



Joint Optimization of D2D-Enabled Heterogeneous Network Based on Delay and Reliability Constraints

Dengsong Yang¹, Baili Ni¹, Haidong Wang², and Baoxiang Wei²(✉)

¹ Jiangsu Expressway Company Limited, Nanjing, China

² College of Computer and Information, Hohai University, Nanjing, China
2819886353@qq.com

Abstract. The D2D-enabled heterogeneous network services have strict requirements on communication delay and quality. D2D users can share spectrum resources with cellular users, which can effectively improve the spectrum efficiency. But it can cause serious co-channel interference in dense user scenarios. In order to satisfy the highly dynamic patterns of the data traffic and wireless communication environment, a joint optimization algorithm of D2D-enabled heterogeneous network resources is proposed while meeting the delay and quality requirements. Specifically, a heterogeneous network is established where users are clustered. We maximize system energy efficiency under the premise of meeting the user delay and reliability requirements. In addition, we use the Lyapunov algorithm to optimize the dynamic allocation of wireless resources. The results of the experiment show that the proposed algorithm can improve the spectrum efficiency, reduce the D2D power consumption and reduce the co-channel interference, while ensuring the reliability and time delay requirements of both D2D users and cellular users.

Keywords: D2D · Resources allocation · Lyapunov optimization

1 Introduction

In traditional cellular networks, communication is divided into uplink and downlink. Users can't communicate directly bypassing the base station. With the rapid development of social economy and the advent of the information age, wireless spectrum resources are becoming increasingly tense.

Device-to-device (D2D) communication is a technology under the control of a cellular network system, which enables two terminal users to communicate with each other directly without a base station. D2D communication is a good solution to the spectrum crisis, which provides high data rate and reduces user delay and transmission

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power. Therefore, it is necessary to study cellular communication and the heterogeneous network of terminal direct communication.

In the heterogeneous network, D2D users' reuse of cellular user (CUE) spectrum resources will produce complex co-channel interference, which will reduce the communication quality of users. Besides, D2D communication is only applicable to short-range communication scenarios. It is necessary to study the network resource allocation to reduce the co-channel interference between users, to improve the spectrum utilization and system performance. At present, some work about resource allocation of heterogeneous network focuses on resource allocation of D2D user side. And, other studies on the joint optimization of D2D user and cellular user resources usually only take the performance of D2D user or cellular user as the optimization goal, ignoring the overall performance optimization. In addition, these studies don't consider the characteristics of random arrival of user data traffic in the network. [1] investigated the problem of network resource allocation by reusing downlink spectrum resources of cellular users. Han et al. considered the dynamic change of data traffic in network by establishing user queue model [2, 3].

Aiming at the above problems, in the scenario where D2D user and cellular user data flow arrive randomly, we optimize spectrum reuse and power consumption of D2D user side and cellular user side. Under the constraints of delay and reliability of D2D users and cellular users, we maximize the energy efficiency of the overall system and ensure the data queue stability of D2D users and cellular users.

2 System Model

Considering that multiple D2D users in a single cell reuse downlink spectrum resources of cellular users, a system model is established as shown in Fig. 1.

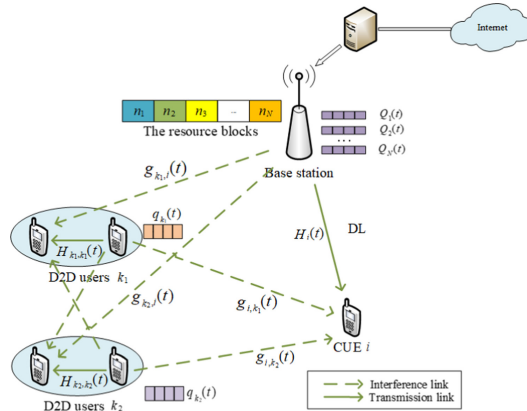


Fig. 1. Resource joint optimization interference model in heterogeneous network

We assume that both base stations and users are equipped with a single omnidirectional antenna. The system includes a base station located in the regional center.

