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Energy-Aware Mode Selection for D2D Resource Allocation in 5G Networks

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Abstract: This paper proposes an energy-aware mode-selection mechanism for device-to-device (D2D) resource allocation in the coexisting 5G network environment of D2D users and traditional cellular users by taking into consideration the mechanisms of mode selection, transmit power, and spectrum resource allocation simultaneously. In the proposed approach, all spectrum resources are fully shared by traditional cellular users and D2D users. We first determine the communication mode of all users after considering the transmission opportunity of traditional cellular users and analyzing the interference degree of different D2D communication modes. Next, we divide all users into three tiers according to the distances between users and the base station to solve the interference problem generated by excessing transmit power in uplink transmission. Afterward, based on the different communication modes, corresponding spectrum resource allocation mechanisms using the Hungarian algorithm are developed. We simulate a single cell environment using Python language and perform several simulations for different pairs of traditional cellular users and D2D users. The simulation results reveal that the proposed approach outperforms the proposed approach by Hou et al. in system throughput. With power control, the energy efficiency of the proposed approach could be enhanced by 20%.

Keywords: D2D communication; mode selection; power control; spectrum allocation; energy efficiency

1. Introduction

With the rapid development of the fifth-generation (5G) communication network and the Internet of Things (IoT), 5.3 billion Internet users will have access to the Internet of Things by 2023 [1], resulting in wireless spectrum resources gradually becoming insufficient for use. Recently, device-to-device (D2D) communication has gained a lot of attention because it allows messages to be transmitted directly between devices without going through access points or base stations (BSs). The D2D communication technology can not only improve the spectrum efficiency and energy efficiency, but also offloads the traffic of the cellular BS and reduces end-to-end delay [2,3]. Although the coexisting network environment of traditional network and D2D communication has such distinct advantages, some potential issues still need to be addressed, such as synchronization between devices and interference. Without proper management, these issues may damage the service quality of the existing cellular network system.

Three communication modes, i.e., the cellular mode [4], dedicated mode [5], and reuse mode [6], are supported in D2D communication. The cellular mode of D2D communication is similar to the traditional cellular network communication. In this mode, each D2D user can send messages to each other through BSs, but it may interfere with other users who use the same spectrum resources. In the dedicated mode of D2D communication, D2D users will be assigned dedicated spectrum resources by BSs, and these spectrum resources will be orthogonal with the traditional cellular network channel resources. Therefore, D2D users will not interfere with other users in the same cell, but they will interfere with users who use the same spectrum resources in other cells. Note that, in the dedicated mode, because the allocated spectrum resources are limited, a large number of D2D users may cause a shortage in resource supply. In the reuse mode of D2D communication, D2D users can reuse the same spectrum resources as cellular users. They may have some interferences coming from traditional cellular users who use the same spectrum or others who use the same spectrum in other cells.

In the coexisting network environment of D2D users and traditional cellular users, interference from other users will increase as the number of D2D users becomes large and intensive. Such a situation will result in the overall system performance decreasing. To cope with these problems, several studies have been proposed for D2D communication resource allocation. Ochia et al. [7] proposed a mode-selection mechanism based on path loss. Although the cost of mode selection is low, path loss cannot reflect the real link status and channel quality. Therefore, their approaches did not allocate resources properly. Additionally, when there are a lot of D2D users transmitting data in the cellular mode, excessive transmit power will interfere with other users and then result in the entire system performance decreasing. Wang et al. [8] proposed an effective method for allocating shared spectrum resources. They used the Hungarian algorithm for downlink resource allocation. However, their approach was not suitable to be applied to a dense network. Hou et al. [9] proposed a resource allocation algorithm based on D2D communication mode selection. They assigned a communication mode and allocated spectrum resources by calculating the optimal throughput. Y. Sun et al. [10] made a point, stating that power allocation is responsible for setting the appropriate D2D and cellular users' transmit power. Reasonable power control can control the interference between the two kinds of users when the D2D pair reuses cellular resources. Under the guarantee of the communication rate of the two, the total system throughput can be improved. The above mechanisms use the best mode selection, resource allocation, or energy efficiency as their research purposes, and these purposes significantly impact system performance. However, these studies did not take into consideration the mechanisms of mode selection, transmit power, and spectrum resource allocation simultaneously.

This paper proposes an energy-aware mode selection for D2D resource allocation in 5G networks. We concentrate on the coexisting network environment of crowded D2D users and traditional cellular users. The BS performs centralized control on all users in a cell. It can collect the channel state information of the links in the system at any time and allocate spectrum resources to each user according to user requirements. In the proposed approach, we assume that all spectrum resources are fully shared by traditional cellular users and newly introduced D2D users. After considering the transmission opportunity of traditional cellular users and analyzing the interference degree of the D2D communication mode, the communication mode of all users is assigned. To solve the interference problem generated by excessive transmit power in uplink transmission, we divided all users into three tiers according to the distances between users and BSs. Afterward, by using the Hungarian algorithm, we developed the corresponding spectrum resource allocation mechanisms based on the different communication modes. Our contribution is that we propose an energy-aware mode selection mechanism for spectrum resource allocation in the coexisting 5G network environment of D2D users and traditional cellular users by taking into consideration the mechanisms of mode selection, transmit power, and spectrum resource allocation simultaneously. We believe that, with our approach, spectrum efficiency and energy efficiency can be ensured and system throughput can be improved.

The rest of this paper is organized as follows. In Section 2, the differences between the three D2D communication modes and the issues of previous studies are introduced. Section 3 describes the system architecture and presents the problem's formulation. The energy-aware mode selection for D2D resource allocation mechanism is also introduced. In

Section 4, a simulation to verify the applicability of the proposed approach is presented and compared with other methods. Lastly, a conclusion and future work are provided.

2. Related Work

This section introduces the D2D communication modes and investigates the literature related to D2D issues.

2.1. D2D Communication Modes

D2D is regarded as a novel communication technology. During the process of D2D communication, users usually have at least two adjacent terminal devices and begin with the same application services, such as social interactions, cooperative games, multi-screen control, Push-to-Talk, etc. A connection needs to be established through procedures such as device searching and pairing. In summary, D2D communication technology refers to direct communication between two peer-to-peer communication nodes. In a distributed network that consists of D2D users, each user node can not only receive and send signals, but also have the function of automatic forwarding. D2D communication technology has different applications in different networks, for example, peer-to-peer in ad hoc networks and machine-to-machine in IoT. A schematic diagram of some D2D application scenarios is shown in Figure 1.

