Improving Device-to-Device Communication Performance in 5G Networks through Joint Power Control and Resource Allocation

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Abstract: - The rapid growth in user population and the proliferation of diverse systems and services place a heavy burden on mobile communication networks. Device-to-Device (D2D) communication technology is considered one of the key technologies in 5G because of its ability to alleviate this burden and improve system performance. Most current research focuses on how to enhance transmission efficiency but proposed solutions tend to be highly complex. Therefore, the base station works for a long duration on this process, increasing the cost of communication equipment. To tackle this issue, we propose a low-complexity method that makes the use of power control and suitable resource allocation. A centralized network architecture is adopted to simplify this process and improve performance. Simulation results show that the proposed approach can significantly decrease interference, reduce power consumption, and increase throughput.

Key-Words: - 5G, D2D communication, power control, resource allocation, RB reuse, decrease interference

1 Introduction

Device-to Device (D2D) communication technology is the latest innovation that can reduce the loads the base stations. It allows two devices within a certain distance to communicate directly among themselves without the help of evolved Node B (eNB) hardware. D2D communication utilizes the cellular spectrum (license band) and is aided by cellular network infrastructure [1]. Current network architecture is divided into two types. First is centralized management knows as, the Resource Block (RB), which is allocated directly from the base station to the designated D2D user. This architecture provides a better allocation of resources and is often used in densely populated areas. Second is decentralized management, in which the base station informs D2D users which RBs they can use, and D2D users then choose RBs. This architecture is more likely to cause collisions unlike the first architecture, thus its efficiency is relatively poor. Hence, this architecture can be used in suburbs and other areas where there are fewer Cellular User Equipment (CUEs).

In this paper, we consider a centralized management environment, where all operations are performed through eNb (Evolved Node B) because of its high computational ability. By using power control [2][5], we can reduce the interference caused by the user, and improve resource utilization by reusing RBs that are used by CUEs [6]. We can also improve the system's transmission efficiency by allocating resources to the D2D pair according to their requests.

1.1 Related Research

In [7], the authors presented several new challenges for the D2D related technology. One of the biggest challenges is how Device User Equipment (DUE) determines the presence of other DUE. D2D is a technology that allow devices to communicate directly with the one another, thus devices need to pair before communicating. There are two main methods for D2D pairing. The first method is searching for nearby devices. Finding more devices in less time is more conducive to establish a connection for transmission. Another method is to directly specifying the device to be paired with. This typically occurs after the previous search has been done, and the device then specifies the other device and successfully pairs. This paper is based on the premise that device exploration has been completed and that all the D2D pairs are paired already.

The next challenge is that of resource allocation. There is an exclusive resource allocation method, in which resources are given directly to the devices. In this case, there is no interference between the D2D pairs and CUEs, but the spectrum efficiency will be lower. Hence, D2D pairs and CUEs can use the same resources to increase spectrum efficiency, i.e., D2D devices can reuse the resources used by the CUEs, thus increasing the spectrum efficiency [13].

In [8], a D2D resource allocation method is proposed where interference between the devices because of reduced reuse of RBs. However, this is a one-to-one mapping problem, so wireless resources can only be reused once. Another study [9] suggests assigning several users to a group/coalition to reduce the complexity of radio resource allocation. This coalition forming method can significantly reduce interference compared to allocating radio resources to the users one by one. In [10], the authors used centralized and decentralized power control algorithms to improve the performance of D2D communication in a single-cell random network model. In the centralized power control algorithm, D2D pairs can communicate with a specific transmit power that can maximize coverage. On the other hand, the decentralized power control algorithm used an on-off power control to manage interference between D2D pairs.

Hence in this paper, we propose a power control and resource management scheme that would help us

- Reduce interference caused by other DUE pairs.
- Reduce power consumption of D2D pairs.
- Reduce resource requirements.
- Improve the average signal-to-interference-plus-noise ratio (SINR) of each D2D pair.