We denote the set of N cellular users by $C = \{C_1, C_2, \dots, C_N\}$, and denote by $B = \{B_1, B_2, \dots, B_N\}$ the set of resource blocks that matched by D2D user pair. In addition, we denote K D2D user pairs by $D = \{D_1, D_2, \dots, D_K\}$, and each D2D user pair contain a sender and a receiver. It is stipulated that one D2D user pair can reuse multiple cellular user spectrum resources, and at the same time, cellular user spectrum resources can be reused by multiple D2D users in different clusters. We assume all users' geographical location obey Poisson distribution, and the base station can obtain the location information of all users.

In order to reduce co-channel interference between adjacent D2D user pairs, we group D2D user pairs into different regions based on their geographic location, which is called clustering. The part about clustering will be introduced in detail later.

2.1 Interference Model

The system considers not only the data queue of D2D users, but also the cache queue of cellular users caused by dynamic data traffic. The power consumption of signals sent by base station to cellular users is no longer a constant, but a variable to be optimized. When D2D user pair D_k reuses the downlink spectrum resources of cellular user C_i , cellular user C_i will be interfered by the sender of D2D user pair D_k . The receiver of D_k will be interfered by the base station and other D2D users. The interference to cellular user C_i can be expressed as

$$I_i = \sum_{k=1}^K x_k^i(t) p_k^i(t) g_{i,k}(t) \quad (1)$$

where $P_k^i(t)$ denotes the transmitting power of D_k on spectrum resource block B_i , $g_{i,k}(t)$ denotes channel gain from D2D user pair D_k transmitter to cellular user C_i . When D_k reuse downlink spectrum resources of C_i , $x_k^i(t) = 1$, otherwise $x_k^i(t) = 0$.

The interference to D_k can be expressed as

$$I_k^i = P_i g_{k,i}(t) + \sum_{k' \in Z_b/k} p_{k'}^i(t) h_{k',k}(t) \quad (2)$$

where P_i , a variable to be optimized, denotes the power consumption of the base station transmitting signals to the i th cellular user, $g_{k,i}(t)$ denotes channel gain of D_k receiver, Z_b is a collection of D2D user pairs in the cluster, $D_{k'}$ denotes the D2D users in cluster Z_b except D_k , $p_{k'}^i(t)$ denotes the transmitting power of D2D users $D_{k'}$ on resource block B_i , and $h_{k',k}$ denotes channel gain from $D_{k'}$ to D_k .

The signal to interference plus noise ratio (SINR) of cellular user C_i can be expressed as

$$\gamma_i(t) = \frac{P_i h_i(t)}{\sigma^2 + \sum_{k=1}^K x_k^i(t) p_k^i(t) g_{i,k}(t)} \quad (3)$$

where $h_i(t)$ denotes channel gain from the base station to cellular user C_i , σ^2 denotes power of Gaussian white noise. Assuming the SINR threshold of cellular user is γ_{iTH} , so communication quality requirement for cellular user can be expressed as $\gamma_i(t) \geq \gamma_{iTH}$.

When D_k reuse C_i , the SINR of D_k receiver can be expressed as

$$\gamma_k^i(t) = \frac{p_k^i(t)h_{k,k}(t)}{\sigma^2 + P_i g_{k,i}(t) + \sum_{k' \in Z/k} p_{k'}^i(t)h_{k',k}(t)} \quad (4)$$

where $h_{k,k}(t)$ denotes channel gain from D_k transmitter to D_k receiver. D_k and $D_{k'}$ belong to the collection Z , which includes all users in a cluster. The content of cluster will be introduced in the following section. We assume the SINR threshold of D2D user pair is γ_{kTH}^i . Then, reliability requirements for D2D user pair can be expressed as $\gamma_k^i(t) \geq \gamma_{kTH}^i$.

