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Energy Efficient D2D Communication Under Downlink Heterogeneous Network

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Abstract

The increase in cellular users (CU) caused data traffic congestion on the Base Station (BS). Device to Device (D2D) communication can be used to reduce the traffic on BS. D2D communication is direct communication between devices without using a central BS to reduce traffic congestion. CU and D2D users will share the same Resource Block (RB), but there is a drawback that causes interference. This study employs a downlink direction Heterogeneous Network (HetNet) system model to mitigate interference issues. Resource allocation is performed using a greedy algorithm, and to enhance its performance, two small cell base stations (SB) were incorporated, denoted as SB1 (1^{st} SB) and SB2 (2^{nd} SB) , thereby transforming the algorithm into a greedy algorithm with SB1SB2. A comparative analysis was conducted between the greedy algorithm with SB1SB2 and the conventional greedy algorithm (without the addition of SB1 and SB2). Furthermore, the authors manipulated the radius of the macro cell base station (MB) in this study to examine its impact on system performance.The results obtained from the simulation are greedy with the SB1SB2 algorithm getting a lower value on the sum data rate with a value of $1.62 \times 10^8 bps$, spectral efficiency with a value of 9.02 bps/Hz, total fairness (CU and D2D) with a value of 0.4095. Meanwhile, in terms of power efficiency, the greedy algorithm with SB1SB2 has a higher value of 10.40%.

Keywords: Device to Device, Power Efficieny, Greedy Algorithm, Heterogeneous Network

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1. Introduction

Over time, there has been a significant surge in the number of cellular users (CUs). The increase in cellular users caused data traffic congestion on the Base Station (BS) [1]. Device to Device (D2D) communication can be the solution to reduce traffic load in BS. D2D communication is direct communication between devices without using a central BS. In D2D in-band communication, D2D users use the same Resource Block (RB) as CU on Uplink (UL) and Downlink (DL) so that the frequency used by D2D users is the same as CU. Using the same RB on D2D users and CU can reduce power consumption and traffic density [2]. However, the use of RB simultaneously also has the disadvantage that it can cause high interference in D2D communication.

One effective method to mitigate interference is to allocate resources using a greedy algorithm. In this study, we propose a solution for interference reduction in a Heterogeneous Network (HetNet) system. Our approach involves incorporating two small cell base stations (SBs), specifically SB1 (1^{st} SB) and SB2 (2^{nd} SB) into the network. So, therefore algorithm used in this study can be written as a greedy algorithm with SB1SB2. The results obtained are then compared with the greedy algorithm (without the addition of SB). Efficient resource allocation is critical for improving system performance and reducing interference. It can optimize the data transmission process, resulting in lower power consumption and higher D2D power efficiency.

In research [3] spectrum allocation uses a proximal minimization algorithm to reduce power consumption. The results obtained are spectrum allocation energy efficiency achieving high data rates and minimizing power usage. Research [4] proposed an efficient fractional frequency reuse (FFR) scheme to reduce interference. The research results prove that the FFR scheme and system optimization can improve system performance compared to other schemes. Research [5] discusses the allocation of resources in HetNet to

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improve energy efficiency. energy efficiency which has the highest value when using the JGXPSO algorithm. Research [6] discusses maximizing energy efficiency based on the HetNet resource allocation scheme. The simulation results show that the optimal solution can be achieved if the number of iterations is relatively small. Based on the simulation results, the number of users and system data rate does not always affect the energy efficiency of a network.

Heterogeneous Network (HetNet) is a network consisting of macro cell base stations (MB) and small cell base stations (SB) [3]. MB is transmitting a high-power level, and SB is in the range of MB. The use of data traffic is increasing but the addition of MB has reached its limit in quite dense cities. To deal with this problem, one thing that can be done is to use SB in the MB area [7]. MB has a cell radius of about 1-10 km. SB can be microcells, picocells, femtocells, etc. The cell radius of a microcell is less than 1 km, a pico cell has a cell radius of about 4-200 m, and a femtocell has a cell radius of about 10-20 m [8]

The purpose of this study is to reduce interference among user and improve energy efficiency for D2D communication, Resource allocation in this study is using a greedy algorithm. This study utilized the HetNet system model comprising two SBs. The greedy algorithm was applied using SB1SB2, while a comparison was made using the greedy algorithm without SBs.