The rest of this paper is organized as follows. In Section 2 we introduce the system model considered in this paper. Section 3 explains power control and resource management methods. Section 4 contains simulation results and analysis. Section 5 concludes the paper.

2 System Model

The system model an outdoor urban macrocell model with only one base station is shown in Fig.1. The coverage of the base station is 500 meters and CUEs and D2D pairs are evenly distributed in the coverage area. D2D pairs are at least 35 meters away from the base station [12]. In this context, D2D pairs want to communicate directly.

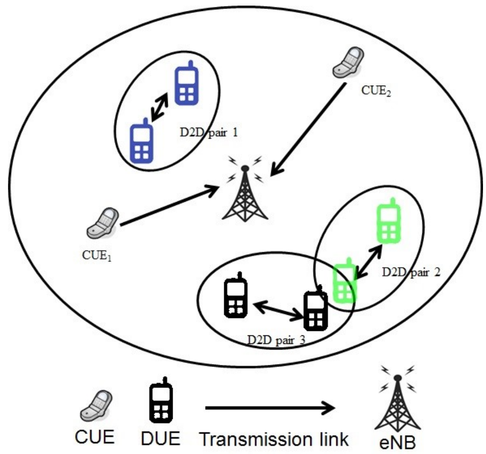


Fig. 1 System Model.

2.1 System Description and Assumptions

A detailed description of the environment considered in this paper are as follows:

1. D2D pairs only reuse CUEs upstream resource.
2. All D2D pairs are already paired.
3. The eNB knows the coordinates of all users.
4. There are N_p D2D pairs and N_c CUEs.
5. $N_i^{RB,req}$ is the number of RB required for D2D pair i.

   The CUE has completed its power control and the number of RBs being used is a uniform random variable between 1 and 10.

We have made some assumptions to simplify the simulation and analysis, which are as follows:

1. D2D pairs can send the required number of RBs through the Physical Random-Access Channel (PRACH).
2. D2D pairs reuse the CUE's uplink spectrum.
3. eNB allocates uplink resources to the CUEs based on semi-persistent scheduling.
4. Interference occurring outside of the interferential coverage can be ignored.
5. The channel quality of all RBs is the same for a D2D pair.
6. The number of RBs required for a D2D pair after power control is only related to SINR.

2.2 Symbol Definition

This paper will use some symbols to facilitate our description, the following symbols used to define:

1. N_p : The number of D2D pairs in the environment.
2. N_c : The number of CUEs in the environment.
3. $PL_{i,i}$: Path loss of a D2D pair i between two DUEs.
4. $N_i^{RB,req}$: The number of RBs required for a D2D pair i
5. P_0 : The transmit power of a D2D pair in environment.
6. P_i : The transmit power of D2D pair i after power control.

2.3 Overview of Proposed Method

In this paper, we use power control method and resource allocation to improve the overall performance of the D2D network [14]. For power control, we assume that interference outside of the interferential coverage is negligible. If there is another D2D pair within the interferential coverage area of a D2D pair, that pair should perform power control at its maximum, so that we can enhance the chances to of allowing the D2D pairs to share RBs with other D2D pairs during RB allocation. Otherwise, the D2D pair need not perform power control, but instead use the default transmit power of 23 dBm. Because the default transmit power is 23 dBm, the maximum interferential coverage distance of DUE is 153 m. To simplify, we choose 150m as the interferential coverage area of DUE before power control.

During resource allocation, users can reuse a CUE's RB provided they do not interfere with each other. This will improve the utility of resources, and can reduce the total number of required RBs.

The steps of our proposed method are as follows:

1. eNB calculates the shortest distance $d_{i,j}$ from D2D pair i to D2D pair j where j = 1, 2, 3, … N_p , $i \neq j$.
2. Calculate the interference value of each D2D in accordance with other D2D pairs.
3. Start power control with the D2D pair with the highest interference value, and then recalculate the interference of each D2D pair caused by the presence of other D2D pairs. Repeat the above steps until all D2D pairs are checked at least once.
4. During RB allocation, D2D pairs that still have interference with other pairs are given different RBs to communicate.