2.2 Delay and Reliability Model

The queuing delay of task traffic and communication reliability that can be measured by the length of user queue are mainly considered in the heterogeneous scenario [1].

Each D2D user pair maintains a cache queue at the transmitter, defining the queue length vector as $q(t) = [q_1(t), \dots, q_K(t)]$, where $q_k(t)$ denotes the queue length of D2D user pair D_k . Similarly, we define the cell user queue length vector as $Q(t) = [Q_1(t), \dots, Q_N(t)]$, where $Q_i(t)$ denotes the queue length of the i th cellular user.

According to Little Law in Queuing Theory [4], in the heterogeneous network system in this paper, the delay is proportional to the system data queue length, and inversely proportional to the data arrival rate. Therefore, the data queue length can be used as a measure of delay. According to the above conclusions, we can set an upper bound d_k for the average queuing delay of each D2D user pair and an upper bound D_i for the average queuing delay of each cellular user.

In addition to queuing delay, queue length is also related to the reliability requirement of communication, so the reliability index can be measured by the violation of queue length boundary. We impose probability to restrain the queue length of each D2D user pair, as

$$\lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T \Pr(q_k(t) \geq l_k) \leq \varepsilon_k \quad (5)$$

where l_k denotes maximum allowable queue length for D2D users, ε_k denotes a tolerable violation probability. However, this probability constraint is difficult to deal with, so the nonlinear constraint is replaced by the linear equivalent constraint, which can be expressed as

$$\lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T E[1\{q_k(t) \geq l_k\}] \leq \varepsilon_k \quad (6)$$

In a similar way, we impose probability to restrain the queue length of each cellular user, as

$$\lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T \Pr(Q_i(t) \geq L_i) \leq E_i \quad (7)$$

where L_i denotes the maximum allowable queue length for cellular user, and E_i denotes a tolerable violation probability. Replace nonlinear constraint of cellular users with linear equivalent constraint, which can be expressed as

$$\lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T E[1\{Q_i(t) \geq L_i\}] \leq E_i \quad (8)$$

Through the above series of constraints on user queue length, the delay and reliability constraints of D2D users and cellular users can be satisfied.

2.3 Optimization

Our goal is to optimize the control of transmission power of the D2D users, the power consumption transmitted by the base station to the cellular user and the spectrum resource matching at the base station, in order to maximize system energy efficiency under the premise of meeting the user delay and reliability requirements. We characterize the system performance by energy efficiency, which is defined as ratio of system throughput to system power consumption.

The spectrum resource block allocation matrix is $X(t) = [x_k^i(t)]$, and the D2D users power matrix is $p(t) = [p_k^i(t)]$, the power matrix of the signal transmitted by the base station to the cellular user is $P(t) = [P_i(t)]$. In this way, our joint optimization problem can be summarized as

$$\max_{X(t), p(t), P(t)} \frac{\sum_{k=1}^K r_k(t) + \sum_{i=1}^N R_i(t)}{\sum_{k=1}^K y_k(t) p_k^{\max} + P^{\max}} \quad (9)$$

meeting:

$$x_k^i(t) \in \{0, 1\}, \forall t, k \in K, i \in N \quad (9a)$$

$$\sum_{i \in N} x_k^i(t) \leq n_k, \forall k \in K \quad (9b)$$

$$\lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T E[q_k(t)] \leq \bar{\lambda}_k d_k, \forall k \in K \quad (9c)$$

$$\lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T E[Q_i(t)] \leq \bar{\lambda}_i D_i, \forall i \in N \quad (9d)$$

$$\lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T E[1\{q_k(t) \geq l_k\}] \leq \varepsilon_k, \forall k \in K \quad (9e)$$

$$\lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T E[1\{Q_i(t) \geq L_i\}] \leq E_i, \forall i \in N \quad (9f)$$

