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Performance Analysis of Radio Resource Allocation to Maximize Power Efficiency in Device-To-Device Communication

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Abstract

Technological developments in the field of telecommunications have progressed. However, the more cellular network users, the more traffic on the Base Station (BS) will be. One way to overcome this is to implement a Device-To-device (D2D) communication system. However, when D2D User Equipment (DUE) reuses Cellular User channel resources Equipment (CUE), then interference will occur. This research is conducted to address interference problems and maximize energy efficiency for CUEs and DUEs by implementing the Greedy algorithm with additional power control. The aim is to block unnecessary resources and optimize resource allocation. The Optimal Power Control (OPC) scheme will utilize the transmit power threshold. The simulation scheme for the D2D communication system used is the uplink and underlay mode single-cell system model. Where the DUE pair will use the same resources as the CUE that has been given by the BS. Resources in CUE can only be reused by one pair of DUEs, and vice versa. The greedy algorithm using power control gets superior performance at a sum rate of 1.79×10^7 bps with an increase of 36.03%. Spectral efficiency of 2.49 bps/Hz with an increase of 36.03%. The power efficiency of 2.08×10^3 bps/mw with an increase of 118.47%. Based on the result the greedy algorithm without power control gets superior performance at CU Fairness of 1 with an increase of 50.14%.

Keywords: D2D communication, Resource allocation, Optimal power control scheme, Greedy algorithm.

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1. Introduction

The Fifth Generation (5G) mobile communication system is a cutting-edge technology that offers a wide range of services and seamless access to unlimited information, empowering users to share data effortlessly anytime and anywhere [1]. As the use of these services and capabilities increases, so does the impact on the number of users on the cellular network. This can lead to traffic congestion at the base station. These problems can lead to more complicated and time-consuming information processing[2]. One way to overcome this is to implement a Device-To-Device (D2D) communication system.

D2D is a short-range, low-power communication technology that allows mobile devices to interact directly with other mobile devices without going through a Base Station (BS)[3]. When the transmission power is high, it can drain the battery of the D2D UE, cause network interference, provide wide coverage, and improve signal quality during D2D communication. Therefore, proper power control during D2D communication is required to control the transmission power level of the D2D UE, handle the interference generated by the D2D UE, reduce energy consumption advancements in technology have led to improved spectral efficiency, increased system capacity, and expanded coverage[4]. When two users communicate directly with high spectrum utilization efficiency and low transmission power[5]. This is very important to achieve information interaction between users. However, when DUE and CUE pairs use channel resources simultaneously, interference occurs. The system performance will be degraded if the interference is not eliminated. Without a good power coordination mechanism, energy consumption is a major problem in the development of D2D communication[6]. The way to reduce interference in CUE and DUE is to locate the resource and use the power control system appropriately.

IThis study utilizes a greedy algorithm for resource allocation coupled with an Optimal Power Con-

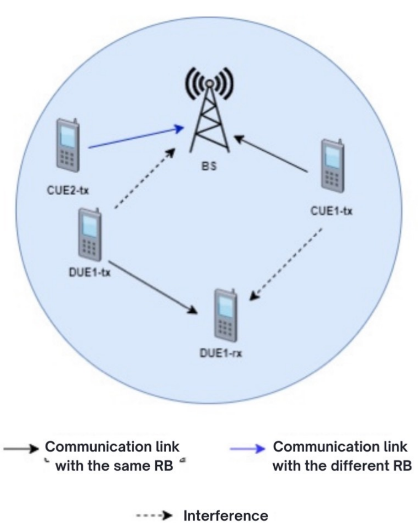

Fig. 1. System Models

trol (OPC) scheme, which aims to minimize interference and maximize the overall power efficiency of the system [2]. The parameters to be analyzed are not only power efficiency as in previous studies, but there are additional parameters namely sumrate, spectral efficiency, and fairness.

2. Research Method

2.1. System Model and Simulation

In this study, a system model design based on the single-cell model is used. CUE and DUE are randomly distributed around the BS at a distance of 25 m, assuming silence. In this model system, the BS already allocates resources to the CUE. The D2D communication used is underlay mode, where the DUE pair uses the same resources as CUE from the BS. Resources in CUE can only be reused by a pair of DUEs and vice versa. Fig.1 shows the system operating in uplink mode.

The resource allocation simulation scheme is performed in two phases. In the first phase, a D2D pair is allocated to an existing channel. In the second phase, some D2D pairs that were not allocated in the first phase and meet the conditions can be added to the available channels. The simulation scheme is shown in Fig.2.