2. Research Method

In this study, several stages must be conducted as shown in Figure 1. The initial stages were carried out by initialization input and distributed users. Each user distances are used to calculate the path loss, Signal Interference and Noise Ratio (SINR), and the capacity of each user. After that, allocating CU's resource s with greedy algorithm is done, to analyze the performance parameters. The performance parameters' outcomes (sum data rate, spectrum efficiency, power efficiency, and total fairness) are analyzed.

2.1. System Model

This study uses the Heterogeneous Network (HetNet) system model which consists of a macro cell base station (MB), the small cell base station (SB) used are two SBs namely SB1 (1st SB) and SB2 (2ndSB), a pair of D2D users (D2D Tx and D2D Rx), and a cellular user (CU).

In band underlay D2D communication is employed, with downlink transmission direction. In underlay communication, both the D2D user and the CU employ RB at the same time, which might cause interferenceThe system model used in this study can be seen in Figure 2. The interference occurs from D2D Tx to CU (in area MB, SB1, or SB2), MB to D2D Rx which is in area MB, SB1 to D2D Rx which is in area SB1, SB2 to D2D Rx which is in area SB2. The CUs do not interfere with each other because the CUs in the MB, SB1, and SB2 areas use different RBs

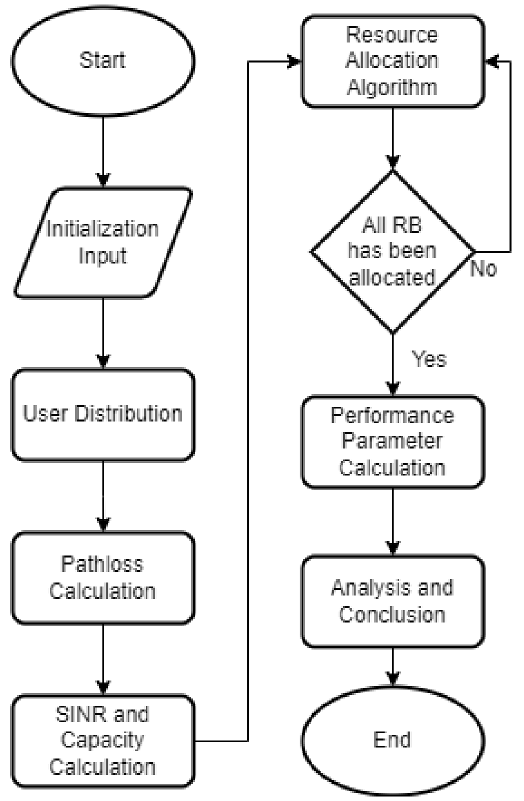

Fig. 1. Simulation Scheme

The interference occurs from D2D Tx to CU (in area MB, SB1, or SB2), MB to D2D Rx which is in area MB, SB1 to D2D Rx which is in area SB1, SB2 to D2D Rx which is in area SB2. The CUs do not interfere with each other because the CUs in the MB, SB1, and SB2 areas use different RBs. Likewise, for D2D users, the D2D pairs do not interfere with each other because the RB used is different for each D2D user so there is no interference for D2D users. Thus, the interference that is calculated is between CU and D2D users only.

2.2. Simulation Parameter

MB has a cell radius of about 1-10 km and SB has a cell radius of less than 1 km. In this study, the simulations carried out only used a 500-800 m MB radius and 150 m SB radius.

2.3. Pathloss

Pathloss can be calculated by using the eq. (1) [9].

$$PL(d) = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right), \quad (1)$$

where $PL(d)$, d, $PL(d_0)$, and n is the pathloss distance between Tx and Rx, pathloss at the closest reference distance d_0 from Tx to Rx, and pathloss exponent respectively.

2.4. Signal to Interference and Noise Ratio (SINR)

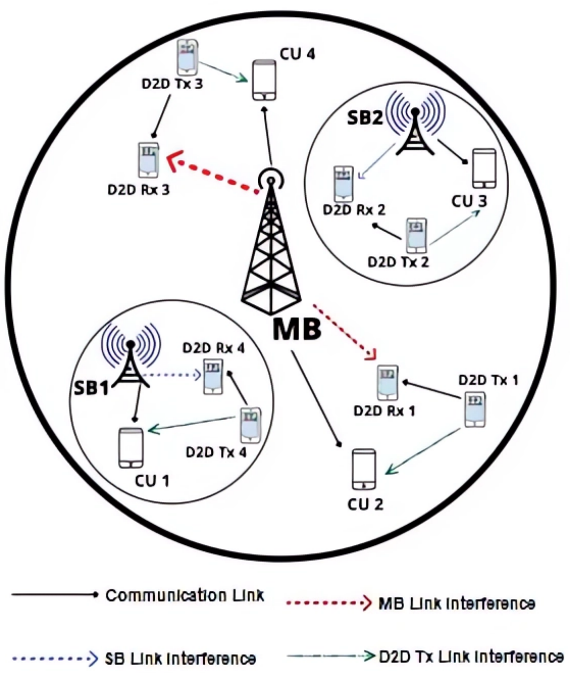

Fig. 2. Downlink HetNet System Model

SINR can be calculated by using eq. (2) [10].

