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Power control scheme using particle swarm optimization method in resource allocation process on D2D underlaying communication

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Abstract — The growing number of cellular telecommunication technology resulted in the increasing number of user equipment. This condition increased the eNodeB load. The device-to-device (D2D) underlying communication is introduced to overcome this problem. In the underlying scheme, the D2D user equipment (DUE) conducts the communication process using the same radio resources as the conventional cellular user equipment (CUE). Good resource allocation is needed to avoid severe interference between these two types of users in the system. In this work, a power control scheme using particle swarm optimization (PSO) is proposed to manage the transmit power of each user on the system. The power control scheme takes place after the greedy scheduling algorithm after all user is given a resource block (RB) to do the communication process. The power transmitted to each user is managed to reach a better system capacity and to reduce the energy consumed in one communication process. From the simulation, the PSO power control can improve the sum rate and spectral efficiency up to 12.97% and 3.38%, respectively. The PSO power control also can reduce the system's energy consumption by up to 8.84%. The fairness among the CUEs was also maintained, despite the decreasing fairness among DUEs.

Keywords – allocation algorithm, D2D underlying network, particle swarm optimization, power control

I. Introduction

The development of cellular technologies is rapidly growing in this era. This cellular communication development includes the growth of cellular users. The rapid, massive growth of cellular users demands an eNodeB to serve many users. This condition overloads the service of eNodeB and causes a declined user service quality. To overcome this problem, LTE enables heterogeneous network schemes in the system, such as using femtocells and D2D communications [1].

LTE-A serves the user using an orthogonal frequency multiple access (OFDMA), which splits its carrier bandwidth to a smaller unit called a resources block (RB) [2]. These RBs are scheduled to the user for the communication process. D2D communication is communication between two devices without going through eNodeB as a central node [3]. In the underlying scheme, the D2D user (usually a pair of devices/DUEs) use the same RBs as the conventional cellular users (CUEs) to do the communication [4]. The CUEs which share their resources with DUEs will suffer interference from DUEs. A good resource allocation algorithm is needed to minimize the interference effect that happens [5].

In the OFDMA system, there are no significant interference effects between two CUEs if the corresponding CUEs use two different RBs. However, in D2D underlying scheme, some DUEs using the same RBs with CUEs will cause an interference [6] to the CUEs and the DUEs. This work tries to minimize the interference effect caused by this condition by allocating the transmit power for each type of user.

There are several works related to resource allocation in D2D underlying networks. Work [7] proposed adaptive resource sharing in device-to-device communication using a two-phased optimization

algorithm as the power control method. This method is proven to increase the overall system data rate. Work [8] can improve the system's data rate by using a heuristic-based power allocation scheme. Interference power management is also proposed in [9] to decrease the dropped CUEs due to high interference from DUEs. Works [10], [11] try a water filling power control and action-reward based power allocation respectively in greedy RBs allocation to improve the system's performance.

Particle swarm optimization (PSO) is an algorithm inspired by bird behavior when searching for the best food spot [12]. In terms of the PSO algorithm, the PSO algorithm has been tried to allocate the RBs to the user in [13] and achieve better throughput. This work tries to implement the particle swarm optimization (PSO) algorithm to control the transmit power for each user. At first, a greedy algorithm will allocate the DUE pairs to a specific CUE to share its RB. After each DUE is paired to a specific CUE, the power transmits of DUE and CUE will be controlled by the PSO algorithm to find the best power to maximize the system's capacity and minimize the interference level of the power usage in the system.

This paper is organized as follows: The first section contains the introduction part, as well as the previous research related to this work. The second section explains the research method in this work, including the system model, problem formulation, and simulation flow. The third section contains the proposed algorithm. The fourth section discussed and analyzed the simulation results. The fifth section is the last section that concludes this work.

II. Research Method

A. System Model

The system model observed in this study is a single cell LTE-A system, with a single eNodeB on the center of the cell. The cell serves two types of users, the conventional CUEs and the DUEs, which use D2D type communications. The side being observed is the down-link side, which uses OFDMA as the main multiple access scheme. RBs are assumed to be orthogonal to each other, so there is no interference among RBs. The cell model can be seen in Fig. 1.