3 Power Control

The following is a detailed description of the power control method.

3.1 Calculation of the Minimum Power

Before carrying out power control, we must define the distance between the DUEs in a D2D pair. As shown in Fig. 2, $d_{i,i}$ and $d_{j,j}$ are the distances between the transmitters and receivers of the D2D pair i and D2D pair j , respectively. $d_{i,j}$ is the shortest distance between D2D pair i and D2D pair j .

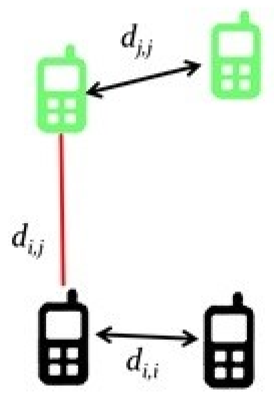


Fig. 2 The distance between D2D pair.

After performing power control, the minimum power that allows D2D pair i to still communicate is denoted by $P_i^{\min}$ and calculated as

$$P_i^{min} = (SINR_{\min} + 10\log[I_i(\mathrm{mW}) + \eta(\mathrm{mW})]) - G_i^D \tag{1}$$

where $SINR_{\min}$ is -6.7 dB. This is the lowest SINR value at which the D2D pair can still communicate [12] I_i is the interference on the D2D pair i caused by the other D2D pairs. The formula for the interference is

$$I_i\ (\mathrm{mW}) = \sum_{j=1, j\neq i}^{N_p} \boldsymbol{E}_j \times 10^{(P_0 - PL_{j,i})/10} \tag{2}$$

where E_j is an indicator function. Because we assume that interference outside of the interferential coverage area can be ignored, we use this function to determine whether interference exists. Thus E_j can be expressed as:

$$\boldsymbol{E}_j = \begin{cases} 1, d_{j,i} \le 150 \text{ m} \\ 0, d_{j,i} > 150 \text{ m} \end{cases} \tag{3}$$

η is thermal noise. With a bandwidth of 20 MHz, η = -101 dBm. G_i^D is the channel gain of D2D pair i, which is the reciprocal of the path loss of D2D pair i.

$P_i^{\min}$ is the minimum transmit power required for D2D pair i to communicate, which can be used to check whether the transmit power generated after power control is sufficient.

The path loss model between D2D pair j and D2D pair i is:

$$PL_{j,i}(\text{dB}) = \begin{cases} \text{Max}[20\log(d_{j,i}) + 38.4,\ 22.7\log(d_{j,i}) + 33.02],\ d_{j,i} \le 17.06 \text{ m} \\ \text{Max}[20\log(d_{j,i}) + 38.4,\ 40\log(d_{j,i}) + 11.73],\ d_{j,i} > 17.06 \text{ m} \end{cases} \tag{4}$$

3.2 Calculation of Transmit Power

To calculate the transmit power after performing power control, we use Eq. (5) to calculate the minimum Received Signal Strength (RSS), denoted by $RSS_i^{\min}$, for D2D pair i and use $RSS_i^{\min}$ to calculate the maximum transmit power that can be used after power control. $SINR_{\min}$, I_i and η are the same as those used in $P_i^{\min}$.

$$RSS_i^{\min} = SINR_{\min} + 10\log[I_i(\text{mW}) + \eta(\text{mW})] \tag{5}$$

Next, we must calculate the transmit power after performing power control as,

$$P_i = RSS_i^{\min} + \Delta \tag{6}$$

where P_i is the required transmit power of D2D pair i which is the sum of $RSS_i^{\min}$ and Δ. As shown in Fig.3, $RSS_i^{\min}$ is the minimum RSS needed to ensure when the two devices in a pair i when separated by a distance $d_{i,i}$, can communicate with each other. This is indicated by the dotted arc in the fig.3. The purpose of adding Δ is to allow the transmit power of D2D pair i to reach the maximum value without causing interference to D2D pair j after performing power control. This is indicated by the solid arc in Fig. 3.