$$\sum_{n \in N} x_k^i(t) p_k^i(t) = p_k^{\max}, \forall t, k \in K \quad (9g)$$

$$p_k^i(t) \geq 0, \forall t, k \in K, i \in N \quad (9h)$$

$$\sum_{i=1}^N P_i(t) = P^{\max} \quad (9i)$$

$$P_i(t) \geq 0, i \in N \quad (9j)$$

$$\gamma_k^i(t) \geq \gamma_{kTH}^i \quad (9k)$$

$$\gamma_i(t) \geq \gamma_{ITH} \quad (9l)$$

where $r_k(t)$ denotes transmission rate of D2D user pair D_k , $R_i(t)$ denotes transmission rate of cellular user C_i . $y_k(t)$ is an indicator variable. If D_k matches to the spectrum resource block, $y_k(t) = 0$; otherwise, $y_k(t) = 1$. $\bar{\lambda}_k$ and $\bar{\lambda}_i$ denote the average task data arrival of D_k and C_i respectively. In order to facilitate representation, the energy efficiency expression (9) is denoted by EE .

3 Dynamic Allocation of Network Resources

3.1 Spectrum Resource Matching Algorithm Based on Cluster

In the scenario of the dense distribution of D2D users in the region, we can group D2D users into different regions to reduce the co-frequency interference between adjacent D2D users, according to their geographical location. The region is named a cluster. Then, it is stipulated that the D2D users in the same cluster can't reuse the same spectrum resource block, so that there will be no co-frequency interference between the D2D users in the same cluster.

D2D Users Clustering Algorithm

We use a dynamic region formation strategy to divide a collection of regions into non-overlapping regions, as

$$\bigcup_{z \in Z} K_z = K \quad (10)$$

$$K_z \cap K_{z'} = \emptyset, \forall z \neq z', z, z' \in Z \quad (11)$$

Gaussian distance similarity is based on the distance between D_k and $D_{k'}$, which can be expressed as

$$g_{kk'}(i) = \exp\left(\frac{-\|g_k - g_{k'}\|_2}{2\sigma_s^2}\right) \quad (12)$$

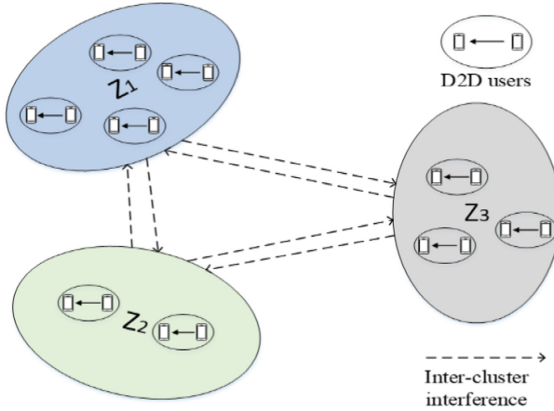


Fig. 2. Clustering mechanism

where g_k and $g_{k'}$ denote two-dimensional geographic coordinates of D_k and $D_{k'}$, parameter σ_s controls influence range of area size. The relationship among D2D users after clustering is shown in Fig. 2. Since the intra-cluster D2D users strictly obey the principle of orthogonal frequency division multiplexing, the interference between users in the cluster is eliminated, and there is only inter-cluster interference.

We note that the solution of the problem depends on the resource block matching and power optimization scheme. And resource block matching and power allocation are coupled. The solution to the problem (9) requires global information, such as $X(t)$ and $P(t)$ in the network. But it's difficult to achieve. Therefore, we use the semi-distributed method to decouple the resource block matching and the power allocation, according to the Lyapunov optimization theory [5].

Spectrum Resource Matching Algorithm

Based on the clustering results, D2D users and the spectrum resource blocks of cellular users are matched bilaterally according to the mutual preference relationship. Since the heterogeneous network resource allocation in the paper involves the power optimization of base station transmitting to cellular users, it is necessary to propose a new utility function according to the model.