2.2. Calculation of Pathloss, SINR, Data Rate

Pathloss is a condition where the power of the information signal is reduced from the transmitter to the receiver that occurs during the signal transmission process[7]. The channel mode used is Rayleigh fading channel with the assumption that the state of the cell is an urban microcell (UMi), so to get the pathloss value you can use the following Eq.1 [8]:

$$PL = 22.0\log_{10}(x) + 28.0 + 20\log_{10}(fc) \qquad (1)$$

where x is the distance between sender and receiver in meter and fc is the carrier frequency in GHz.

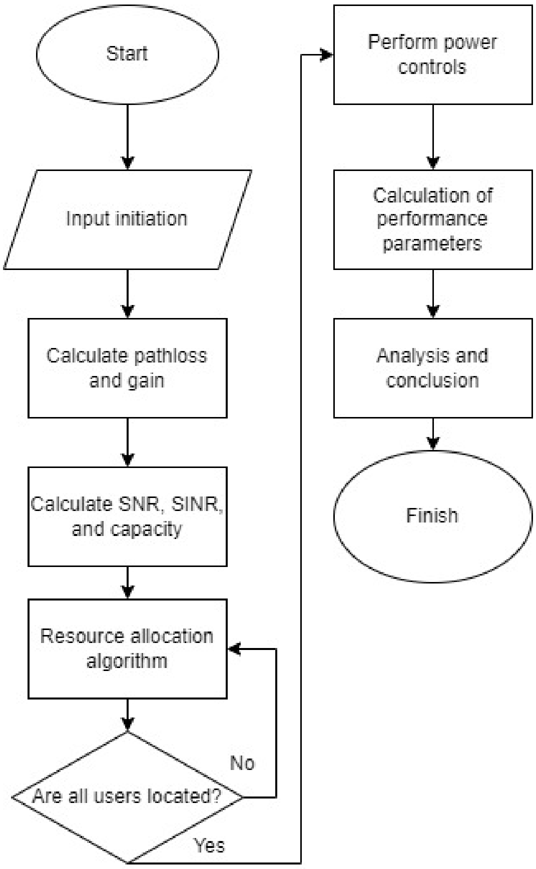

Fig. 2. Simulation Scheme

Signal-to-Interference-plus-Noise Ratio (SINR) is a measure that compares the received signal power with the combined interference and noise power [9]. Mathematically, SINR can be formulated using Eq.2 and Eq.3 [2].

$$\Upsilon c_{i,j} = \frac{P_i G_{i,BS}}{P_j G_{jTx,BS} + \sigma^2} \qquad (2)$$

with $\Upsilon c_{i,j}$, P_i, $G_{i,BS}$, P_j, $G_{jTx,BS}$, and σ^2 are SINR CUE, Power transmit CUE to i, Gain CUE to BS, The transmit power D2D j, Gain DUE Tx to DUE Rx, and Noise respectively.

$$\Upsilon d_{i,j} = \frac{P_j G_{jTx,jRx}}{P_i G_{i,jRx} + \sigma^2} \qquad (3)$$

with $\Upsilon d_{i,j}$, P_j, $G_{jTx,jRx}$, P_i, $G_{i,jRx}$, and σ^2 are SINR DUE, The transmit power D2D to j, Gain DUE Tx to DUE Rx, Power transmit CUE to i, Gain CUE to DUE Rx, and Noise respectively.

The data rate is the amount of data that can be transmitted as written in Eq.(4) and Eq.(5)[10].

$$Rc_{i,j} = B\log_2(1 + \Upsilon c_{i,j}) \qquad (4)$$

$$Rd_{i,j} = B\log_2(1 + \Upsilon d_{i,j}) \qquad (5)$$

with $Rc_{i,j}$, j is the data rate CUE, $Rd_{i,j}$ is data rate DUE, B is bandwidth RB in Hz, $\Upsilon c_{i,j}$ is SINR CUE, and $\Upsilon d_{i,j}$ is SINR DUE.