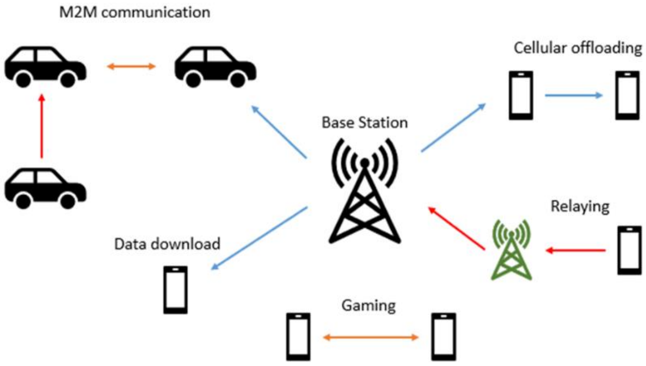

Figure 1. D2D communication application scenario.

D2D communication in a cellular network can be divided into three working modes according to its different transmission methods and characteristics. There are cellular modes, dedicated modes, and reuse modes. In the cellular mode, D2D users are similar to traditional cellular users, they can send messages to each other by BSs. As D2D users do not occupy the same spectrum resources as cellular users, they do not interfere with each other, as shown in Figure 2.

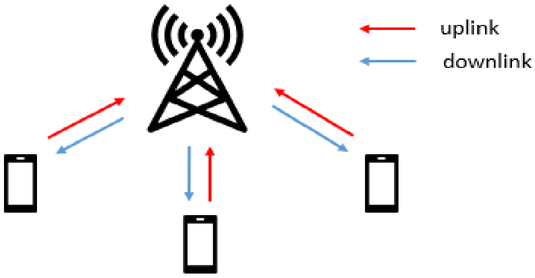

Figure 2. The cellular mode of D2D communication.

In the dedicated mode, the BS allocates a spectrum that can only be used by D2D users. The channel resources of D2D users and cellular users are orthogonal, so D2D users will not have any interference from other cellular users. The interference generated by D2D users who use the same resources in other cells is presented in Figure 3.

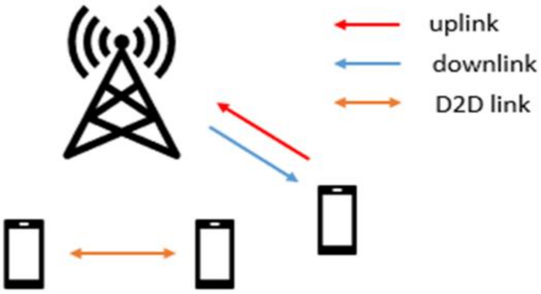

Figure 3. The dedicated mode of D2D communication.

In the reuse mode, D2D users will reuse the same spectrum resources as traditional cellular network users. In this case, when D2D users use the same spectrum resources as traditional cellular users, it will cause interference. In addition, its interference will also come from users who use the same spectrum in other cells, as shown in Figures 4 and 5. Figure 4 illustrates how D2D users and cellular users (CUE) use the same spectrum of resources. In the uplink, the D2D receiver (DRU) is interfered with by CUE, and the BS is interfered with by the D2D transmitter (DTU). In the downlink, DRU is interfered with by the BS and CUE is interfered with by the DTU.

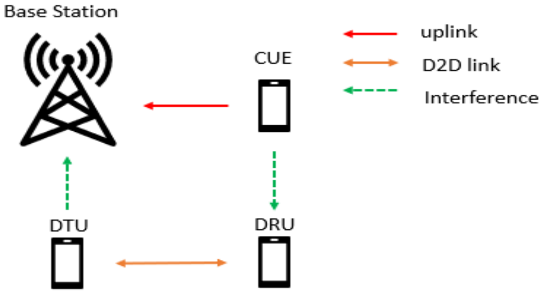

Figure 4. The reuse mode of D2D communication in uplink.

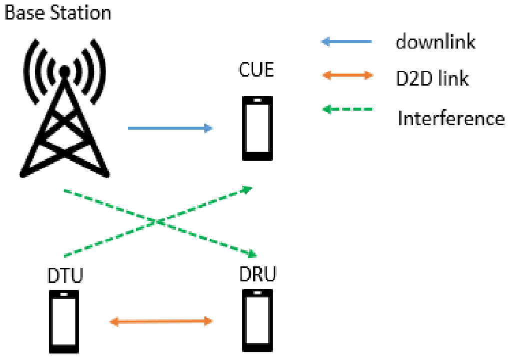

Figure 5. The reuse mode of D2D communication in downlink.

2.2. Related Studies

Several research issues related to D2D resource allocation, such as mode selection, spectrum allocation, and energy efficiency, have been discussed in existing works. Ochia et al. [7] proposed a path loss-based mode selection scheme where D2D users can set a default path loss threshold. If the path loss between users is bigger than the default threshold, D2D users will work in the cellular mode. Otherwise, they will work in the reuse mode. However, based on the path loss mode standard, it cannot reflect the actual channel quality and link interference. Wang et al. [8] optimized spectrum resource allocation by using the Hungarian algorithm. However, their environment only considered the downlink situation. Hou et al. [9] took system throughput into system performance indicators, selected a mode, and allocated spectrum resources by calculating the optimal throughput. Sobhi-Givi et al. [11] used the degree of interference between D2D users as the mode selection scheme. However, the distance between D2D users was fixed. It could not reflect the actual network environment. Huang et al. [12] proposed a concept of energy efficiency for mode selection by calculating ergodic capacity (EC) and energy efficiency (EE). Ji et al. [13] proposed a dynamic reward approach with deep reinforcement learning to maximize the EE while satisfying the system throughput constraints, as well as the quality of service (QoS) requirements of D2D pairs and cellular users, in an underlay D2D communication network. Penchala et al. [14] conducted a survey on a massive MIMO system with underlying D2D communication and discussed the coexistence of mMIMO and D2D communication. They reported that the 5G network or system performance could be improved drastically in massive MIMO with D2D communication. Reduced-energy wireless communication in 5G networks and maximizing the energy efficiency of D2D communication are two important issues. Lalitha et al. [15] formulated these two issues into a derivative algorithm and proposed a modified derivative algorithm to solve this optimization. Su et al. [16] focused on the problem of the simultaneous wireless information and power transfer (SWIPT)-based energy-efficient (EE) optimization for D2D communications supporting IoT networks with UAV assistance. They solved this problem by decoupling the original problem into several sub-problems and solving them sequentially.

