radius	500m
Maximum distance within D2D cluster	$50\,m$
Maximum transmit power of the uplink users	$10\,mw$
Maximum transmit power of the data-requesting users	$0.1\,mw$
Constant circuit power	$10^{-4}\,mw$
Noise variance (σ^2) for 1 MHz bandwidth	$-144\,dbm$
Minimum throughput of the uplink users	$3.46\,bits/s/Hz$
Minimum throughput of the data-requesting users	$4.39\,bits/s/Hz$
The ratio of the power of PA to the transmit power	1.5
The compensate function parameter μ	0.5

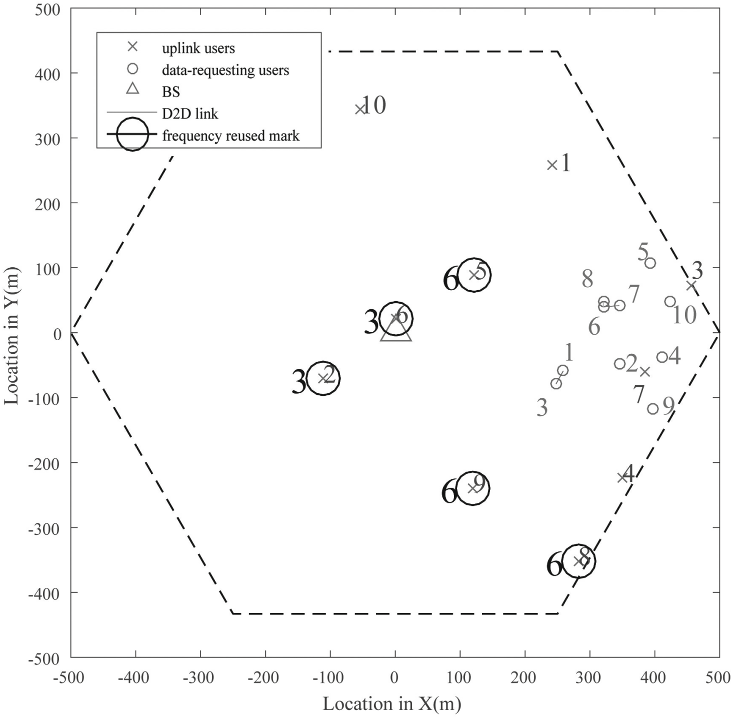

Fig. 2. D2D clusters reuse the cellular users uplink resource

user. The line between two data-requesting users means that they are in the same cluster, and the cluster head user is the one with the most lines. The cellular user besets with a big circle shares its uplink resource with a cluster, and the number near the big circle denotes the cluster head of the cluster. The data-requesting users 1 and 3 form a cluster called $clu1$, while data-requesting users 6, 7 and 8

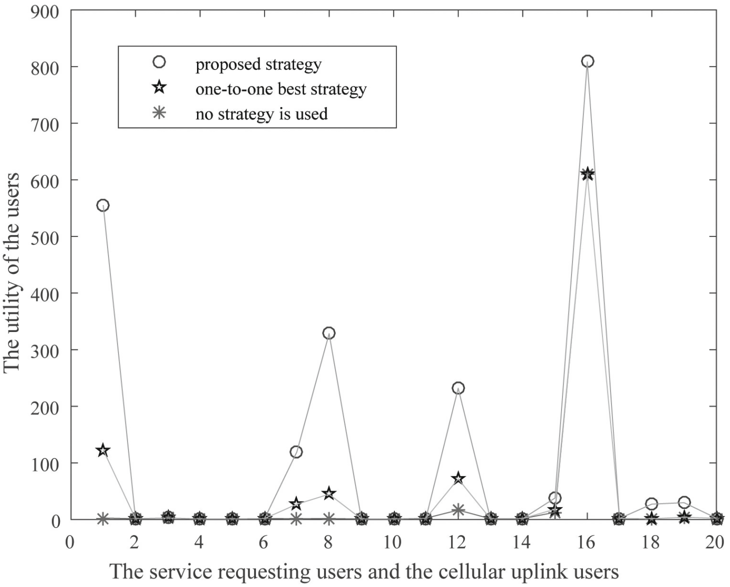

Fig. 3. The utility of the users

form cluster *clu*2. Uplink users 2 and 6 constitute a coalition with *clu*1, which means their uplink resource is reused by *clu*1. And uplink users 5,8,9 constitute a coalition with *clu*2, which means their uplink resource is reused by *clu*2. The rest users each constitutes a coalition.