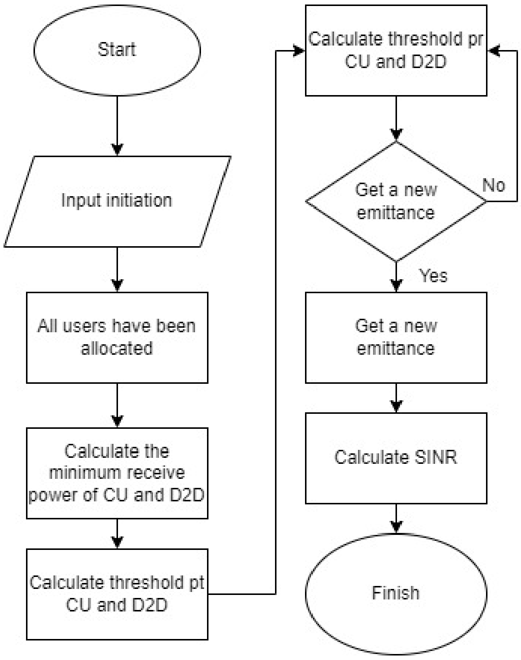

Fig. 3. Optimal Power Control Schematic Flowchart

2.3. Proposed Algorithm

The greedy algorithm functions to allocate RB to the most optimal user depending on the channel conditions of each user. When a D2D pair selects RB at CUE, it looks at the highest sumrate result [13] and selects the maximum capacity or datarate values of CUE and DUE users in total at the same time. However, other D2D pairs cannot use the same RB [14].

The use of an OPC scheme aims to reduce interference and increase power efficiency in the system. Power control operates based on the new transmit power value, employing a resource allocation approach identical to that of the greedy algorithm [15]. The transmit power of some users comes from the threshold. The OPC scheme can be seen in Fig.3:

The use of the OPC scheme starts with the calculation of the minimum received power. Minimum acceptability can be formulated by Eq.6 and Eq.7:

$$\mathrm{Pr}x_c^{\min} = 0.5 \cdot \left(\mathrm{mean}\left(\mathrm{mean}\left(\mathrm{Pr}x_b^{dtx}\right)\right)\right), \tag{6}$$

with $\mathrm{Pr}x_c^{\min}$ is the minimum receipt value CUE and $\mathrm{Pr}x_b^{dtx}$ is the receipt of the D2D Tx to BS.

$$\mathrm{Pr}x_d^{\min} = \left(\min\left(\mathrm{Pr}x_{drx}^{c}\right)\right) \tag{7}$$

with $\mathrm{Pr}x_d^{\min}$ and Pr_{drx}^{c} is the receipt of the CUE to D2D Rx.

The calculation of the acceptability threshold is carried out using Eq.8.

$$\mathrm{Pr}x_{th} = \Upsilon\left(\mathrm{Pr}x^{\min} + N\right) \tag{8}$$

where Prx_{th} is the threshold of acceptability.

After obtaining the transmit power threshold value, then the received power threshold calculation is performed using Eq.9.

$$Ptx_{th} = \mathrm{Pr}x_{th} + PL + \tau \tag{9}$$

Table 1: Simulation Parameter

Parameter	Value
Number of CUs	40 Units
Number of D2D	30 Units
Radius cells	200, 250, ..., 500 m
Frequency	2.3 GHz
Maximum distance between DUE	25 m
CUE transmit power	24 dBm
DUE transmit power	21 dBm
Bandwidth RB	180 KHz
Noise power	25MHz
Stop Frequency	-174 dBm/Hz
Pathloss	UMI models

where Ptx_{th} is the transmit power threshold, and τ is a random variable for Rayleigh fading. Eq. 10 is used to get the new transmit power value:

$$Ptx_c^{new} = \begin{cases} Ptx_c^{th}, 0 < Ptx_c^{th} \le Ptx_c \\ Ptx_c^{th}, 0 < Ptx_c^{th} > Ptx_c \end{cases}, \tag{10}$$

with $\mathrm{Pr}x_c^{new}$, $\mathrm{Pt}x_c^{th}$, and Ptx_c are The CUE and DUE to transmit power after using power control, threshold CUE and DUE transmitting power that has been allocation, and transmit power of CUE and DUE before using power control respectively.

$$Ptx_d^{new} = \begin{cases} Ptx_d^{th} \cdot Ptx_d, 0 < Ptx_d^{th} \le Ptx_d \\ Ptx_d^{th}, 0 < Ptx_d^{th} > Ptx_d \end{cases}, \tag{11}$$

with $\mathrm{Pr}x_d^{new}$, $\mathrm{Pt}x_d^{th}$, and Ptx_d are The CUE and DUE to transmit power after using power control, A threshold CUE and DUE transmitting power that has been allocation, and Transmit power of CUE and DUE before using power control respectively. For users with low gain, power can be adjusted to a minimum value that is below the threshold. Maximizing power consumption can result in the sumrate value being higher than the power consumed.

2.4. Calculation of Pathloss, SINR, Data Rate

Table 1 shows the parameters that have been set to be used in the implementation of the simulation.