3. Energy-Aware Mode Selection for D2D Resource Allocation

In the proposed approach, we assume that all resources are fully shared by traditional cellular users and D2D users. Our approach first considers the transmission opportunity of traditional cellular users. Next, we determine the communication mode of D2D users based on the degree of interference. We also divide all users into three tiers according to the distances between users and the base station to solve the interference problem generated by excessive power transmission in uplink transmission. Afterward, based on the different communication modes, we develop corresponding resource allocation mechanisms using the Hungarian algorithm. In the following, we detail the system architecture and the proposed approach.

3.1. System Architecture and Problem Formulations

As shown in Figure 6, the discussed network environment consists of N cellular users and M D2D users in a single cell, where M is greater than or equal to N. In this environment, the BS collects the channel state information of all links in the cell at any time and allocates spectrum resources to each user according to the user's requirements. Owing to the characteristics of dedicated and cellular modes, no spectrum occupancy problem is generated in either mode. When D2D users use the reuse mode to transmit data, the spectrum occupancy problem occurs. We assume that a pair of D2D users in the same cell can only reuse the spectrum resource with a cellular user. Therefore, the limit of spectrum occupancy of traditional cellular network users is defined as:

$$\sum_{i=1}^{N} x_{ij} \le 1 \, , \; j = 0, 1, \, 2, \, \ldots, \, M, \tag{1}$$

where i and j denote the number of traditional cellular network users and D2D user pairs, respectively. Note that, when $x_{ij} = 1$, it means that users i and j share a spectrum, otherwise, $x_{ij} = 0$.

This paper uses the signal-to-noise ratio (SNR) to represent the quality of channel resources for each D2D user. In the following, we separately discuss the SNR of D2D users in each mode according to the Shannon theorem [17]. Firstly, when D2D users transmit data in the cellular mode, the SNR of uplink and downlink, r_{up} and r_{down}, are separately calculated and can be obtained using the following formulas:

$$r_{up} = P_d * G_{dbs} / N_0, \tag{2}$$

$$r_{down} = P_{bs} * \; G_{dsb} / N_0, \tag{3}$$

where P_d and P_{bs} denote the transmit power of D2D users and BSs, respectively; G_{dbs} and G_{dsb} represent the channel gain from the D2D transmitter to the BS and from the BS to the D2D receiver, respectively; N_0 denotes the channel noise power during data transmission. As shown in Formula (4), we set the minimum SNR value between uplink and downlink, r_{cell}, as the SNR value of the traditional cellular mode. Consequently, the performance of D2D users will be better than this situation at any time.

$$r_{cell} = min\left\{ r_{up}\ ,\ r_{down}\right\}. \tag{4}$$

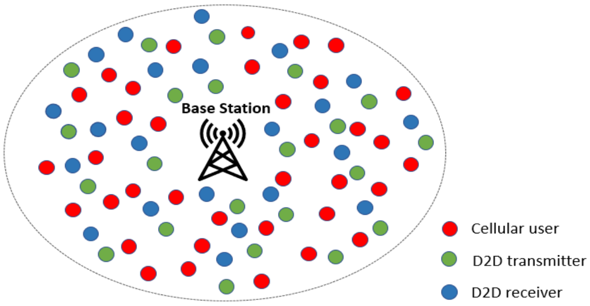

Figure 6. Network environment.

Next, in the dedicated mode, D2D users will be assigned the dedicated radio resources by BSs and these resources will be orthogonal with the traditional cellular network channel resources. The formula for calculating SNR value in this mode is shown in Formula (5),

$$r_{ded} = P_d\ G_{dd}/N_0, \tag{5}$$

where G_{dd} denotes the channel gain of the link between devices in the dedicated and reuse modes.

Lastly, the D2D reuse mode will cause shared interference between D2D user pairs and cellular users. When a pair of D2D users reuse the uplink resources, the BS and other D2D users will be interfered with. During the case of downlink reuse, the BS is the original interference. In fact, the D2D receiver will have interfered heavily, and the corresponding interference coordination and suppression will be difficult in the case of downlink reuse. In the case of the reuse of a cellular uplink, D2D users will restrict sharing the same spectrum resource with a cellular user in the same cell as they can effectively control and reduce the cumulative interference of the BS. Therefore, the formula for calculating SNR value in the reuse mode is different from those for the cellular and dedicated modes. The SNR value in the reuse mode is calculated as

$$r_{re} = P_d\ G_{dd}/\ (\ N_0 + P_c\ G_{cd}), \tag{6}$$

where G_{cd} denotes the channel gain when D2D users are interfered with by traditional cellular network users and P_c represents the transmit power of traditional cellular users.

By referring to Shannon's formula, we can obtain the system throughput for the corresponding modes, as shown in Formulas (7)–(9).

$$TP_{cel} = Blog_2(1 + r_{cell}), \tag{7}$$

$$TP_{ded} = Blog_2(1 + r_{ded}), \tag{8}$$

$$TP_{reu} = Blog_2(1 + r_{re}), \tag{9}$$

where TP_{cel}, TP_{ded}, and TP_{reu} denote the system throughput for the cellular mode, dedicated mode, and reuse mode, respectively, and B represents the bandwidth that is allocated to communication for users. Additionally, to measure the efficiency of the proposed power control policy, we use the following formula to calculate the energy efficiency (EE),

$$EE = \frac{TP_{tot}}{P_{tot}}, \tag{10}$$

where TP_{tot} denotes the sum of the total throughput in the system and P_{tot} represents the total transmit power, which is the sum of the transmit power by the overall system.