The system used an in-band underlying system. In this system, the CUEs and DUEs share the same radio resources. In an in-band system, the control over the cellular spectrum is high, so the interference that occurs is more controllable [14]. The allocation of CUEs to specific RBs is assumed to be done. The CUEs already have the RBs to do the communication. The first is to allocate the DUE pairs to CUEs to share their RBs. This study's allocation algorithm is greedy, which simply chooses the highest total capacity on CUEs and DUEs. After all, DUEs get the resource block related to CUEs;

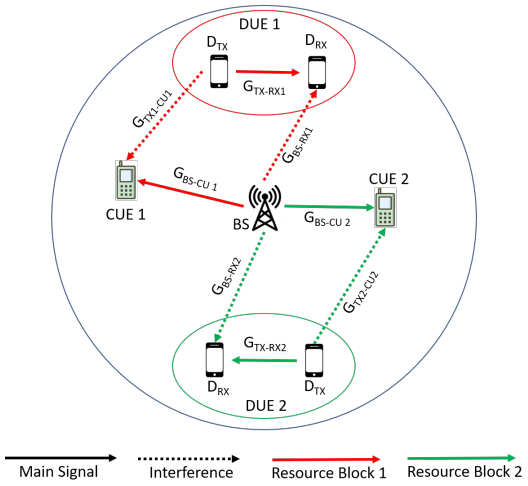

Fig. 1. System cell model.

the PSO power allocation takes place to manage the transmit power of DUEs and CUEs to maximize the system's total capacity.

The total number of CUE in the system denotes by C, and the total number of DUE indicates by D. Each CUE will occupy one RB to do the communications. Complete DUE that being served in the cell cannot exceed the total number of CUE ($C \geq D$). The received signal power on c-th CUE from the BS, noted by SCU(c) can be calculated by [15]:

$$S_{CU}(c) = P_c^{BS} \times G_{BS-CU}(c) \quad (1)$$

with P_c^{BS} is the BS transmit power on c-th CUE, and $G_{BS-CU}(c)$ is the channel gain value from base station (BS) to c-th CUE. The received signal power on d-th DUE receiver from the DUE transmitter, noted by $S_{DU}(d)$ is formulated by:

$$S_{DU}(d) = P_d^{DU} \times G_{TX-RX}(d) \quad (2)$$

with P_d^{DU} is the d-th DUE transmit power, and $G_{TX-RX}(d)$ is the channel gain value from d-th DUE transmitter to DUE receiver.

If the d-th DUE use the RB related to c-th CUE, the interference occurred in both users. The interference power from BS that occurred on DUE receiver, noted by $I_{BS-DU}(c,d)$ can be calculated:

$$I_{BS-DU}(c,d) = P_{BS} \times G_{BS-RX}(d) \quad (3)$$

with $G_{BS-RX}(d)$ is the channel gain value from the BS to DUE receiver. The interference also occurs on the CUE side. The interference power from d-th DUE transmitter that occurred on the c-th CUE, noted by $I_{TX-CU}(c,d)$ can be calculated by equation:

$$I_{TX-CU}(c,d) = P_{DU} \times G_{TX-CU}(c,d) \quad (4)$$

with $G_{TX-CU}(c,d)$ is the channel gain value from d-th DUE to c-th CU.

The signal-to-noise ratio (SINR) noted by Γ that happens on the CUE and DUE if c-th CUE shares its

resource with the d-th DUE can be calculated by (5) and (6), respectively [16]:

$$\Gamma_{CU}(c,d) = \frac{S_{CU}(c)}{I_{TX-CU}(c,d) \times \mu(c,d) + N} \quad (5)$$

$$\Gamma_{DU}(c,d) = \frac{S_{DU}(d)}{I_{BS-DU}(c,d) \times \mu(c,d) + N} \quad (6)$$