Spectral efficiency is the amount of data that can be transmitted on a bandwidth unit allocated to the system. Spectral efficiency is formulated by Eq.12 [11]:

$$SE = \frac{R_{sum}}{rb.B} \tag{12}$$

with R_{sum} is sumrate, B is bandwidth, and rb is resource block.

Power efficiency in terms of the data rate value can be achieved in 1 Watt. The higher the efficiency

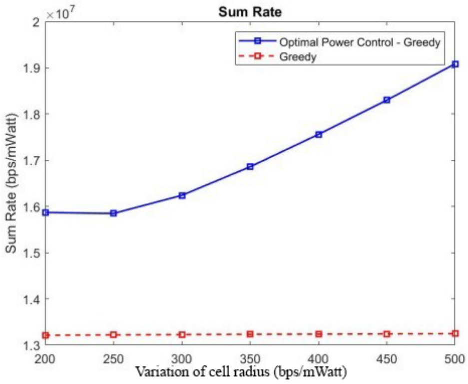

Fig. 4. Sumrate comparison

rating of a system, the more effectively and efficiently the power is used, allowing more data to be transmitted. Power efficiency is formulated by Eq.13 [2]:

$$\eta_{ee} = \frac{R_{\text{sum}}}{P_{\text{tot}}} \tag{13}$$

with P_{tot} is the total power in the system and R_{sum} is the sumrate.

Fairness is a parameter to assess the fairness obtained by each user in receiving resources. user in receiving resources. To find out the value of fairness in this study can use Jain's Fairness Index. Fairness is formulated with Eq.14 [12] :

$$F = \frac{(\sum_{i=1}^{n} C_i)^2}{n\sum_{i=1}^{n} C_i^2} \tag{14}$$

where n is the total user on the system, and C_i is the allocated user data rate.

3. Result and Discussion

3.1. *Sumrate and Spectral Efficiency*

The increase in sumrate is shown in Fig.4, while Fig.5 displays the spectral efficiency. Both metrics increase as the cell radius increases, with a slight decrease observed in the plot for the greedy algorithm. This reduction is due to the total power consumed being less than that of the greedy algorithm. In Fig.4, the optimal power control is obtained from the threshold value of the user's transmission power and will give more power to users who have better gain. While in Fig.5, the optimal power control has a higher value than the algorithm because it is influenced by the sumrate value. Therefore, the spectral efficiency value of the algorithm is also large. While in greedy, the sumrate and spectral efficiency values also do not increase.

Table 2 shows sumrate with power control has an average value of 1.82×10^7 bps, which is 37.32% higher than the greedy algorithm, which has an average value of 1.33×10^7 bps. This is because the total power used in the optimal power control scheme is less than that of the greedy algorithm. Meanwhile, the spectral efficiency results have an average value of 2.53 bps/Hz, which is 37.32% higher than the greedy algorithm, which has an average value of 1.84 bps/Hz. This is because the spectral efficiency is affected by the sumrate value.

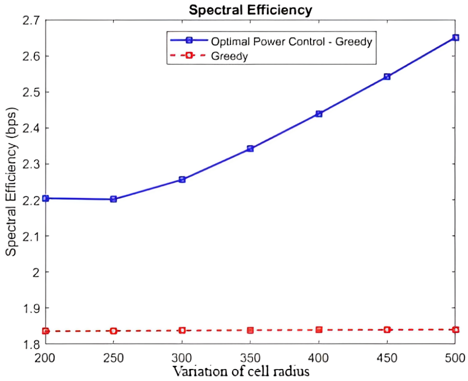

Fig. 5. Spectral Efficiency Comparison

Table 2: Simulation Result

Parameter	OPC	Greedy
Sumrate	1.82x10^7	1.33x10^7
Spectral Efficiency	2.53	1.84
Power Efficiency	2.05x10^3	962.58
Fairness CUE	0.6	0.99
Fairness DUE	0.38	1
Complete fairness	0.51	0.99

3.2. *Power Efficiency*

Fig.6 shows the increase in sumrate with power control as the cell radius increases and the greedy algorithm plot tends to be constant. The difference between the two plots is due to the different transmit power used. The OPC scheme achieves an average power efficiency of 2.05×10^3 bps/mWatt. Meanwhile, the greedy algorithm achieves an average of 962.58 bps/mWatt. The OPC scheme outperforms the greedy algorithm by 113.26%.