3.2. Energy-Aware Mode Selection for D2D Resource Allocation

3.2.1. Mode Selection

In the coexisting wireless network of traditional cellular and D2D users, traditional cellular users transmit data using the traditional cellular network, while D2D users send data using the cellular, dedicated, or reuse modes. In our environment, there are C traditional cellular users and D D2D users. We assume that the total available spectrum resources for traditional cellular users, C_s, and the total available spectrum resources for dedicated mode users, D_s, are provided.

Note that traditional cellular users transmit data using cellular networks, and they will not interfere with D2D users in a single cell. Our approach first considers the transmission opportunity of traditional cellular users. If all traditional cellular users can be satisfied and there are still some available spectrum resources of cellular networks remaining, denoted as RC_s, then RC_s will be allocated to D2D users. If not, the traditional cellular users who cannot obtain enough spectrum resources will wait for the spectrum resources released by other traditional cellular users.

Next, we assign the communication mode for D2D users based on the degree of interference. Different communication modes have different interference degrees. The transmission in the dedicated and cellular modes is relatively stable compared with the reuse mode. Therefore, we first assign the dedicated communication mode to D2D users and then compute how many D2D users' spectrum resources remain. If some D2D users cannot be satisfied, denoted as RD_{pair}, and some spectrum resources of the traditional cellular network remain, then $RC_s > 0$, the cellular communication mode will be assigned to those D2D users. Next, if some D2D users with the cellular mode cannot be satisfied, we will assign the reuse communication mode to those D2D users. D2D users with the reuse mode will share the spectrum resources with traditional cellular users. Finally, four parameters, NC_a, ND^{cell}, ND^{ded}, and ND^{reuse}, which record the communication mode for traditional cellular and D2D users, are output. A pseudocode for mode selection is presented in Algorithm 1.

3.2.2. Power Control

As shown in Figure 7, for downlink transmission, the data are transmitted from BSs to the users. Therefore, the transmit power is consistent in this cell. If the users are near the BS in the uplink transmission, they can satisfy their transmission requirement without excessively transmitting power to transmit data. In a crowded environment, it will cause other users to receive interference due to the current transmission user power being too large. The transmission power of other users will increase due to the need to maintain the transmission quality during the transmission process, which will cause new interference to other users. Lastly, it will increase the overall energy consumption of the system. To cope with this problem, we classified all users into three tiers according to the distances between users and BSs. Users are classified into Tier 1 when the distance between the user and the BS is less than or equal to 350 m, Tier 2 when the distance between the user and the BS is between 350 m and 700 m, and the others belong to Tier 3. With this policy, it can not only be closer to reality, but it can also effectively reduce the excessive energy consumption of the equipment.

Algorithm 1 Mode selection

```
Input: $C, D, C_s, D_s$
Output: $NC_a, ND^{cell}, ND^{ded}, ND^{reuse}$
Initial $NC_a, ND^{cell}, ND^{ded}, ND^{reuse}$ are empty list
$NC \leftarrow$ Compute the spectrum resources required by $C$ cellular users
$ND_{pair} \leftarrow$ Compute the spectrum resources required by $(D/2)$ D2D pairs
if $NC > 0$ and $C_s > 0$ and $NC \geq C_s$ then
    $NC_a \leftarrow$ cellular users whose resource requirements can be satisfied
    $RC_s \leftarrow 0$
else
    if $NC > 0$ and $C_s > 0$ and $NC < C_s$ then
        $NC_a \leftarrow$ cellular users whose resource requirements can be satisfied
        $RC_s \leftarrow (C_s - NC)$
    end if
end if
/* Dedicated mode */
if $ND_{pair} > 0$ and $D_s > 0$ and $ND_{pair} \geq D_s$ then
    $ND^{ded} \leftarrow$ Assign dedicated mode to D2D users whose resource requirements can be satisfied
    $RD_{pair} \leftarrow (ND_{pair} - D_s)$
else
    if $ND_{pair} > 0$ and $D_s > 0$ and $ND_{pair} < D_s$ then
        $ND^{ded} \leftarrow$ Assign dedicated mode to D2D users whose resource requirements can be satisfied
        $RD_{pair} \leftarrow 0$
    end if
end if
/* Cellular mode */
if $RD_{pair} > 0$ and $RC_s > 0$ and $RD_{pair} \geq RC_s$ then
    $ND^{cell} \leftarrow$ Assign cellular mode to D2D users whose resource requirements can be satisfied
    $RC_s \leftarrow 0$
else
    if $RD_{pair} > 0$ and $RC_s > 0$ and $RD_{pair} < RC_s$ then
        $ND^{cell} \leftarrow$ Assign cellular mode to D2D users whose resource requirements can be satisfied
        $RC_s \leftarrow (RC_s - RD_{pair})$
    end if
end if
/* Reuse mode */
if $RD_{pair} > 0$ and $C_s \geq 0$ then
    $ND^{reuse} \leftarrow$ Assign reuse mode to D2D users whose resource requirements can be satisfied
else
    $ND^{reuse} \leftarrow 0$
end if
return $NC_a, ND^{cell}, ND^{ded}, ND^{reuse}$
```

3.2.3. Spectrum Resource Allocation

After assigning the communication modes to D2D users and dividing all users into three tiers, we allocated the spectrum resources to all users according to different communication modes by using the Hungarian algorithm. Before applying the Hungarian algorithm to solve the spectrum allocation problem, we first define the system throughput for each communication mode. By referring to Formula (7), the system throughputs of the traditional cellular network, dedicated mode, and cellular mode are as follows:

$$TP_C = \max \sum_{k=1}^{K} S_{c,k} B_k \, log_2 \left(1 + SNR_k\right), \tag{11}$$

$$\sum_{c=1}^{C} S_{c,k} \leq 1, \; S_{c,k} \in \{0,1\}, \tag{12}$$

where k denotes traditional cellular users, $S_{c,k}$ represents whether traditional cellular users occupy spectrum resources, and c denotes the spectrum resources.