The value of Δ is calculated as follows:

$$\Delta\ (\text{dB}) = 40\log(\frac{d_{j,i}}{d_{i,i}}) \tag{7}$$

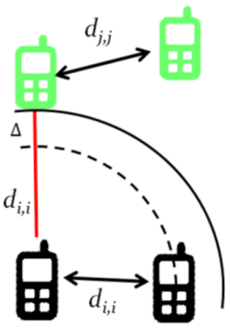


Fig. 3. Calculation of the transmit power for D2D pair i.

This formula is modified by formula (4) because the value is different only when the distance is greater than or equal to 22 meters. It is also possible to eliminate the constant term because $RSS_i^{\min}$ is included. Therefore, we choose the maximum value,and hence the formula will be as shown in (5).

3.3 Resource Allocation

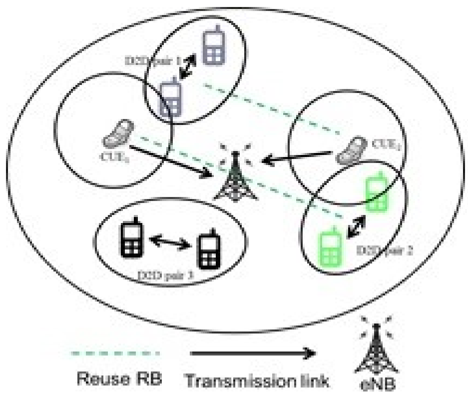


Fig. 4 Scenario depicting the reuse of RBs.

For resource allocation, we must find how the RBs can be reused, taking interference into account. As illustrated in Fig. 4, there are three D2D pairs and two CUEs. D2D pair 1 is in the interferential coverage area of CUE1, hence D2D pair 1 can only share RBs with CUE2. Similarly, D2D pair 2 is in the interferential coverage area of CUE2 and can only share RBs with CUE1. However, D2D pair 3 is not in the interferential coverage area of either CUE1 or CUE2 therefore, it can share RBs with both CUEs.

3.4 Greedy Algorithm

The throughput obtained using power control was compared with the output obtained using a greedy algorithm which is as follows:

1. A D2D pair and CUE share the same uplink RB. Also considering the power control technique, we assume that each CUE can share only one RB with a D2D pair.
2. The eNB allocates the RB to the D2D pair based on its priority.
3. Greedy algorithm is used for resource allocation and to cancel the interferences [15]. The throughput obtained using a greedy algorithm is

$$\frac{(\text{result with power control})-(\text{result of greedy})}{(\text{result of greedy})}\times 100\% \qquad (8)$$

4 Simulation Results and Analysis

Table 1 Example of CUE parameters.

CUE number	Number of used RBs (allocated by eNB)	Interference distance (m)
1	7	148
2	8	69
3	5	94
4	7	182
5	4	185
6	4	170
7	2	134
8	9	183
9	3	144
10	10	176

Table 1 shows an example of the key parameters of 10 CUEs. The first column represents the number (ID) of each CUE. The second column is the number of RBs used by each CUE allocated by eNB. The last column is the interferential coverage area of each CUE. eNB will first determine whether a D2D pair is in the interferential coverage range of a CUE, and then select the CUE with the largest number of RBs to share RBs with the D2D pair.

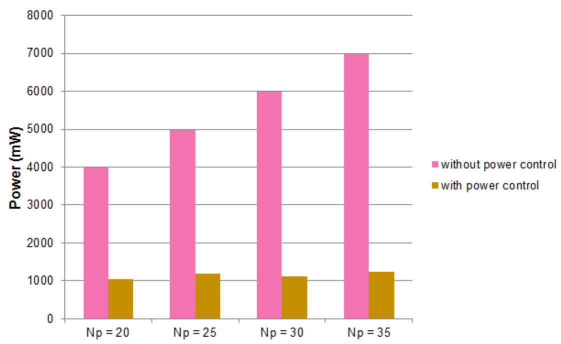
4.1 Simulation Setup

Table 2 Simulation parameters.