We use the framework of matching theory to solve the problem [6–10]. The matching $K_z \rightarrow N$ of each region is essentially a bilateral matching problem of two disjoint users, namely, the matching of D2D users set K_z and resource block set N . We assume that each user in K_z matches one or more users in N , and each user in N matches one user in K_z at most. In the proposed matching, D2D users with longer queues need more resource blocks to transmit data from the queue buffer.

The matching framework defines the utility that reflects the preferences of D2D users and resource blocks. The utility of D_k matched to B_i can be expressed as

$$U_k(t) = - \sum_{i \in N} \Gamma_{ki}(t) \tag{13}$$

Accordingly, the utility of B_i matched to D_k can be expressed as

$$U_{ki}(t) = -\Gamma_{ki}(t) \quad (14)$$

$\Gamma_{ki}(t)$ will be introduced in detail in the following section.

When optimizing resource block selection to maintain queue stability, each D2D user maximizes its utility. Therefore, D2D users sorts the subset of the resource block, namely, $P \subseteq N$ and $P' \subseteq N$. We can define the preference of D_k as

$$P >_k P' \Leftrightarrow U_k(P) > U_k(P') \quad (15)$$

On the other hand, each resource block will sort D_k and $D_{k'}$ to maximize its utility value, which can be expressed as

$$k >_n k' \Leftrightarrow U_{ki} > U_{k'i} \quad (16)$$

Using the above formulas, we obtain an algorithm that can be used for appropriate matching. The matching result is that the set of matched resource blocks for D_k is N_k , and $\cup N_k = N, k \in K_z$.

3.2 Power Optimization Based on Lyapunov Method

Lyapunov optimization theory can provide online solutions to meet the optimization objectives. For the dynamic network in the paper, it can dynamically adapt to changes. With the help of virtual queue method, the original stochastic optimization problem is transformed into equivalent solvable problem. Then we can use the Lyapunov optimization framework to solve the problem [11].

Optimization Problem Transformation

By using Lyapunov optimization, the time-average inequality constraint is transformed into a virtual queue. If the stability of the virtual queue is maintained, the time constraint can be satisfied. Therefore, virtual queues $J(t)$ and $F(t)$ for D2D users are defined by constraints (9c) and (9e) respectively, as follows

$$J_k(t+1) = \max\{J_k(t) + q_k(t+1) - \bar{\lambda}_k \cdot d_k, 0\} \quad (17)$$

$$F_k(t+1) = \max\{F_k(t) + 1\{q_k(t+1) \geq l_k\} - e_k, 0\} \quad (18)$$

If the corresponding virtual queue is stable, in other words, $\lim_{t \rightarrow \infty} E[|J_k(t)|]/T = 0$ and $\lim_{t \rightarrow \infty} E[|F_k(t)|]/T = 0$, the time average inequality constraint is satisfied.

Similarly, virtual queues $B(t)$ and $M(t)$ for cellular users are defined by constraints (9c) and (9e) respectively, as follows

$$B_i(t+1) = \max\{B_i(t) + Q_i(t+1) - \bar{\lambda}_i \cdot D_i, 0\} \quad (19)$$

$$M_i(t+1) = \max\{M_i(t) + 1\{Q_i(t+1) \geq l_i\} - E_i, 0\} \quad (20)$$

In this way, the original optimization problem is equivalent to maximize the system energy efficiency in the condition that the average rate of virtual queue is stable.

D2D Network Resource Dynamic Allocation Algorithm

Using Lyapunov Optimization Theory, combination of virtual queues can be expressed as $y(t) = [J(t), F(t), B(t), M(t)]$. Define the Lyapunov function $L(y(t))$ as

$$L(y(t)) = \frac{1}{2} \{ \|J(t)\|^2 + \|F(t)\|^2 + \|B(t)\|^2 + \|M(t)\|^2 \} \quad (21)$$