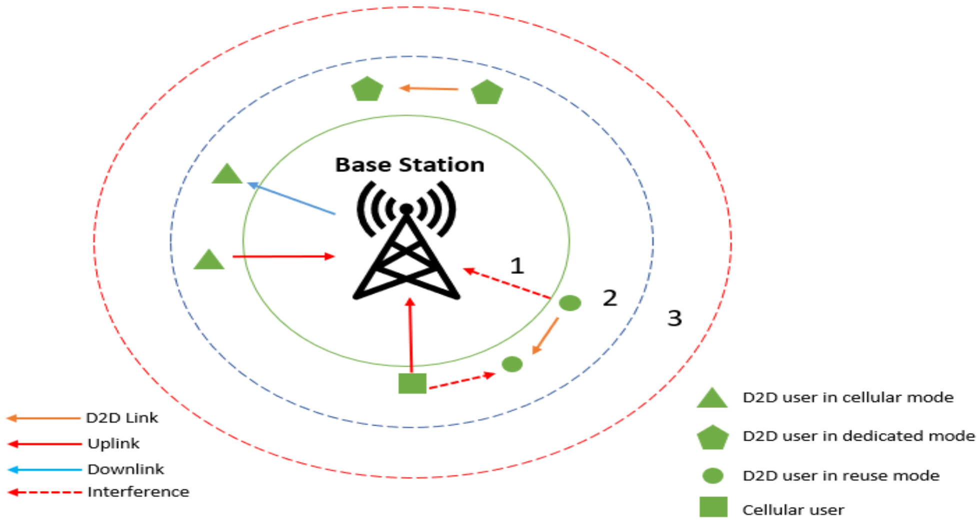

Figure 7. Stratified transmit power.

Next, we defined the system throughput of the reuse mode as follows:

$$TP_{ci,di} = \text{Max}\ \sum_{j=1}^{J} \sum_{k=1}^{K} [S_{ci,k} B_{ci,k}\ log_2\ (1 + SNR_{ci,k}) \\ + W_{di,j} B_{di,j}\ log_2\ (1 + SNR_{di,j})\ ], \tag{13}$$

$$\sum_{ci=1}^{Re} S_{ci,k} \leq 1,\ S_{ci,k}\ \in \{0,1\}, \tag{14}$$

$$\sum_{di=1}^{Re} W_{di,j} \leq 1,\ W_{di,j}\ \in \{0,1\}, \tag{15}$$

$$S_{ci,k}.\ W_{di,j}\ \in \{0,1\}, \tag{16}$$

where k represents traditional cellular users, j denotes D2D users in the reuse mode, $S_{ci,k}$ represents whether traditional cellular users occupy shared spectrum resources, and $W_{di,j}$ denotes whether the D2D users of the reuse mode occupy shared spectrum resources. Formulas (14)–(16) are restriction formulas for occupied spectrum resources. In order to find the maximum by using the Hungarian algorithm, Formula (13) was converted to Formula (17), where $S_{ci,k}$ and $W_{di,j}$ are solved by the Hungarian algorithm.

$$TP_{ci,di} = \min\ \sum_{j=1}^{J} \sum_{k=1}^{K} [-S_{ci,k} B_{ci,k}\ log_2\ (1 + SNR_{ci,k}) \\ - W_{di,j} B_{di,j}\ log_2\ (1 + SNR_{di,j})\ ] \tag{17}$$

Algorithm 2 shows the allocating flow of the Hungarian algorithm, where N denotes the number of users, S represents the total number of available spectrum resources, T denotes the array of the SNR of each user in different spectrum resources, and FC represents an array of the final selected resources.

Lastly, the complete algorithm of the proposed mechanism is shown in Algorithm 3. Four parameters T, C, D, C_s, and D_s, are inputs, where T denotes the channel resources generated by the channel model, C represents the data of the total traditional cellular users, D denotes the data of the total D2D users, C_s represents the total available spectrum resources of cellular users, and D_s denotes the total available spectrum resources of dedicated mode users. After performing the proposed mechanism, four parameters, FC, FDC, FCC, and FRC, were generated, which represented the allocated resources for every user in each communication mode, respectively. With these four parameters, the total system throughput could be obtained.

Algorithm 2 Hungarian Algorithm

```
1:  Input: T [1, 2, 3..., N] [1, 2, 3..., S]
2:  Output: FC [N]
3:  if N < S then
4:      T [N] [S] padding zero until N is equal to S
5:  end if
6:  Each column or row of matrix T subtracts the minimum
7:  Ensure each column or row has at least one zero
8:  Remove the row or column with zero
9:  Ensure the number of removed rows and removed columns are the smallest
10:  num ← number of removed rows and removed column
11:  if num is not equal to N then
12:      repeat line 6 to 9
13:  else
14:      FC [N] ← final selected resources
15:      return FC [N]
16: end if
```

Algorithm 3 Energy-aware mode selection for D2D resource allocation

```
Input: $T$, $C_s$, $D_s$, $C$, $D$
Output: $FC$, $FDC$, $FCC$, $FRC$
$NC_a$, $ND_{cell}$, $ND_{ded}$, $ND_{reuse}$ = $Modeselection(C, D, C_s, D_s)$
Perform $PowerControl$
$FC = HungarianAlgorithm($T [$C$] [$NC_a$]$)$
$FDC = HungarianAlgorithm($T [$D$] [ $ND_{ded}$]$)$
$FCC = HungarianAlgorithm($T [$D$] [ $ND_{cell}$]$)$
$FRC = HungarianAlgorithm($T [$D$] [$ND_{reuse}$]$)$
return $FC$, $FDC$, $FCC$, $FRC$
```

4. Simulation and Performance Evaluation

In order to verify the feasibility of the proposed mechanism, we simulate a simple environment using Python language and compare it with the proposed approach without power control and Hou's approach [9] in terms of total system throughput and energy efficiency.

4.1. Simulation Environment

As shown in Figure 8, we simulated a single cell with a radius of 1 km. The single cell consists of a single BS, several traditional cellular users, and D2D users. All users were randomly distributed in this cell. According to the distance from the transmitter to the receiver, all users were classified as line-of-sight (LoS) or non-line-of-sight (NLoS). Therefore, D2D users using the reuse mode and dedicated mode were classified as LoS, while others were classified as NLoS. We simulated the small-scale fading of LoS and NLoS by using Rician fading and Rayleigh fading, respectively.