$$SINR = \frac{P_{Tx} \cdot G_{Tx}}{N \cdot P_{int} \cdot G_{int}}, \quad (2)$$

where P_{Tx}, G_{Tx}, N, P_{int}, and G_{int} is power from transmitter, gain from transmitter, noise, received power from interference and gain from interference respectively. This study uses the downlink transmission direction with the HetNet system model, so the calculated SINRs are CU-MB SINR, CU-SB1 SINR, CU-SB2 SINR, D2D-MB SINR, D2D-SB1 SINR, and D2D-SB2 SINR. The CU-MB SINR value can be calculated using eq.(3).

$$SINR_i^C MB = \frac{Pr_i^{MB} \cdot Gr_i^{MB}}{N \cdot Pr_{itx}^{MB} \cdot Gr_{itx}^{MB}}, \quad (3)$$

where i, Pr_i^{MB}, Gr_i^{MB}, Pr_{itx}^{MB}, Gr_{itx}^{MB}, N is i-th CU, received power from MB to CU, gain MB to CU, received power from D2DTx to CU, gain D2DTx to CU, and the noise respectively. The formula to calculate the values of SINR CU-SB values, is shown by eq.(4).

$$SINR_i^C SB = \frac{Pr_i^{SB} \cdot Gr_i^{SB}}{N \cdot Pr_{itx}^{SB} \cdot Gr_{itx}^{SB}}, \quad (4)$$

where Pr_i^{SB}, Gr_i^{SB}, Pr_{itx}^{SB}, Gr_{itx}^{SB} is the received power from SB to i-th CU, the gain from SB to i-th CU, received power from D2DTx to CU, and gain from D2DTx to CU respectively. The value of the D2D-MB SINR value can be calculated using eq. (5).

$$SINR_j^D MB = \frac{Pr_j^{MB} \cdot Gr_j^{MB}}{N \cdot Pr_{jtx}^{MB} \cdot Gr_{jtx}^{MB}}, \quad (5)$$

where Pr_j^{MB}, Gr_j^{MB}, Pr_{jtx}^{MB}, Gr_{jtx}^{MB} is received power from D2D Tx to D2D Rx, gain D2D Tx to D2D Rx, received power from MB to D2D Rx, and the gain MB to D2D Rx respectively. The SINR value of D2D-SB can be calculated by eq. (6).

$$SINR_j^D SB = \frac{Pr_j^{SB} \cdot Gr_j^{SB}}{N \cdot Pr_{jtx}^{SB} \cdot Gr_{jtx}^{SB}} \quad (6)$$

Pr_j^{SB}, Gr_j^{SB}, Pr_{jtx}^{SB}, Gr_{jtx}^{SB} is the received power from D2D Tx to D2D Rx, gain D2D Tx to D2D Rx, received power SB1 or SB2 ke D2D Rx and gain SB1 or SB2 to D2D Rx respectively.

2.5. *Greedy Algorithm*

The greedy algorithm is an algorithm used to distribute RB to users. This algorithm allocates the RBs to the user that can maximize the RB capacity. In this work, a D2D pair chose the best RB that is used by a CU by calculating the total capacity of D2D and CU. This scheme uses First in first out (FIFO). To limit the interference that happens in 1 RB, the D2D cannot choose the same RB as the other D2D. The flowchart of the greedy algorithm can be seen in Figure 3.

2.6. *Greedy Algorithm with SB1SB2*

This study implements a greedy algorithm for the RB allocation process and incorporates two SBs, namely SB1 (1^{st} SB) and SB2 (2^{nd} SB) into the simulation. As a result, the algorithm is formulated as a greedy algorithm with SB1SB2. There are CU and D2D users in the SB1, SB2 and MB areas. CU located in SB1 use RB from SB1, CU located in area SB2 use RB from SB2, and CU located in area MB use RB from MB. The allocated RB cannot be allocated to the next user. The difference is that there is an addition of SB, so the capacity used is also different.

