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Radio Resource Allocation Using Graph Algorithm for Device-To-Device Underlay Communication System

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Abstract

The increasing demand for higher data rates for local area services caused traffic congestion at the base station (BS). A Device to Device (D2D) communication system is one way to overcome this. Device to Device allows nearby User Equipment (UE) to communicate using a direct link with each other without going through the BS. However, D2D communication caused interference to the traditional cellular user, because usually they use the same frequency spectrum. A good radio resource allocation algorithm is a must to overcome this problem. This research proposes graph-based allocation algorithm, to allocate resources for D2D users and Cellular users. Graph algorithm is an algorithm that allocated the resource depending on the edge level of each user. The simulation parameters that is used to analyze the graph algorithm's performance are sumrate, efficiency spectral, power efficiency and fairness, and the graph algorithm is compared with a traditional greedy algorithm. Based on the result, the graph algorithm can improve the fairness among the user in the system by 3.7%**. Meanwhile, the system's sumrate, spectral efficiency, and power efficiency are decreased by** 4.24%**,** 4.52%**, and** 4.57% **respectively compared with a traditional greedy algorithm.**

Keywords: resource allocation, device-to-device, graph alogorithm, greedy algorithm

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1. Introduction

Wireless communication development caused increasing number of users in the system. This condition can cause increasing load in Base Station BS. To re-duce the load in BS, Device-to-device (D2D) communication was introduced. In D2D communication, 2 users can directly communicate without going through BS. In 5G, D2D become one of the hot topics that can give a solution to increasing load in BS [1].

In underlay mode, D2D User Equipment (UE) shares common resources with the rest of the user's cellular networks that result in better network performance, such as spectral and energy efficiency [2]. However, in D2D communication underlay causes interference between D2D users and cellular users. D2D links that work at the same time in the same cellular spectrum can cause severe interference to both mobile and D2D users [3].

Research [4] proposed an intermediate interference graph scheme for D2D users based on graph coloring theory. This study can solve the problem of high-power consumption in wireless communication and increase the user's fairness index. Work [5], proposes a resource allocation algorithm scheme with power control, node priority calculation, and communication index optimization based on the principle of a graph coloring algorithm. The results show that the algorithm can maintain the systems delay, user fairness, and user throughput while maintaining low power consumption.

Work [6] The results show that the proposed scheme has also improved system throughput and increases fairness. Research [7] proposes to allocate resources using a method based on graph theory on the Full-Duplex (FD) scheme. The results show that the executed scheme increases the sumrate by selecting the highest or lowest node. Research [8], joint mode selection is used to allocate resources with the help of relays to maximize power efficiency between D2D pairs. The results show that the proposed greedy algorithm with joint mode selection scheme has better performance in terms of power efficiency.

This study tries to analyze the resource allocation algorithm based on graph coloring process on D2D underlay communication system. The algorithm is designed to reduce the effect of interference in underlay system that happens because of the same spectrum used by D2D user equipment (DUE) and Cellular user equipment (CUE). This algorithm is compared with the traditional greedy algorithm to evaluate its performances level [9]. The performance parameter that being observed are total sumrate, spectral efficiency,