By referring to [12], the transmit power of cellular users on tier 1, tier 2, and tier 3 were set to 23 dBm, 30 dBm, and 32 dBm, respectively. The transmit power of D2D users in the reuse and dedicated modes was set to 20 dBm, and the transmit powers of D2D users in the cellular mode on tier 1, tier 2, and tier 3 were set to 18 dBm, 21 dBm, and 23 dBm, respectively. The distance of each D2D pair was randomly distributed in the range of 1 m and 30 m. The total spectrum was set to 200 Hz, the available spectrum for cellular users was set to 100 Hz, and the available spectrum for D2D users in the dedicated mode was set to 100 Hz. The bandwidth was set to 180 kHz and the noise power was set to -174 dBm/Hz [9]. Note that, in this paper, we compare the proposed approach with Hou's approach [9] in terms of the total system throughput and energy efficiency. To allow the comparison on the same base, we chose simulation parameters, such as the noise power of -174 dBm/Hz and a total spectrum of 200 Hz, that were the same as Hou's approach. Table 1 shows our simulation parameters.

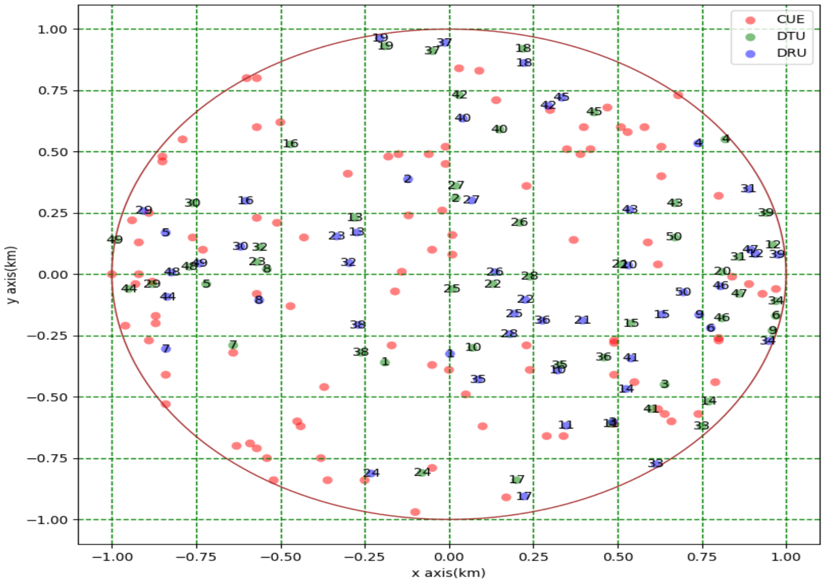

Figure 8. A D2D simulation environment.

Table 1. Simulation parameters.

Parameter	Value
Cell Radius (R)	1 km
Transmit power of cellular users on tier 1	23 dBm
Transmit power of cellular users on tier 2	30 dBm
Transmit power of cellular users on tier 3	32 dBm
Transmit power of D2D users in reuse and dedicated modes	20 dBm
Transmit power of D2D users in cellular mode on tier 1	18 dBm
Transmit power of D2D users in cellular mode on tier 2	21 dBm
Transmit power of D2D users in cellular mode on tier 3	23 dBm
Distance from the transmitter to receiver in a D2D pair	1–30 m
Total spectrum	200 Hz
Available spectrum for cellular user	100 Hz

4.2. Performance Evaluation

We performed simulations for different pairs of traditional cellular users and D2D users, (50, 50), (100, 100), (100, 200), (100, 300), and (100, 400). To make the simulation easier to calculate, we simplified the process of D2D pairing. For the fairness of the experiment, we repeated each pair simulation 10 times. The ten times simulation results of different pairs of traditional cellular users and D2D users are shown in Figures 9–13. Figure 14 shows the average system throughput of three approaches for different pairs of traditional cellular users and D2D users. Note that in Figure 9, the standard deviations of the proposed approach, the proposed approach without power control, and Hou's approach were 0.83, 1.03, and 0.66, respectively; in Figure 10, the standard deviations of the proposed approach, the proposed approach without power control, Hou's approach were 1.10, 1.097, and 0.697, respectively; in Figure 11, the standard deviations of the proposed approach, the proposed approach without power control, and Hou's approach were 0.674, 0.71, and 0.594, respectively; in Figure 12, the standard deviations of the proposed approach, the proposed approach without power control, and Hou's approach were 1.409, 1.414, and 0.609, respectively; in Figure 13, the standard deviations of the proposed approach, the proposed approach without power control, and Hou's approach were 1.153, 1.157, and 1.368, respectively.

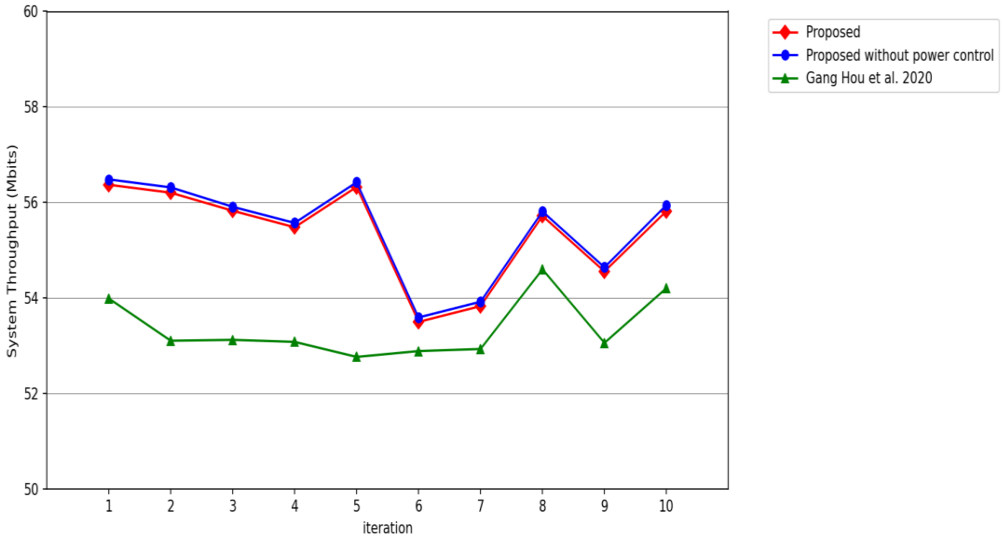

Figure 9. Comparison of system throughput. Cellular users = 50, D2D users = 50 [9].