Table 1: Simulation Parameter

Definition	Value
MB Radius	500, 550, ..., 750, 800 m
SB Radius	150 m
Number of CU	100
Number of D2D User	50
Frequency	2 GHz
System Bandwidth	20 MHz
Bandwidth of RB	180 kHz
Gain Tx of CU, D2D	10 dBm, 24 dBm
Gain Tx of MB, SB	43 dBm, 30 dBm

3. Result and Discussion

The results obtained from the simulation are analyzed to know the performance of each system. The performance parameters that are being analyzed are the sum data rate, spectral efficiency, power efficiency, and fairness level.

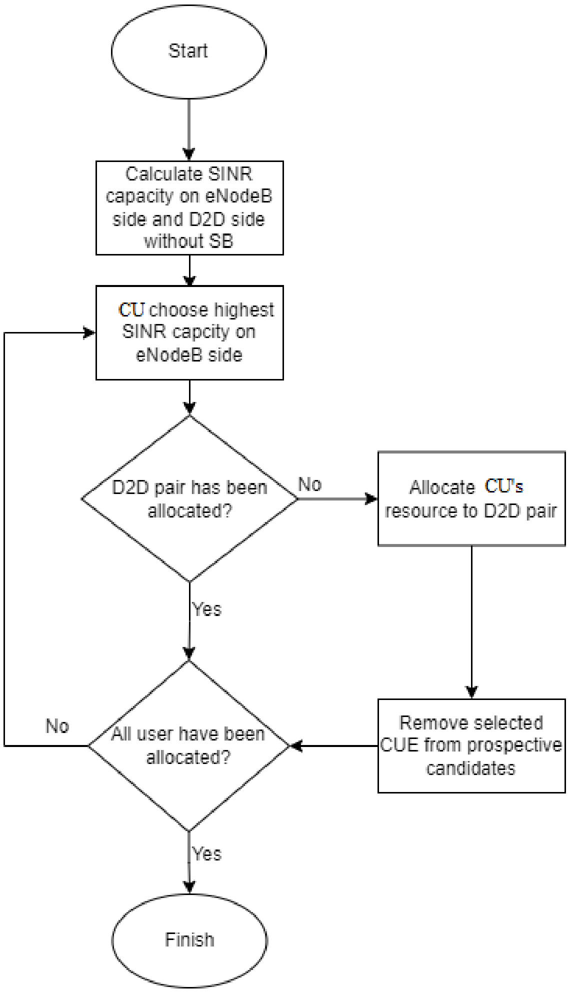

Fig. 3. Flowchart of Resource Allocation Algorithm

3.1. *Data Rate*

The data rate is the number of bits sent per second. To calculate the data rate can use the eq.(7) and eq.(8). [12].

$$R^C_{i,j} = B \times log_2(1 + SINR^C_{i,j}) \quad (7)$$

$$R^D_{i,j} = B \times log_2(1 + SINR^D_{i,j}) \quad (8)$$

where $R^C_{i,j}$, $R^D_{i,j}$, B, $SINR^C_{i,j}$ is the and $SINR^D_{i,j}$ are CU data rate, D2D user data rate, resource block's bandwidth in Hertz, SINR of CUs and, SINR of D2Ds respectively.

3.2. *Sum Data Rate*

Sum data rate is obtained by summing all data rate users (CU and D2D users). To calculate the sum data rate can use the eq.(9) [13].

$$SR = \sum_{i=1}^{I} \sum_{j=1}^{J} (a_{ij} \cdot R^C_{i,j}) + (a_{ij} \cdot R^D_{i,j}) \quad (9)$$

where SR is the sum data rate, I is the number of CUs, J is the number of D2D users, a_{ij} is the allocation matrix if the i^{th} CU uses the same resource as the j^{th} D2D.