where N is the thermal noise that happens. The binary allocation index, noted by $\mu(c,d)$ is an allocation matrix that represents the CUE-DUE pair which share same resource. The value of $\mu(c,d)$ is 1 if the c-th CUE shares its RB with d-th DUE. Otherwise, the value is 0. If a CUE does not have to share its RB to a DUE (in this case $C > D$), so the signal-to-noise of the corresponding CUE can be calculated by:

$$\Gamma_{CU}(c) = \frac{S_{CU}(c)}{N} \quad (7)$$

The user data rate noted by the $\tau_{c,d}^{X}$ can be calculated with the Shannon capacity formula:

$$\tau_{c,d}^{CU} = B \times (1 + \Gamma_{CU}(c,d)) \quad (8)$$

$$\tau_{c,d}^{DU} = B \times (1 + \Gamma_{DU}(c,d)) \quad (9)$$

Eqs. (8) and (9) are the data rate of CU and DU, respectively, and B is the bandwidth of each RB. The total data rate that happens on the system (sum rate) can be calculated by [17]:

$$S = \sum_{c=1}^{C}\sum_{d=1}^{D} \tau_{c,d}^{DU} + \tau_{c,d}^{CU} \quad (10)$$

And the spectral efficiency and power efficiency of the system can be calculated by (11) and (12), respectively:

$$SE = \frac{S}{B \times C} \quad (11)$$

$$PE = \frac{S}{\sum_{d=1}^{D} P_{DU} + \sum_{c=1}^{C} P_{CU}} \quad (12)$$

Therefore, the fairness index among each type of user (CUE and DUE) can be calculated with (13) and (14), respectively [18]:

$$F_{CU} = \frac{(\sum_{c=1}^{C}\sum_{d=1}^{D} \tau_{c,d}^{CU})^2}{C \times \sum_{c=1}^{C}\sum_{d=1}^{D} \tau_{c,d}^{CU^2}} \quad (13)$$

$$F_{DU} = \frac{(\sum_{c=1}^{C}\sum_{d=1}^{D} \tau_{c,d}^{DU})^2}{C \times \sum_{c=1}^{C}\sum_{d=1}^{D} \tau_{c,d}^{DU^2}} \quad (14)$$

B. Problem Formulation

The main objective of this study is to maximize the total system data rate while ensuring that each user uses the efficient amount of power transmitted. By allocating the power transmit for each user, the interference on the cell can be maintained at a certain level. In general, the formulation of the main problem for this study is defined as follows,

maximize:

$$\sum_{c=1}^{C}\sum_{d=1}^{D} \tau_{c,d}^{DU} + \tau_{c,d}^{CU} \quad (15)$$

subject to:

$$\sum_{c=1}^{C} \mu(c,d) \leq 1, \forall c \in \{1,...,C\} \quad (16)$$

$$\sum_{d=1}^{D} \mu(c,d) \leq 1, \forall d \in \{1,...,D\} \quad (17)$$

$$\sum_{c=1}^{C} P_c^{BS} \leq P_{max}^{BS}, \forall c \in \{1,...,C\} \quad (18)$$

$$P_c^{DU} \leq P_{max}^{DU}, \forall d \in \{1,...,D\} \quad (19)$$

Eqs. (16) and (17) ensure that each CUE can only shares its RB to one specific DUE, and each DUE only use one specific RB at a time, respectively. Eq. (18) ensures that the total transmitted power for each CUE cannot exceed the BS maximum power transmits, and (19) ensures that the power transmitted from each DUE cannot exceed the maximum allowable power.

C. Greedy Allocation Algorithm

Greedy allocation algorithm is a low complexity allocation algorithm that maximize the overall sum rate capacity [19]. At first, the BS calculate the capacity matrix for each type of user (DUEs, and CUEs). The capacity matrix for CUEs and DUEs, respectively, are in accordance with the formula:

$$\tau_{CU} = \left[\tau_{1,1}^{CU} \cdots \tau_{1,D}^{CU} \vdots \tau_{c,d}^{CU} \vdots \tau_{C,1}^{CU} \cdots \tau_{C,D}^{CU}\right] \quad (20)$$

$$\tau_{DU} = \left[\tau_{1,1}^{DU} \cdots \tau_{1,D}^{DU} \vdots \tau_{c,d}^{DU} \vdots \tau_{C,1}^{DU} \cdots \tau_{C,D}^{DU}\right] \quad (21)$$