We define the Lyapunov drift function as

$$\begin{aligned} \Delta(L(t)) &= E[L(y(t+1)) - L(y(t))] \\ &= E \left[\sum_{k=1}^K \sum_{i=1}^N \left(\frac{J_k(t+1)^2}{2} - \frac{J_k(t)^2}{2} + \frac{F_k(t+1)^2}{2} - \frac{F_k(t)^2}{2} \right. \right. \\ &\quad \left. \left. + \frac{B_i(t+1)^2}{2} - \frac{B_i(t)^2}{2} + \frac{M_i(t+1)^2}{2} - \frac{M_i(t)^2}{2} \right) \right] \end{aligned} \quad (22)$$

By expanding $J(t)$, $F(t)$, $B(t)$, $M(t)$ and taking into account $\max\{x, 0\}^2 \leq x^2$, we can get

$$\begin{aligned} \Delta(L(t)) &\leq E \left[\sum_{k=1}^K \sum_{i=1}^N \left(-\tau(J_k(t) + F_k(t) + 2q_k(t) + 2\lambda_k(t))r_k^i(t) \right. \right. \\ &\quad \left. \left. - \tau(B_i(t) + M_i(t) + 2Q_i(t) + 2\lambda_i(t))R_i(t) \right) \right] + C \end{aligned} \quad (23)$$

where C can be regarded as a constant part, which can be ignored in optimization problem. The stability of virtual queues can be guaranteed by minimizing the nonconstant part. Our goal is to maximize the system energy efficiency, namely $\max\{EE\}$ or $\min\{-EE\}$.

Therefore, if the sum of the negative value of the Lyapunov drift function and the energy efficiency function is minimized, the constraint conditions can be satisfied and the optimization objective can be realized. The optimal solution can be obtained by implementing the following polynomial

$$\min_{X(t), p(t), P(t)} \text{imize} \sum_{k=1}^K \sum_{i=1}^N \Gamma_k^i(t) \quad (24)$$

where

$$\begin{aligned} \Gamma_k^i(t) &= -\tau(J_k(t) + F_k(t) + 2q_k(t) + 2\lambda_k(t))r_k^i(t) \\ &\quad - \tau(B_i(t) + M_i(t) + 2Q_i(t) + 2\lambda_i(t))R_i(t) - EE \end{aligned} \quad (25)$$

After subset B_k of the spectrum resource block is assigned to the D2D users in cluster z_b , the D2D user pair $D_k \in K_{z_b}$ optimizes the transmission power of the allocated spectrum resource blocks. D2D users optimize the power allocation locally, and the base

station optimizes the power consumption transmitted to cellular users. Therefore, local power allocation based on matching algorithm can be written as a convex optimization problem, as follows

$$\min_{p_k^i, P_i} \left\{ \sum_{k=1}^K \sum_{i=1}^N (-\tau(J_k(t) + F_k(t) + 2q_k(t) + 2\lambda_k(t))r_k^i(t) - \tau(B_i(t) + M_i(t) + 2Q_i(t) + 2\lambda_i(t))R_i(t)) - EE \right\} \quad (26)$$

meeting the following constraints

$$\gamma_k^i \geq \gamma_{kTH}^i, \forall k \in K_{z_b}, i \in B_k \quad (26a)$$

$$\gamma_i \geq \gamma_{iTH}, \forall k \in K_{z_b}, i \in B_k \quad (26b)$$

$$\sum_{i \in B_k} p_k^i(t) = p_k^{\max}, \forall t, k \in K \quad (26c)$$

$$\sum_{i=1}^N P_i(t) = P^{\max} \quad (26d)$$

where K_{z_b} denotes the set of D2D users in cluster z_b , B_k denotes the set of matched spectrum resource blocks for D_k . The power optimization solution can be obtained by solving the convex optimization problem in each time slot. The paper uses MATLAB convex optimization tool CVX to solve the convex optimization problem [12].