Figure 3 shows the utilities of all users using different strategies. The users with numbers from 1 to 10 are the data-requesting users, while the users with numbers from 11 to 20 are the uplink users. For each user, the circle means the utility is calculated using the proposed strategy, and the pentagon means the utility is calculated using the one-to-one best strategy. The rice word means that the utility is 0 when no strategy is used. For the cases that strategy is used but the utility doesn't change, the utility is still 0. So only the utilities of the cluster tail users and the uplink users who share their resource are changed. Apparently, the utilities obtained from the proposed strategy is best. So the energy efficiency can be improved while the QoS of the users are satisfied.

Figure 4 shows the throughput of the data-requesting users. There is only one tail user in cluster *clu*1, and the transmit power of the cluster head and the uplink-sharing uplink users are designed basing on it, so the throughput of the tail user just meet the minimum requirement. However, there are two tail users in cluster *clu*2, when the most remote tail user 7 meet the minimum requirement, the throughput of the other tail user 8 would definitely be improved because of the short distance. The throughput marked with circle, pentagon, and rice word are respectively corresponded to the proposed strategy, the one-to-one

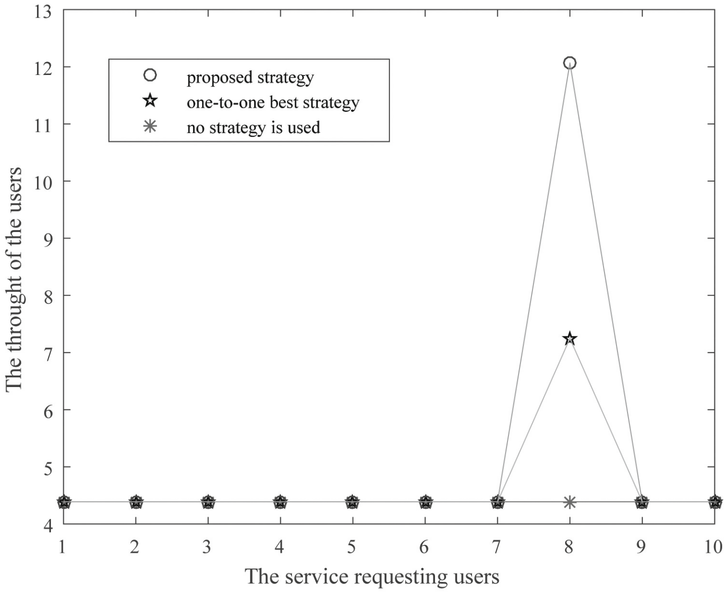

Fig. 4. The throughput of the users

best strategy and the situation with no cooperative strategy. As we can see, the proposed strategy shows the best performance of throughput.

From the simulations, the effectiveness of the game model and the algorithm is demonstrated.

5 Conclusion

In this paper, we proposed a new energy-efficient uplink resource sharing scheme. After establish and analyse the network model, we formulate the resource sharing problem as an NTU coalition formation game, and the algorithm with the merge and split rule is presented. The joint issue of uplink resource allocation and power management is solved. The simulation shows the scheme indeed improve the performance comparing with other methods.

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References

1. Zhang, H., Jiang, C., Cheng, J., Leung, V.C.M.: Cooperative interference mitigation and handover management for heterogeneous cloud small cell networks. IEEE Wirel. Commun. **22**(3), 92–99 (2015)