The matrix column number is equal to the number of DUEs D, and the matrix row is equal to the number of CUE C. Then the total capacity matrix is calculated by:

$$\tau_{total} = \tau_{CU} + \tau_{DU} \quad (22)$$

All CUEs in this simulation are assumed already have RB to do the communication process. Greedy allocation algorithm only tries to schedule every DUEs in the system to RB that being used by a specific CUE. Greedy algorithm simply searches for the maximum value on the τ_{Total} to pair the DUE to a CUE. The pseudo-code of the greedy algorithm can be seen on Algorithm 1.

Algorithm 1 Greedy resource allocation algorithm

calculate τ_{total}
for d ∈ D **do**
  τ_{max} = arg $arg\ \tau_{total}$
  (Find the maximum value of τ_{total})
  c^* = row of τ_{max}
  d^* = column of τ_{max}
  allocates d^*-th DUE on c^*-th CUE
  $\tau_{allocation}(c^*, d^*) = \tau_{max}$
  (Store the maximum value)
  $\mu(c^*, d^*) = 1$
  (Update the allocation matrix, DUE-CUE pairs is defined)
  $\tau_{total}(c^*, :) = 0$
  $\tau_{total}(:, d^*) = 0$
  (Update total to prevent repeated selection on corresponding DUE-CUE pair)
end for

D. Particle Swarm Optimization Power Control

This work uses a PSO algorithm to find the power transmitted to each user. There is a J particle in total where $j = 1, 2, \ldots, J$. These particles are scattered in a Cartesian field. The x-axis and y-axis represent the P^{CU} and P^{DU} respectively. The algorithm is done through several iterations K. Each particle will calculate its objective function to maximize the system's total data rate [13].

PSO uses several notations in the process. The best fitness value of each particle and its position is denoted by fit^j_{best} and z^j_{best} respectively. The movement velocity, the position, and the fitness value of $j-th$ particle on $k-th$ iteration is noted by v^j_k, z^j_k, and fit^j_k respectively. The global best fitness value is noted by g_{best}, while the global best position denoted by $gpos_{best}$. Cognitive velocity noted by c_{vel}, while social velocity noted by s_{vel}. Notation R_1 and R_2 are random constants. The fixed PSO parameters value that being used in this work are shown in Table 1.

At the initial stage, PSO generates a set of particles with a random position. The PSO iterates several times to find the best position with the best fitness value. At each iteration, PSO evaluates the fitness value of each particle and updates the value of fit^j_{best} and z^j_{best}, and determines the velocity on the next iteration. The value of g_{best}, and $gpos_{best}$ also updated on each iteration to find the optimum position and fitness value. The process of PSO algorithm can be seen on Algorithm 2.

Table 1. PSO Simulation Parameters

Parameters	**Value**
Particle size	10
Iterations	40
Insertion constant (w)	0.8
Cognitive constant (C_1)	1
Social Constant (C_2)	1

Algorithm 2 PSO algorithm

initiate g_{best}, and $gpos_{best}$
(initial value of global best)
for all j ∈ J **do**
  Initiate $z^j(x, y)$
  (initiate random particle position)
end for
initiate fit^j_{best}, and z^j_{best}
(initial best value of each particle)
for all k ∈ K **do**
  for all j ∈ J **do**
    evaluate fit^j_k
    (evaluate particle fitness value)
    if fit^j_k ¿ fit^j_{best} **then**
      update fit^j_{best} , and z^j_{best}
    end if
    (update particle best value)
    if fit^j_{best} ¿ g_{best} **then**
      update g_{best}, and $gpos_{best}$
    end if
    (update global best value)
    $c_{vel} = C_1.R_1.(z^j_{best} - z^j_k)$
    $s_{vel} = C_2.R_2.(gpos^j_{best} - z^j_k)$
    $v^j_k = w.(v_{k-1} * j + c_{vel} + s_{vel})$
    (update the particle velocity)
    $z^j_{k+1} = z^j_k + v^j_k$
    (update the particle position)
  end for
end for
assign $gpos_{best}$ **to** P^{CU} and P^{DU}