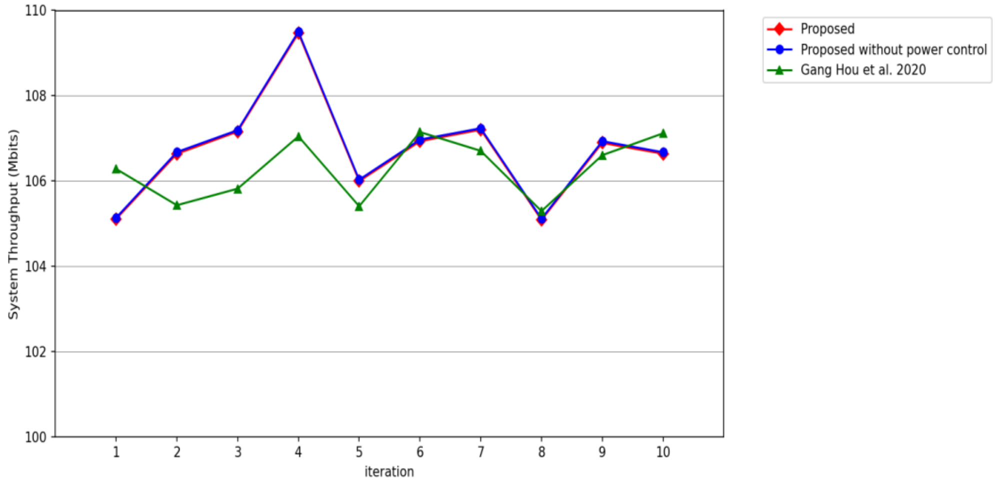

Figure 10. Comparison of system throughput. Cellular users = 100, D2D users = 100 [9].

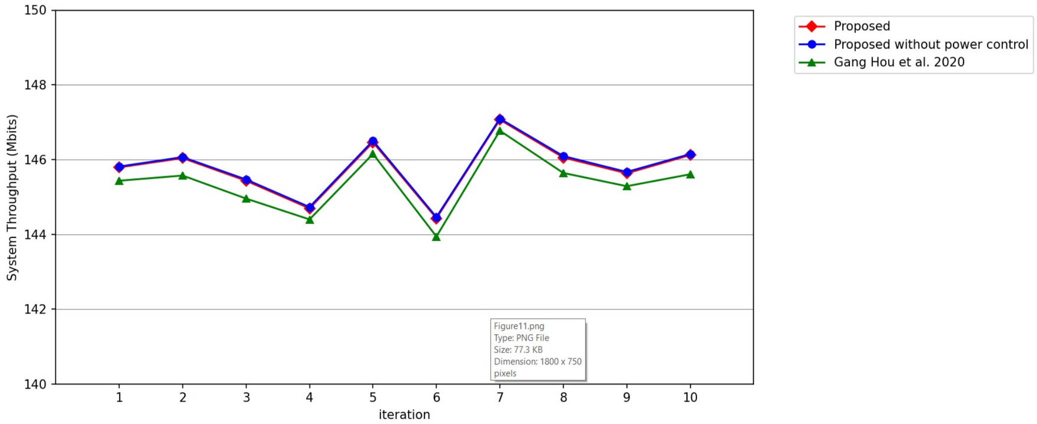

Figure 11. Comparison of system throughput. Cellular users = 100, D2D users = 200 [9].

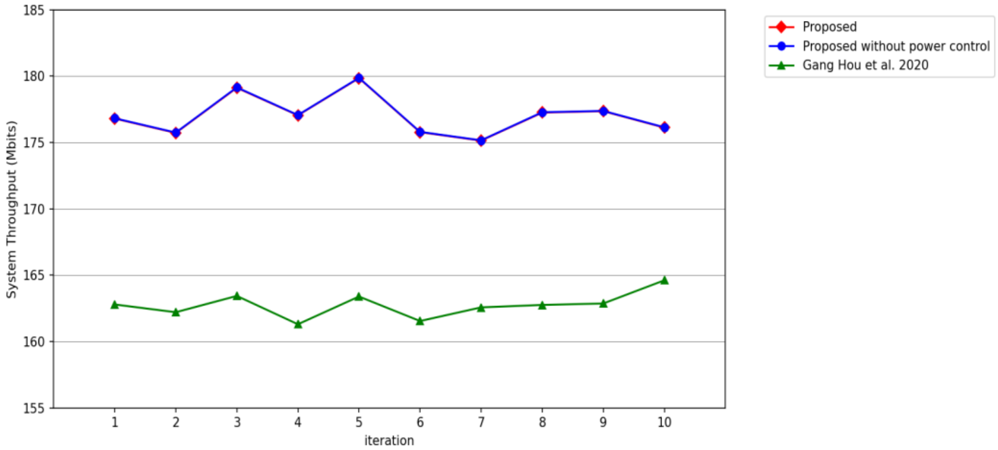

Figure 12. Comparison of system throughput. Cellular users = 100, D2D users = 300 [9].

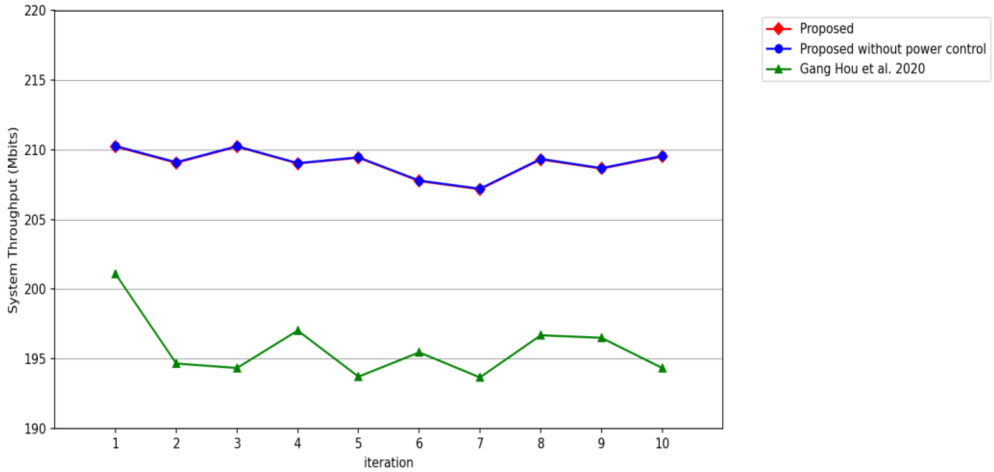

Figure 13. Comparison of system throughput. Cellular users = 100, D2D users = 400 [9].