2. Zhang, H., Jiang, C., Mao, X., Chen, H.H.: Interference-limited resource optimization in cognitive femtocells with fairness and imperfect spectrum sensing. IEEE Trans. Veh. Technol. **65**(3), 1761–1771 (2016)
3. Zhang, H., Liu, H., Jiang, C., Chu, X., Nallanathan, A., Wen, X.: A practical semidynamic clustering scheme using affinity propagation in cooperative picocells. IEEE Trans. Veh. Technol. **64**(9), 4372–4377 (2015)
4. Zhang, H., Chu, X., Guo, W., Wang, S.: Coexistence of wi-fi and heterogeneous small cell networks sharing unlicensed spectrum. IEEE Commun. Mag. **53**(3), 158–164 (2015)
5. Arvidsson, A., Manxing, D., Aurelius, A., Kihl, M.: Analysis of user demand patterns and locality for youtube traffic. In: 2013 25th International Teletraffic Congress (ITC), pp. 1–9. IEEE (2013)
6. Al-Kanj, L., Dawy, Z., Yaacoub, E.: Energy-aware cooperative content distribution over wireless networks: Design alternatives and implementation aspects. Commun. Surv. Tutorials IEEE **15**(4), 1736–1760 (2013)
7. Wang, F., Chen, X., Song, L., Han, Z., Zhang, B.: Energy-efficient radio resource and power allocation for device-to-device communication underlaying cellular networks. In: 2012 International Conference on Wireless Communications and Signal Processing (WCSP), pp. 1–6. IEEE (2012)
8. Qiu, X., Xuewen, L., Dong, K., Zhu, S.: Energy efficiency analysis in device-to-device communication underlaying cellular networks. In: 2013 IEEE Consumer Communications and Networking Conference (CCNC), pp. 625–630. IEEE (2013)
9. Mukherjee, A., Hottinen, A.: Energy-efficient device-to-device mimo underlay network with interference constraints. In: 2012 International ITG Workshop on Smart Antennas (WSA), pp. 105–109. IEEE (2012)
10. Wen, S., Zhu, X., Lin, Z., Zhang, X., Yang, D.: Energy efficient power allocation schemes for device-to-device (d2d) communication. In: 2013 IEEE 78th Vehicular Technology Conference (VTC Fall), pp. 1–5. IEEE (2013)
11. Wang, F., Chen, X., Song, L., Zhao, Q., Wang, X., Han, Z.: Energy-aware resource allocation for device-to-device underlay communication. In: 2013 IEEE International Conference on Communications (ICC), pp. 6076–6080. IEEE (2013)
12. Saad, W., Han, Z., Debbah, M., Hjorungnes, A., Basar, T.: Coalitional game theory for communication networks. Signal Process. Mag. IEEE **26**(5), 77–97 (2009)
13. Akkarajitsakul, K., Phunchongharn, P., Hossain, E., Bhargava, V.K.: Mode selection for energy-efficient d2d communications in lte-advanced networks: A coalitional game approach. In: 2012 IEEE International Conference on Communication Systems (ICCS), pp. 488–492. IEEE (2012)
14. Chia Hao, Y., Doppler, K., Ribeiro, C.B., Tirkkonen, O.: Resource sharing optimization for device-to-device communication underlaying cellular networks. Wirel. Commun. IEEE Trans. **10**(8), 2752–2763 (2011)
15. Wang, J., Zhu, D., Zhao, C., Li, J.C.F., Lei, M.: Resource sharing of underlaying device-to-device and uplink cellular communications. IEEE Commun. Lett. **17**(6), 1148–1151 (2013)
16. Belleschi, M., Fodor, G., Abrardo, A.: Performance analysis of a distributed resource allocation scheme for d2d communications. In: 2011 IEEE GLOBECOM Workshops (GC Wkshps), pp. 358–362 (2011)
17. Chien, C.P., Chen, Y.C., Hsieh, H.Y.: Exploiting spatial reuse gain through joint mode selection and resource allocation for underlay device-to-device communications. In: 2012 15th International Symposium on Wireless Personal Multimedia Communications (WPMC), pp. 80–84 (2012)

18. Dan, W., Wang, J., Rose, H., Cai, Y., Zhou, L.: Energy-efficient resource sharing for mobile device-to-device multimedia communications. Veh. Technol. IEEE Trans. **63**(5), 2093–2103 (2014)
19. Apt, K.R., Radzik, T.: Stable partitions in coalitional games. CoRR, abs/cs/0605132 (2006)
20. Wang, F., Song, L., Han, Z., Zhao, Q., Wang, X.: Joint scheduling and resource allocation for device-to-device underlay communication. In: 2013 IEEE Wireless Communications and Networking Conference (WCNC), pp. 134–139. IEEE (2013)
21. Chen, X., Song, L., Han, Z., Zhao, Q., Wang, X., Cheng, X., Jiao, B.: Efficiency resource allocation for device-to-device underlay communication systems: a reverse iterative combinatorial auction based approach. Sel. Areas Commun. IEEE J. **31**(9), 348–358 (2013)