E. Simulation Process

The overall allocation algorithm is simulated by these steps below. First all CUEs and DUEs are deployed randomly in the cell. All the RBs for CUEs are given and the allocation process assumed to be done. Then, the BS will calculate the value of τ_{total}. Then the greedy allocation algorithm is executed to choose the RB for each DUE. From this process, the DUE and CUE which share the same RB is defined, where each DUE get an RB to do the communication.

The power transmit for each user will be controlled and calculated through the PSO allocation algorithm process on each DUE and CUE pair. After all power for each user is determined, the performance system parameters will be calculated to measure the overall system performance. The value of the other simulation parameters can be seen in Table 2.

III. RESULT

The simulation result is explained below. The simulation analyzes the system's performance of the proposed algorithm. There are five parameters that observed in this work: system sum rate, spectral efficiency, power efficiency, system fairness, and total used power. To know the performance level of the

proposed algorithm, which is the greedy allocation algorithm combined with PSO power control scheme (greedy-PSO), is compared with the original greedy algorithm without PSO power control scheme.

A. System Sumrate

The system sum rate is calculated by (10). The graph result of the system sum rate can be seen in Fig. 2. The system sum rate of the greedy-PSO scheme shows better results compared to conventional greedy without PSO power control. The PSO-Greedy algorithm can achieve the system sum rate of 113.70 Mbps, while the conventional greedy algorithm achieves 100.65 Mbps. The addition of the PSO process as a power control scheme, can improve the sum rate of the system up to 12.97%.

B. Spectral Efficiency

The system spectral efficiency calculated by 11. The result of the system spectral efficiency shown on Fig. 3. Greedy-PSO algorithm spectral efficiency is higher than the conventional greedy allocation algorithm. The greedy-PSO average spectral efficiency can achieve 11.37 bps/Hz, which is 3,38% higher than 10,99 bps/Hz achieved by greedy without PSO.

C. Power Efficiency

The power efficiency of the system is calculated by 12. The simulation result of Power efficiency is shown in Fig. 4. The result shows that the Greedy-PSO algorithm achieves the average power efficiency at 607 kbps/Watt, which is 27.3% higher than the conventional greedy algorithm, which only achieved 477 kbps/Watt.

Table 2. Simulation Parameters

Parameter	Value
Frequency carrier	1800 MHz
Bandwidth	10 MHz
RB's Bandwidth	180 kHz
Number of RBs	50
Number of CUEs	50
Number of DUEs	5-50, with increment of 5
Cell radius	500 meter
Maximum distance between D2D	20 meter
Cell Layout	Single Cell
Power for each RB	1-4 Watt
Power for each DUE Tx	0.01-2 Watt
Shadowing	Lognormal distribution
Multipath	Rayleigh distribution

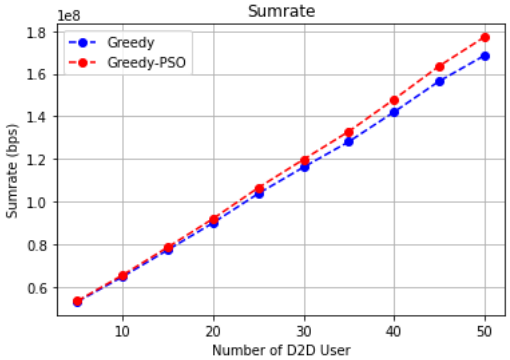

Fig. 2. Greedy-PSO system sumrate.

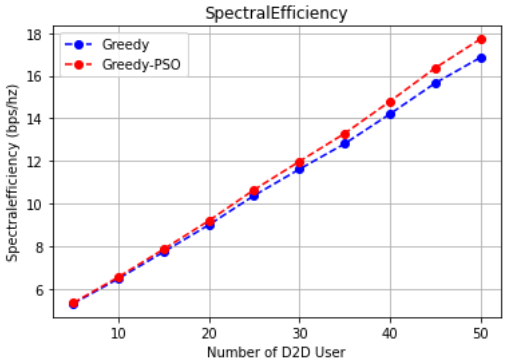

Fig. 3. Greedy-PSO spectral efficiency.