Parameter	Value
Cell radius	500 m
Minimum distance between DUE and eNB	35 m
Number of D2D pairs	20
Number of CUEs	10
Maximum distance between UE and UE for one D2D pair	50 m

Table 2 summarizes the parameters used in the simulation. There are 20 D2D pairs and 10 CUEs distributed evenly in the 500-meter coverage. DUEs must be at least 35 meters away from the base station [12]. In this scenario, we can perform D2D communication and verify performance with our proposed power control and resource allocation methods.

4.2 Simulation Results

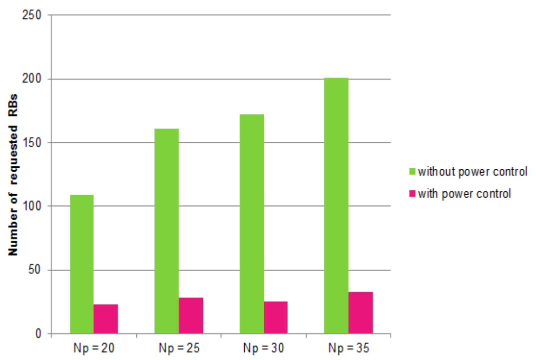


Reduction (%)	73.60	76.09	81.29	82.27

Fig. 5 Total power consumption of D2D pairs before and after power control.

We simulate the scenario up to 100 times, considering the distribution of DUEs and CUEs. The number of D2D pairs inside the eNB coverage starts at 20 pairs and increases to 25 pairs, 30 pairs, and 35 pairs. The results are obtained using our proposed power and resource allocation methods and are compared with results obtained without power control. The comparative results are shown in a bar chart. We also analysed the cause of performance improvement.

At N_p = 20, the total power consumption before power control was about 4000 mW, and after power control was done, the average total power consumption dropped to about 1173 mW, giving a power savings ratio of 70.6%. At N_p = 25, the total power consumption before performing power control increased with the number of D2D pairs, reaching to about 4988 mW, and after performing power control, the average total power consumption dropped to about 1192 mW, yielding a 76.09% power saving ratio. At N_p = 30, the total power consumption before performing power control was about 5986 mW, and the average total power consumption dropped to about 1120 mW after power control, for a power savings ratio of 81.29%. At N_p = 35, the total power consumption before performing power control was about 6983 mW,and power control dropped the average total power consumption to 1238 mW, giving a power savings ratio of 82.27%. As N_p increased, so did the total power consumption before performing power control. But after carrying out power control, total power consumption decreased, thus the proportion of power savings will increase. From this result, we can see that when the system has many D2D pairs, we can save more power through our proposed method.

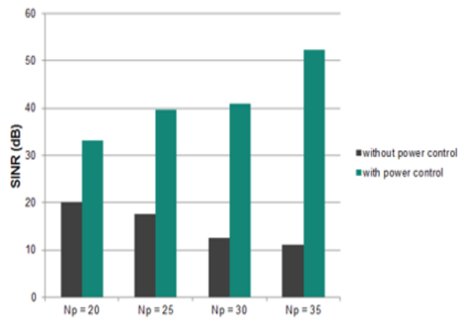


Reduction (%)	78.89	85.71	85.46	83.58

Fig. 6 Average total number of RBs required by D2D pairs before and after power control.

Figure. 6 shows the average total number of RBs required by D2D pairs before and after performing power control. For N_p = 20, the total number of required RBs before power control was 109 and the total number of RBs after power control was 23. Therefore, the ratio of reduction in required RBs was 78.89%. the total number of required RBs for N_p =25, was 161 before power control and 28 after power control leading to an 85.71% reduction in required RBs. Similarly, the average number of RBs for N_p = 30, was 172 before power control and 25 after power control, yielding a RB reduction ratio of 85.46%.