From Figures 9 and 11–13, the proposed approach performed better than Hou's approach and the system throughput of the proposed approach without power control had a slim lead over the proposed approach with power control. However, in Figure 10, the system throughput between the proposed approach and Hou's approach was almost on par. The reason is that, in the proposed approach, when the number of users was few, the spectrum resources may not have been effectively allocated, which resulted in a lower throughput. Figure 11 shows that the system throughput was consistent. But in Figures 12 and 13, the gap in throughput between our approach and Hou's approach became bigger and bigger as the number of D2D users increased. Nonetheless, the overall system performance was not affected severely. From Figure 14, we can see that the average system throughput of our approach increased as the number of D2D users increased. We also can see that the average system throughput of our approach outperformed that of Hou's approach. The reason is that Hou's approach aims to maximize the throughput of the current user. This method will make full use of the current user at the current moment resources to achieve maximum throughput. However, it may result in some users receiving more resources while others may be throttled, which may cause fairness issues in some cases. We allocated the overall spectrum more efficiently using the Hungarian algorithm. We tried to balance resource allocation to the greatest extent to ensure that each user could obtain a certain bandwidth. With the increase in the number D2D users, there was a clear gap between the proposed approach and Ho's approach in the effect of resource allocation

Lastly, we performed a comparison of three approaches in terms of energy efficiency, as shown in Figure 15. From the figure, we can see that the energy efficiency of our approach increased as the number of D2D users increased. With power control, the energy efficiency could be enhanced by 20%. Although the system throughput of our approach with power control was less than the system throughput without power control, there was a big gap in energy efficiency between the two methods. This demonstrates that our scheme with power control is effective and feasible.

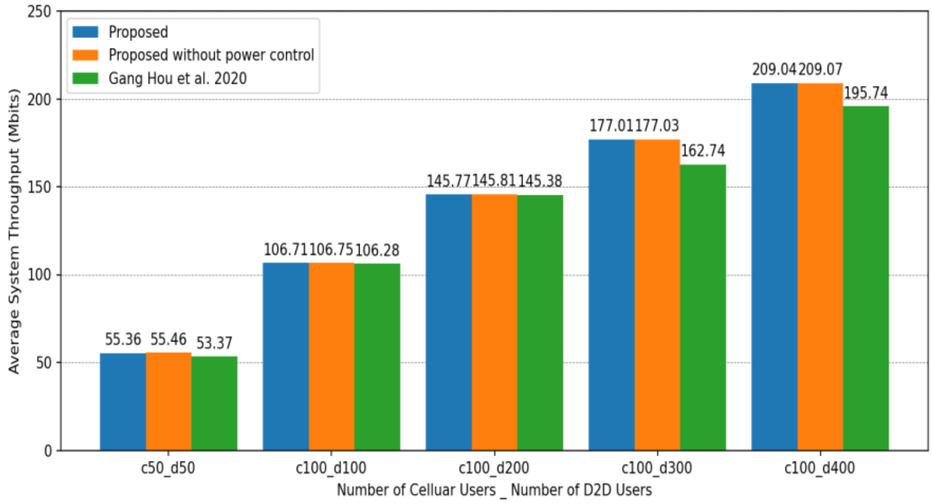

Figure 14. Comparison of the average system throughput [9].

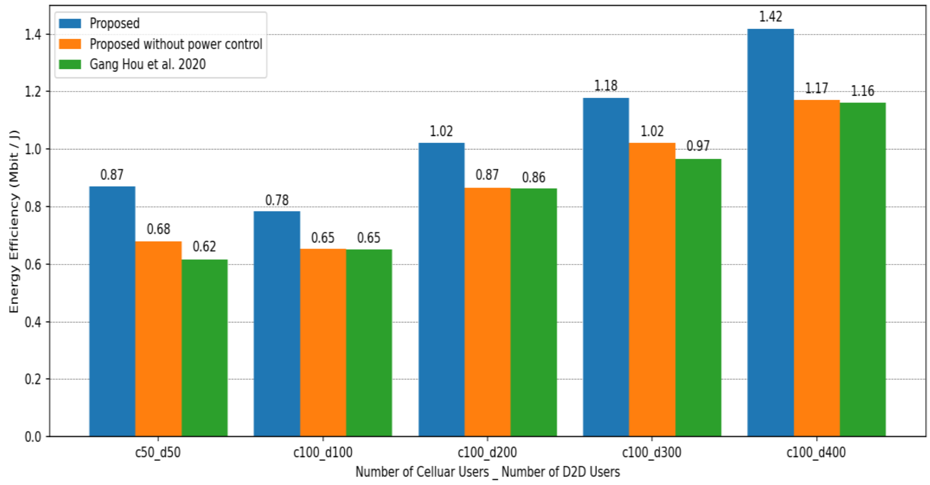

Figure 15. Comparison of energy efficiency [9].

5. Conclusions and Future Work

This paper proposed an energy-aware mode selection for D2D resource allocation in 5G networks. Our approach first considered the transmission opportunity of traditional cellular users. Next, we determined the communication mode of D2D users based on the degree of interference. We also divided all users into three tiers according to the distances between users and the BS to solve the interference problem generated by excess transmit power in uplink transmission. Afterward, based on the different communication modes, we developed corresponding resource allocation mechanisms using the Hungarian algorithm. The benefits of the proposed approach are as follows: we dealt with the overall system interference, considering the energy consumption of D2D users and ensuring the usage rights of all users. The simulation results revealed that the average system throughput of our method was 7% higher than that of the method proposed by Hou et al. [9]. With power control, the energy efficiency could be enhanced by 20%. In future work, to make the environment more realistic, one can increase the number of BSs and users. Moreover, under the constraints of guaranteeing user QoS requirements and effectively managing the interference among users, we plan to apply machine learning techniques to solve the joint optimization problem of mode selection and channel allocation in D2D-enabled 5G networks.

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