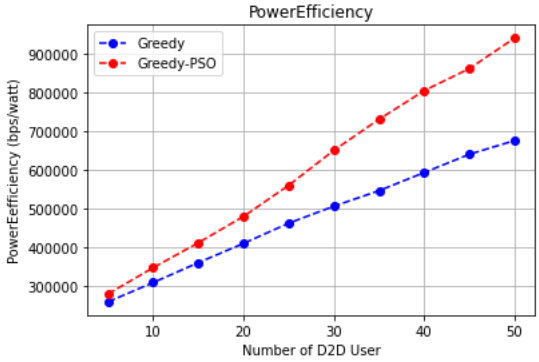

Fig. 4. Greedy-PSO power efficiency.

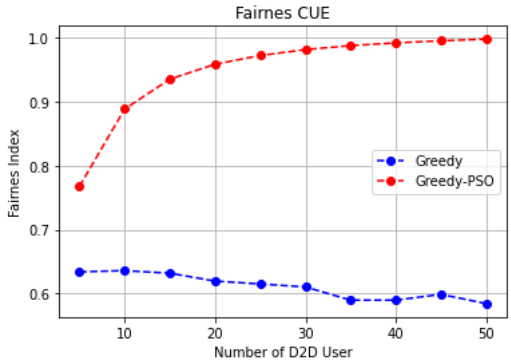

Fig. 5. Greedy-PSO CUE fairness.

D. System Fairness

The system fairness in this work is observed in each type of user, CUE and DUE because each type has a different data rate distribution. Hence, the fairness calculation is also will be different for each user. The fairness level is calculated by 13 and 14. The CUE and DUE fairness level results are shown in Fig. 5 and Fig. 6, respectively.

On the CUE side, the greedy-PSO algorithm can improve the fairness level among CUEs by 55.02%. The greedy-PSO achieves the average fairness level of 94,73%, while the average fairness level of the conventional greedy algorithm only achieves 61.10%. On the contrary, the average fairness level of the greedy-PSO algorithm is depressed by 0.08%. The greedy-PSO algorithm only achieves the average fairness level among DUEs of 90,36%, which is lower than the conventional greedy algorithm average value of 91,16%.

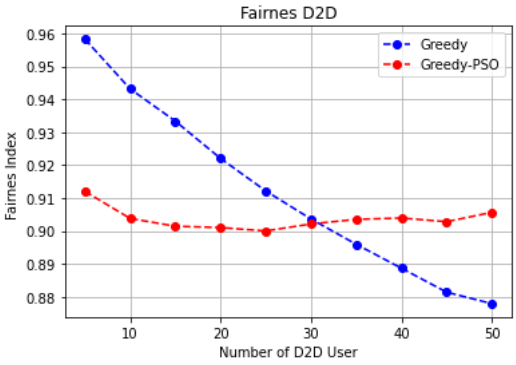

Fig. 6. Greedy-PSO DUE fairness.

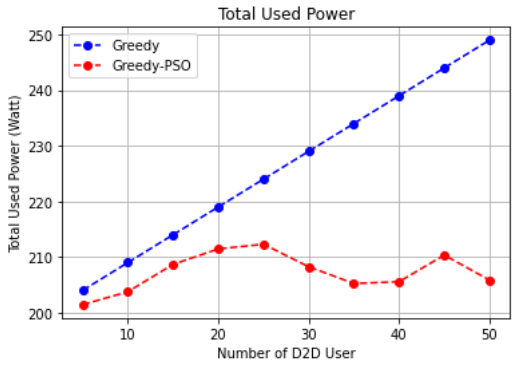

Fig. 7. Greedy-PSO total used power.