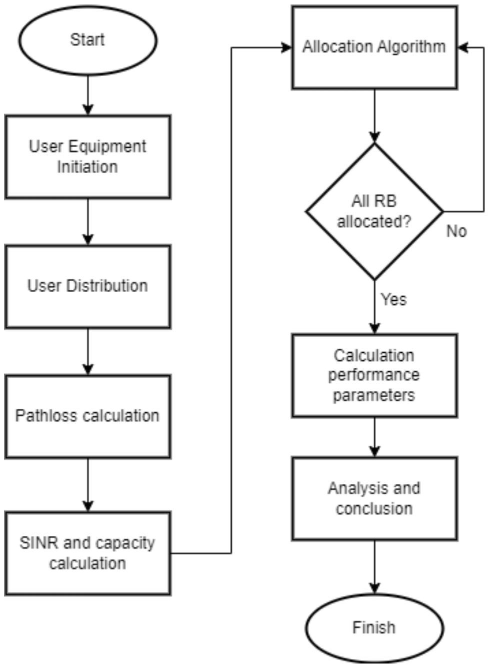

Fig. 1. Simulation Scheme

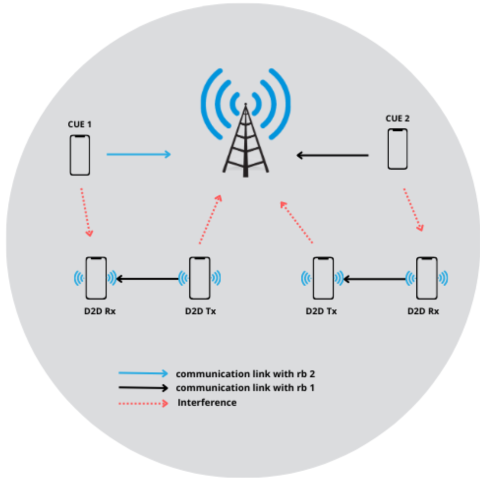

Fig. 2. System model

power efficiency and user fairness.

2. Research Method

The D2D communication system reduces the loads on the BS, but a good allocation algorithm is needed to keep the interference level at a minimum [10]. To evaluate the allocation algorithm and its performances in the system, this paper uses a simulation process that is shown in Fig. 1. The graph algorithm scheme is used after all the users calculate their SINR and capacity on each resources blocks (RB) that used by CUE. In this research, the stage begins with user initialization and distribution. Then followed by calculating SINR and capacity for each user (CUE dan DUE) on each RB. Then the graph allocation algorithm take place and the parameters calculated after that to be analyzed.

2.1. System Model

The system model used in this study is a single cell with one BS in the middle of the cell with the CUE and the DUE pair scattered randomly around the BS. The DUE and CUE used the same frequency to do the communication. This scheme can be seen in 2.

CUE communicates with BS, and the DUE communicates with its pair. Interference occurs if the CUE and DUE use the same RB to do the communications. Graph algorithms take place to allocate DUE to an RB that is being used by CUE with the best SINR to keep the performance level of the system.

The system works with an Underlay communication system mode with communication direction uplink so that interference occurs in the system due to the isolated state of the cell. When CUE 1 sends data to the BS there will be an interference with DUE 1 Tx goes to BS and when DUE 1 Tx sends data to DUE 1 Rx then there will be an interference in DUE 1 Rx by CUE 1. This also applies to CUE 2 and DUE 2 but what differentiates them is the channel to be used, CUE 1 and DUE 1 use the same RB as well as CUE 2 and DUE 2.

The purpose of this research is to allocate RB to one CUE and one DUE partner to minimize the interference that occurs due to D2D underlay communication. The formulation of the problem is defined and formulated by Eq.1-3.

$$\sum_{i=1}^{C} Rc_j^i + \sum_{i=1}^{C}\sum_{j=1}^{D} Rd_j^i \times y_{(i,j)}, \tag{1}$$

$$\sum_{i=1}^{C} y_{(i,j)} \leq 1, \forall i \in \{1, \ldots D\}, \tag{2}$$

$$\sum_{i=1}^{D} y_{(i,j)} \leq 1, \forall j \in \{1, \ldots C\}. \tag{3}$$

Eq.1 defines the total sumrate value obtained from the system when all DUE and CUE do the communication. Eq.2 shows the restrictions and constraints that one RB can only be used by one CUE and Eq.3 shows that one pair of DUE can only used 1 RB.