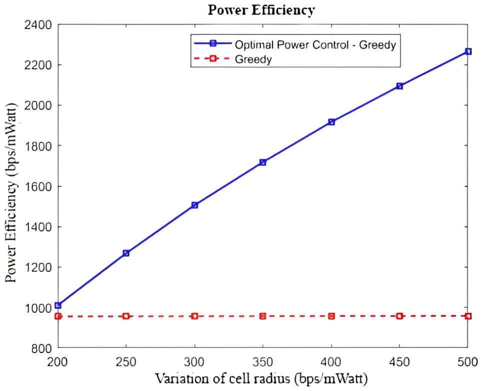

Fig. 6. Power Efficiency Comparison

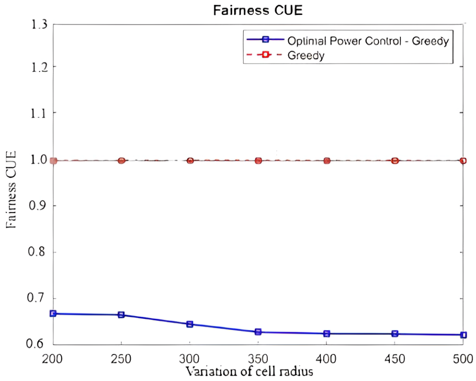

Fig. 7. CUE Fairness Comparison

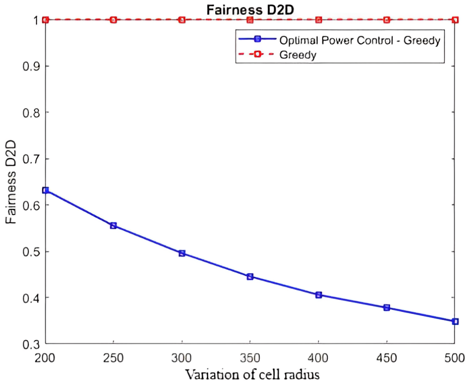

Fig. 8. DUE Fairness Comparison

3.3. *Fairness CUE*

The fairness CUE simulation can be seen in Fig.7, there is a decrease in fairness CUE as the cell radius increases and the greedy algorithm plot is constant. This is influenced by the increasing distance between users. The fairness value in the greedy algorithm shows that each user gets the same resource, which is fair for each user.

The average outcome for the OPC scheme is 0.6. While the greedy algorithm gets a result of 0.99 which shows that each user gets the same resources where the value is fair for each user. The two results have a difference of 65.29% where the greedy algorithm without power control is superior due to the increasing gap between users. The small fairness value in the OPC scheme is caused by unfair power allocation between one user and another.

3.4. *Fairness DUE*

Fairness DUE According to Fig. 8, the greedy algorithm plot tends to remain constant as Fairness DUE is decreasing. The average output of the OPC scheme is 0.38, which is 155.9% less than the average output of the greedy algorithm, which is 1. So each user gets the same resource which is fair for each user.

3.5. *Total fairness*

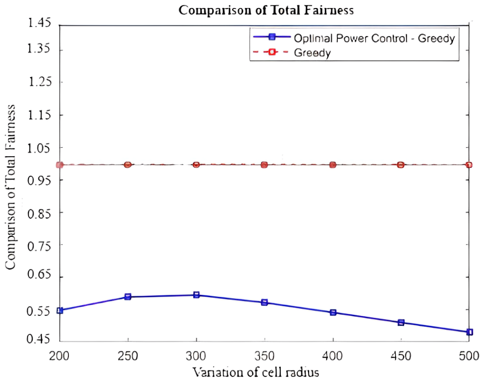

Fig. 9. Comparison of Total Fairness

Fig.9 represents the total fairness, As the cell radius increases, the value decreases, while the plot for the greedy algorithm remains relatively constant. The notable contrast shown in the graph above is primarily attributed to the growing distance between users. The fairness of the greedy algorithm is evident, ensuring equitable resource allocation for each user.

According to Table 2, the OPC system achieves an average fairness score of 0.51, which is 94.5% less than the greedy algorithm without power control's score of 0.99. The difference in value is due to the larger gap between users. The low value of fairness in the OPC scheme is caused by unfair power allocation between one user and another.

4. Conclusion

The simulation results show that the use of power control in resource allocation can improve the performance such as sumrate, spectral efficiency, and power efficiency because the allocation is done by giving more power to the user who only has a better gain. Meanwhile, the greedy algorithm without power control has an advantage over fairness on the CUE, DUE, and total side. The simulation results were obtained with a sumrate of 1.82×10^7 bps, power efficiency of 2.05×10^3 bps/mwatt, the spectral efficiency of 2.53 bps/Hz, CU fairness of 0.99, D2D fairness of 1, and total fairness of 0.99.

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