E. Total Used Power

The total used power of the system can be calculated by:

$$P_{total} = \sum_{d=1}^{D} P_{DU} + \sum_{c=1}^{C} P_{CU} \tag{23}$$

Which is the total power used in the system by all users. The simulation results of the total power used can be seen in Fig. 7. The result shows that greedy-PSO use less power than the conventional greedy algorithm. The average used power of greedy-PSO is 207,28 Watt, while the conventional greedy algorithm averaged 226,5 Watt. This means PSO power control can decrease the total power used by 8,48%.

IV. Discussion

The simulation results show that the addition of the PSO power control algorithm performs better than the conventional greedy algorithm. Adding the PSO algorithm improves almost all parameters, except the fairness between DUEs. The system performance parameters increased because the power allocation strategy objective is to find an optimal combination between P^{CU} and P^{DU} which maximizes the data rate of each user. The overall simulation results are shown in Table 3.

By controlling the transmit power of each user, the interference level on the system can be minimized, this makes the system sum rate and spectral efficiency also have better value. The total used power also decreases because of the optimal power transmit allocation. The system can achieve a better sum rate with a lower total used force, which means the power efficiency improves.

Table 3. Average Simulation Results

Parameter	Algorithm Mean Value		Gap
	Greedy	Greedy-PSO	
Sum rate (Mbps)	100.65	113.70	12,97%
Spectral Efficiency (bps/Hz)	10.99	11.37	3,38%
Power Efficiency (Kbps/Watt)	477.11	607.79	27,39%
CUE Fairness	61.10%	94.73%	55,03%
DUE Fairness	91.16%	90.36%	-0,88%
Total Power Used (Watt)	226.5	207,28	-8,48%

These conditions happen because the interference that happens on each user also is maintained. By controlling P_{BS} and P_{DU}, the value of S_{CU}, S_{dU}, I_{BS-DU}, and I_{TX-CU} can be maintained. Finding the optimal combination of P_{BS} and P_{DU} is critical. PSO power control allocates P_{BS} and P_{DU} in their optimal combination, so the value of Γ_{CU} and Γ_{DU} can be maximized. On the contrary, the conventional greedy allocation algorithm is an algorithm without a power control scheme, and the power for each user is constant at the maximum value. Because the CUEs and DUEs share the same RB in the underlay scheme, the maximum power allocation makes the interference level in the system also on the maximum value, so the value of Γ_{CU} and Γ_{DU} can't be maximized. The value of sum rate, spectral efficiency, and power efficiency is increasing along with the increased number of users. These conditions mean the resource is allocated well among the user, and can increase the system's performance.

The fairness of users has different conditions. The addition of PSO power control improves the fairness among CUEs. By allocating the power of each user, the sum rate gap among CUEs can be minimized, even though several CUEs share its RB with DUEs, and the other CUEs have the RB for their own. On the contrary, the fairness level among DUEs is slightly decreased compared with the conventional greedy algorithm. However, the fairness level is stable among DUEs. As shown in Fig. 6, the greedy-PSO has a flat curve compared with the traditional greedy decreased curve. These conditions mean, that by allocating maximum power to each user, the interference level of the system increases along with the increment of the user. Hence, the quality gap among users is also increasing, because there are differences in the interference level that happens among DUEs, so the fairness is also decreasing.

V. Conclusion

In this work, the PSO-based power control algorithm on D2D underlay communication is observed and analyzed. From the results, the addition of a PSO-based power control algorithm can improve the system performance. PSO power control can improve the sum

rate up to 12.97%, and improve the spectral efficiency up to 3.38%. By allocating the power efficiently, the total used power decreased by 8.48% and the power efficiency increased by 27.39% in average. The fairness level among users also can be maintained, in average of 94.73% in CUE's fairness, and 90.36% in DUE's fairness.

To improve the results of this study, future studies can consider the calculation of the time complexity of the proposed algorithm, and the performance compared to the other power control scheme. PSO is also a powerful algorithm to find the combination optimal solution, but it needs an iteration process for the optimization process. It is also an interesting topic to modify the PSO algorithm to find the solution faster, with a smaller number of iterations.

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