4 Simulation Results and Analysis

4.1 Simulation Configuration

D2D users and cellular users are distributed in the rectangular area of $400 \text{ m} \times 400 \text{ m}$ and they obey Poisson distribution. The loss is a free-space propagation model $L_0 = 32.45 + 20 \log(f) + 20 \log(d)$. The carrier frequency used by cellular users is 5.8 GHz. We set the number of cellular users $N = 10$, which is the same as the number of resource blocks. The number of D2D users is $K = 15$. For each D2D user pair, the maximum transmit power is $P_k^{\max} = 20 \text{ dBm}$. Base station transmit power is $P^{\max} = 20 \text{ dBm}$. D2D users and cellular users packet size is fixed, $N_k = N_i = 6400 \text{ bit}$. The packet arrival rate is independent and identically distributed in different time, which follows Poisson distribution. The average packet arrival rate of D2D users is $\bar{\zeta}_k = 100$, and the average packet arrival rate of cellular users is $\bar{\zeta}_i = 10$. The bandwidth of spectrum resource block is $\omega = 180 \text{ kHz}$, the time slot length is $\tau = 5 \text{ ms}$. D2D users' delay constraint threshold is $d_k = 10 \text{ ms}$, cellular users' delay constraint threshold is $D_i = 20 \text{ ms}$. The number of clusters is b .

4.2 Results and Analysis

For the convenience of expression, the average distribution scheme of base station transmitting power is denoted as APRA, and the joint optimization scheme proposed in the paper is denoted as OPRA.

Energy Efficiency

System energy efficiency reflects the amount of transmitted data per unit time per unit power. It's very meaningful to improve energy efficiency in the era of green communication. Figure 3 shows the complementary cumulative distribution function (CCDF) of system energy efficiency in OPRA and APRA. It can be seen that in the process of increasing the number of clusters from 3 to 5, the energy efficiency of the two systems is continuously improving. With the increase in the number of clusters, the number of spectrum resource blocks that can be matched to each D2D user pair will increase. Then, the transmission rate and the system energy efficiency of D2D users will be significantly improved, while cellular users are less affected by co-channel interference.

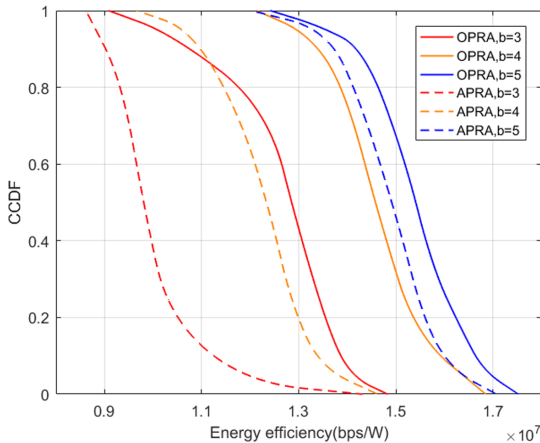


Fig. 3. System energy efficiency CCDF of OPRA and APRA

By comparison, the energy efficiency performance of OPRA is better than that of APRA. It's due to the decrease of the co-frequency interference among users. After obtaining the matching results of spectrum resource blocks, optimizing the transmit power of the base station can improve data transmission rate of D2D users and reduce the co-channel interference of the downlink signal of the base station to the D2D users. Meanwhile, optimization of power consumption for D2D users also reduces interference to cellular users.

User Delay in Heterogeneous Networks

Figure 4 shows the CCDF of D2D users and cellular users delay. No matter the number of clusters, the delay performance of D2D users and cellular users is OPRA better than APRA. With the increase of the number of clusters, the delay performance of D2D users

improves greatly. When the number of clusters increases, the number of D2D users in a cluster will decrease accordingly, the number of spectrum resource blocks matched to each D2D user pair will increase, the transmission rate will increase, and the delay will decrease. With the increase of the number of clusters, the delay of cellular users increases. It's because the more clusters, the greater the co-frequency interference of D2D users to cellular users is, and the delay will increase.