At N_p = 35, the average number of RBs required before power control was 201, and the average number of RBs required after power control was 33, giving a reduction ratio of 83.58%. As a result, as the number of N_p increases, D2D pairs using the power control scheme also increase, leading to mutual interference between the D2D pair. Hence, the number of D2D pairs that reuse the RBs will also decrease. As a result, the ratios of RB demand when N_p = 30 and N_p = 35 are lower than that of N_p = 25. Nonetheless, the reduction is still impressive.



Improvement (dB)	12.97	21.98	28.51	41.24

Fig. 7 Average SINR of each D2D pair before and after power control.

Figure 7 shows the average SINR of each D2D pair before and after performing power control. At N_p =20, the average SINR of each D2D pair before and after power control is done was 20 dB and 33 dB, respectively, a reduction of up to 13 dB. At N_p = 25, the interference increased with N_p, resulting in the average SINR of each D2D pair falling up to 18 dB. After performing power control, the transmission power of the D2D pairs also dropped. But because of the hypothesis of this paper, interference out of interferential coverage area is ignorable. Thus, the interference is drastically reduced or even eliminated. In this case, the average SINR for each pair of D2D pair was greatly increased, reaching about 40 dB, an increase of about 22 dB. At N_p = 30, the average

SINR was about 12 dB before performing power control and 41 dB afterward, an increase of up to 28 dB.

At N_p = 35, the average SINR before power control was about 11 dB, and it increased up to 52 dB after power control, resulting in a 41 dB difference. After comparison, we can find that the interference of each D2D pair is obviously reduced. When N_p = 20, the throughput obtained by directly allocating RBs without power control is about 0.44 Gbps, and the result obtained performing using power control is about 0.78 Gbps. After power control, the average SINR of the overall D2D pair can be improved, which makes the communication more significant. When the number of N_p is a higher number, the lift ratio will be more pronounced.

In Fig. 8 we compare, the throughput of three different algorithms. Only limited number of RBs were reused. But after performing power control, most of the D2D pairs will not interfere with each other and are more likely to share their RBs. Using the proposed power control method allows us to achieve a more than 400% increase in throughput compared to a greedy algorithm.

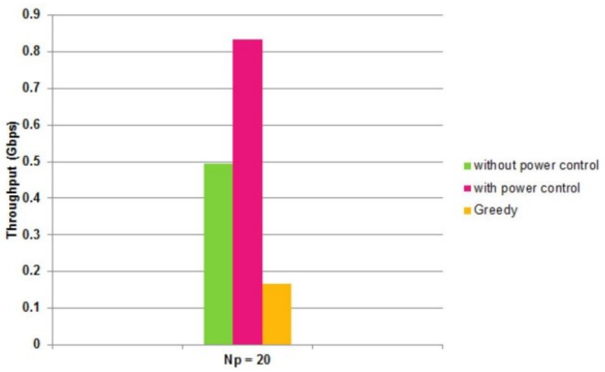


Fig. 8 Throughput of three different algorithms.

5 Conclusion

In this paper, we reduce the interference between D2D pairs by means of a proposed proper power control scheme and by allocating allocate resources, accordingly so that the D2D pairs do not interference with each other. Simulation results show that performance has been improved significantly compared to D2D communication when no power control was employed. Specifically, the proposed method jointly considers power control and resource allocation and exhibits superior performance in power consumption, SINR, throughput, and number of RBs required to meet the demand of D2D pairs. Hence through the formation of coalitions and power control, the average SINR of each D2D pair is significantly increased. The ratio of reuse of RBs was also high. Future research will focus on improving the SINR of D2D pairs by considering interference outside the interference coverage area to achieve better performance. Comparisons with other methods such as greedy resource allocation will also be investigated.

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