2.2. Pathloss, Channel Gain and SINR

Pathloss is a loss of power information signal when passing through the air medium on signal transmission process. The pathloss value can be calculated by Eq.4 [11].

$$PL = 22.0\log_{10}(d) + 28.0 + \log_{10}(fc), \tag{4}$$

where d is the distance between the transmitter and receiver in meter and fc is the carrier frequency (Ghz). Channel gain between x (transmitter) and y (receiver) can be calculated by using Eq.5.

$$G_{x,y} = PL^{(x,y)} - h^{(x,y)}, \tag{5}$$

where $PL^{(x,y)}$ and $h^{(x,y)}$ is the pathloss value and zero mean with random gaussian variables and units of variance which is the characteristic of rayleigh fading. Signal to Noise and Interference Ratio (SINR) is the ratio of the signal strength with interference and noise. SINR value can be calculated by Eq.6.

$$SINR = \frac{P_{Tx} \cdot G_{Tx}}{N \cdot P_{int} \cdot G_{int}}, \quad (6)$$

2.3. *Sumrate*

Sumrate is the number of bits transmitted per one second. The value of the CUE data rate and the DUE data rate is summed up so that it becomes a sumrate. Sumrate can be calculated using the Eq.7 [14].

$$SR = Rc + Rd, \quad (7)$$

where SR, Rc, and Rd are the sumrate value, the CUE datarate or capacity value and the DUE data rate or capacity value, respectively. CUE and DUE data rates can be calculated by Eq.8-8.

$$Rc = B \times log_2(1 + (SINR_n^c)), \quad (8)$$

$$Rd = B \times log_2(1 + (SINR_n^d)), \quad (9)$$

where B, $SINR_n^C$, and $SINR_n^d$ is bandwidth of a RB, SINR CUE, and SINR DUE respectively.

2.4. *Spectral Efficiency*

Spectral efficiency is a parameter that represents how effective a frequency spectrum is used and can be determined in bps/Hz. Spectral efficiency can be calculated by using Eq.10 [15].

$$SE = \frac{SR}{W \times RB}, \quad (10)$$

where RB is the number of resource block in the system.

2.5. *Power Efficiency*

Power efficiency parameter that determines how much capacity can be achieved by using 1 level of power. In this study, this parameter is represented in bps/mW. Power efficiency can be calculated by using Eq.11 [16]:

$$EE = \frac{SR}{P_{tot}}, \quad (11)$$

where P_{tot} is the total power that being used in the system, that can be calculated by Eq.12.

$$P_{tot} = (P_d \times D) + (P_c \times C) \quad (12)$$

where P_d, D, P_c, and C are the power of DUE, total number of DUE, power of CUE, and total number of CUE, respectively.

2.6. *Fairness*

Fairness is the principle that every user on the network must be treated in a fair, balanced, and proportional in accessing available network resources. To determine whether the algorithm in use meets the fairness parameter, use the formula. Jain's Fairness Index can be calculated using Eq.13 [17]:

$$J = \frac{\left(\left(\sum_{i=1}^{I} R_i\right)^2\right)}{\left(I \times \left(\sum_{i=1}^{I} R_i^2\right)\right)} \quad (13)$$

where i, I, and R_i are i-th user, total number of user, and the capacity of i-th user.

2.7. *Greedy Algorithm*

The greedy algorithm is a conventional method that assigns RBs to the most efficient users. It operates by selecting the maximum capacity or data rate values of both CUE and DUE users simultaneously, and allocating the available RBs accordingly.

In this paper, the CUE already has an RB to communicate with BS. The DUE chooses the best RB in capacity or data rate that already used by CUE that maximize both capacities. This process repeated until all DUE have RB or there is no RB available.

2.8. *Graph Algorithm*

In the graph algorithm, every vertex or point in the graph represents the CUE and DUE pairs whereas the edge represents the interference that occurs between the two connected nodes, so as to prevent interference that occurs between these two type of users [13]. To build an edge, the desired signal value to interference must below the threshold value that has been set so that the edge will be formed between these two user.

However, the graph algorithm only considers the interference between the two users [3]. The graph algorithm consists of two stages

1. First CUE and DUE pairs are represented as a point that has not been connected.
2. Build an edge that connects two points based on the interference that occurs between the two, the interference value must not be above the threshold value that already set in the system.
3. Calculates the degree that can be represented by the number of edges that enter a point or vertex.
4. Degrees are used to determine resource allocation starting from the largest degree to the smallest degree.
5. Remove all edges in a vertex after that vertex already allocated to another vertex
6. The allocation process is carried out until all nodes allocated which means that one node connected to one specific other node.