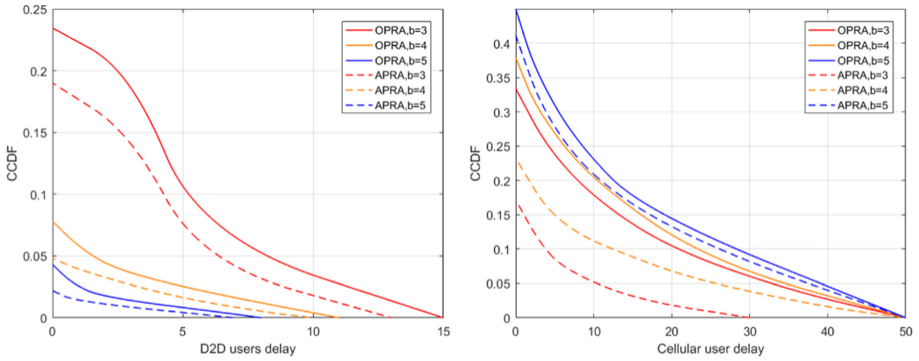


Fig. 4. Time delay CCDF of D2D users and cellular users

It can be seen that there is a trade-off between the delay performance of D2D users and that of cellular users. The decrease of D2D users delay will lead to the increase of cellular users delay, and vice versa.

User Reliability of Heterogeneous Network

Because we set an upper limit threshold for the cache queue, the situation that exceeds this threshold is considered unreliable, and the situation that doesn't exceed the threshold is considered reliable. Figure 5 shows the comparison of D2D users and cellular users reliability in different clustering cases.

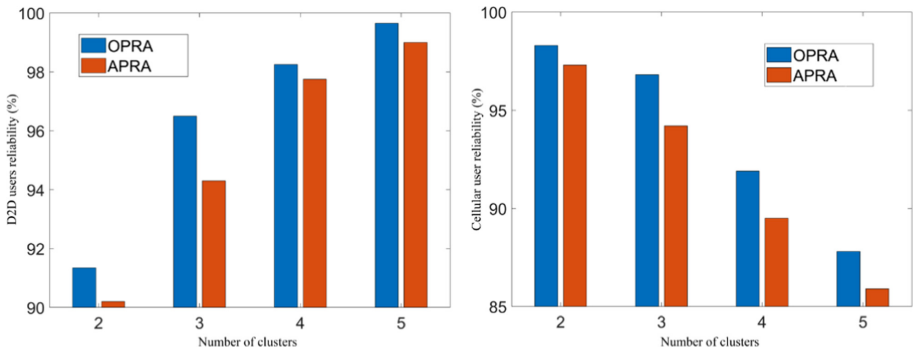


Fig. 5. Reliability of D2D users and cellular users in some scenarios

With the increase of clusters, the reliability of D2D users increases, meanwhile the reliability of cellular users decrease. The reasons are the same as before, which are given in delay section. We note that OPRA is more reliable than APRA for both D2D users and cellular users. Because OPRA outperforms APRA in terms of energy efficiency, which means that the transmission capability of OPRA is better than APRA at the same power consumption.

5 Conclusion

The data flow of 5G-oriented D2D-enabled heterogeneous network is random, and the communication requirements for delay and quality are also very high. In view of the current situation that the research on the allocation of heterogeneous network resources focuses on optimizing the resources on the D2D users side, but ignores the optimization of cellular users resources, we propose an improved joint optimization algorithm for dynamic heterogeneous network resources based on delay and reliability constraints.

Firstly, we construct a dynamic heterogeneous network model based on the random data flow arrival of D2D users and cellular users. Secondly, based on Lyapunov optimization method, the delay and reliability constraints of D2D users and cellular users are transformed into virtual queues, and a dynamic network model for maximizing energy efficiency of heterogeneous network system is established. Finally, we propose an energy efficiency maximization algorithm for heterogeneous network system. Compared with the average allocation scheme of base station transmitting power, the algorithm has improved the overall system energy efficiency and the performance of users delay and reliability.

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