3. Result and Discussion

In this study, the performances of graph-based allocation algorithm is evaluated through a computer

Table 1: Simulation parameters.

Parameter	Value
Cell radius	500 m
Total CUE	40
Total DUE	10,12,14,..,40
Frequency	2.3 Ghz
Fading Channel	Rayleigh fading
Pathloss	Model UMI
Power transmit CUE	23 dBm
Power transmit DUE	12 dBm
Threshlod	20 dB
Max distance of D2D pairs	25 m
Min distance of D2D pairs	5 m
RB bandwidth	180 KHz
Sistem bandwidth	8 Mhz

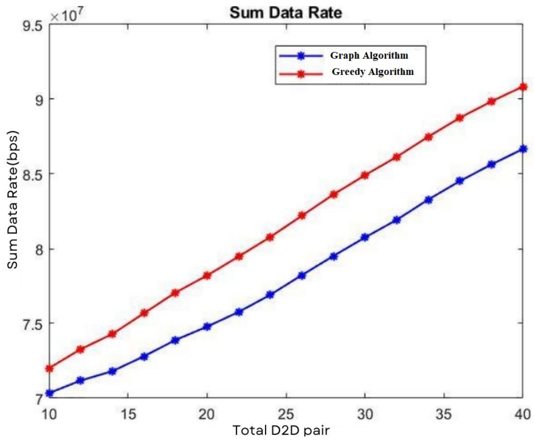

Fig. 3. Sumrate comparison for each algorithm

simulation. The results of the graph based algorithm are compared with the greedy algorithm to find out performance level. Table 1 represents the simulation parameters that being used.

3.1. Sumrate

The sumrate comparison of graph and greedy algorithm can be seen in Fig.3. As Shown in Fig.3 the graph algorithm has a lower sumrate value than the greedy algorithm. This condition happens because graph algorithm allocates the highest edge node first, which means the user with the most interference link. By allocates the user with most interference in the first place, the SINR of the corresponding user is low, so that the capacity is also low. In contrary, greedy algorithm always chooses the best total capacity for each DUE and CUE to use same RB. This constraint maximizes the sumrate of the system overall.

This affects the overall system sumrate, in Table 2, the graph algorithm only achieves 7.80×10^7 bps compared with 8.15×10^7 that achieved by greedy algorithm in average. Greedy algorithm can achive 4.24% more than graph algorithm. The value of sumrate will increase along with the increasing number of D2D pairs means the usage of RB by two types of users (CUE and DUE) can improve the system performance. Although there is more interference that occurs, the D2D underlay scheme is working well in the system.

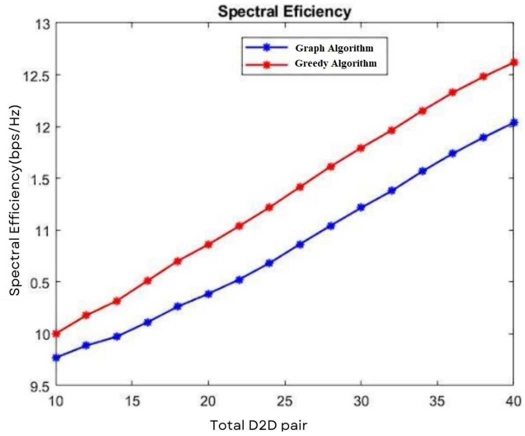

Fig. 4. Spectral efficiency comparison for each algorithm

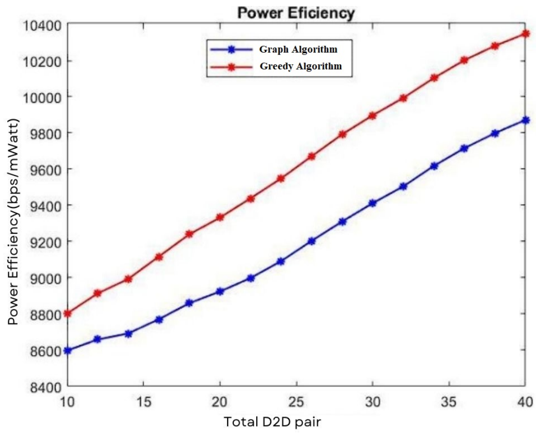

Fig. 5. Power Efficiency comparison for each algorithm

3.2. Spectral and Power Efficiency

The spectral efficiency simulation result can be seen in Fig.4, while the power efficiency of the system can be seen in Fig.5. From the figure can be seen that the greedy algorithm also give more value in efficiency, compared with graph algorithm. Same with the sumrate, this condition happens because graph algorithm allocates the highest edge node first, which means the user with the most interference link. By allocating the user with the most interference first, the SINR of the corresponding user is low, resulting in a low capacity, whereas greedy algorithms always try to find the highest capacity value.

Table 2 shows that in spectral efficiency, greedy algorithm, in average, can achieve 11.32 bps/Hz which is 4.52% higher than the spectral efficiency of graph algorithm at 10.83 bps/Hz. In power efficiency greedy algorithm has a value of 9.6×10^3 bps/mW which is 4.57% higher than power efficiency at 9.18×10^3 bps/mW that achieved by graph algorithm.

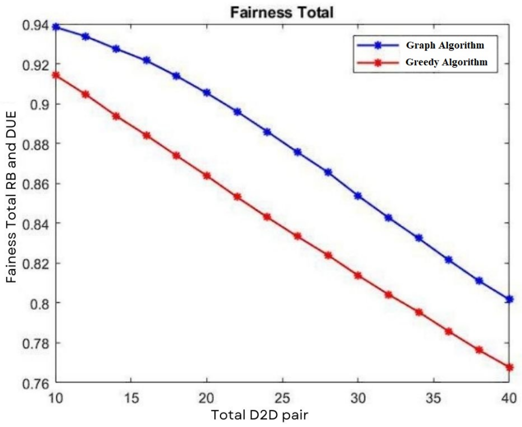

Fig. 6. Fairness comparison for each algorithm

Table 2: Parameter performance comparison

Parameter Performance	Graph algorithm	Greedy algorithm
Sumrate (bps)	7.80×10^7	8.15×10^7
Spectral efficiency (bps/Hz)	10.83	11.32
Power Efficiency (bps/mW)	9.18×10^3	9.60×10^3
Fairness	87.6%	83.9%

3.3. Fairness

Fig.6 shows the fairness comparison of graph algorithm and greedy algorithm. from the figure can be concluded that graph algorithm can achieve more fairness among the user compared with greedy algorithm. Graph algorithm can achieve fairness index of 87.6%, which is 3.7% higher that greedy algorithm at 83.9%.

This condition happens because graph algorithm prioritizes user with many interferences to choose the RB first. The user with more edges in graph, can choose on the first iteration, that can increase the probability to get more capacity. User with less edges allocated later after high edges user has been allocated. The fairness index can be maintained by this constraint. Meanwhile greedy algorithm allocates the worst capacity user on the later stages of algorithm that makes that corresponding user has less option in RB.

4. Conclusion

The simulation results show that graph algorithm achieve less value in sumrate, and efficiency of the system compared with greedy algorithm. These outcomes occur as a result of greedy algorithms prioritizing the best capacity user over the worst capacity user in order to maximize the sumrate and system efficiency. Greedy algorithm, compared with graph algorithm, can achieve the sumrate 4.24% higher, spectral efficiency 4.52% higher, and power efficiency 4.57% higher.

Meanwhile, graph algorithm can achieve more fairness index among the user. Graph algorithm can improve the system fairness up to 3.7% compared to the greedy algorithm. This happens because graph algorithm prioritize the user with high interference level first to be allocated, that can maximize the RB option for that corresponding user. The greedy algorithm allocates high interference user in the later stage of the algorithm which means limiting the option for that user.

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