The results of the comparison of the average sum rate in this study can be seen in Table 2. The greedy

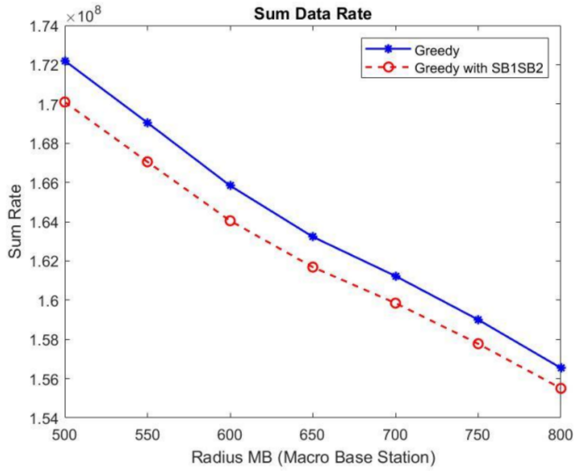

Fig. 4. Result of Sum Data Rate Simulation

Table 2: Result of Simulation

Parameter	Greedy	Greedy SB1SB2
Sum Data Rate (bps)	1.64 x 10^8	1.62 x 10^8
Spectral Efficiency (bps/Hz)	9.02	9.10
Power Efficiency (bps/mW)	81.62	90.11
Total Fairness (CU and D2D)	0.4110	0.4095

algorithm on SB1SB2 has an average sum rate of 1.62 x 10^8 bps. Meanwhile, the greedy algorithm has an average sum rate of 1.64 x 10^8 bps. According to the results of the two data, the greedy algorithm with SB1SB2 has an average sum rate lower by 1.22% compared to the greedy algorithm. In scenario 2, it shows that the performance of the greedy algorithm sum rate on SB1SB2 is not superior compared to the greedy algorithm. This happens because the greedy algorithm with SB1SB2 has a smaller total capacity value in the resource allocation process.

3.3. *Spectral Efficiency*

The value of spectral efficiency can be calculated using eq.(10) [14].

$$SE = \frac{SR}{B \cdot C} \quad (10)$$

where SR, and C are sum data rate, and the number of CU respectively.

Table 2 shows that the greedy algorithm with SB1SB2 has a lower value than the greedy algorithm itself. The result of the spectral average value of the greedy algorithm with SB1SB2 is 9.02 bps/Hz. Meanwhile, the greedy algorithm has an average spectral efficiency value of 9.10 bps/Hz. A greedy algorithm with SB1SB2 has an average value of 0.88% lower spectral efficiency because it has a smaller sum rate. As a result, if the total rate obtained is low, the spectral efficiency value will be low as well.

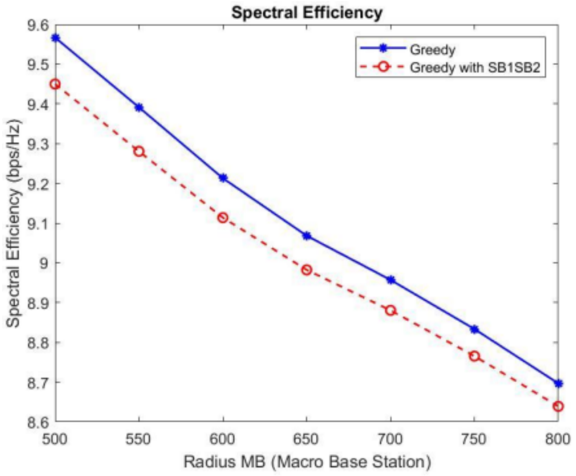

Fig. 5. Result of Spectral Efficiency Simulation

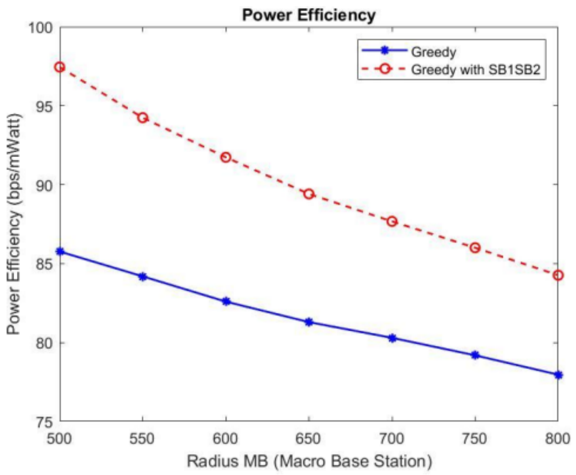

Fig. 6. Result of Power Efficiency Simulation

3.4. *Power Efficiency*

Power efficiency is a performance parameter used to determine the efficient level of power used by a system in transmitting. The value of power efficiency calculated using eq. (11) [15].

$$PE = \frac{SR}{P_C \times C + P_D \times D} \tag{11}$$

where, P_C, and P_D are the transmit power of CU, and transmit power of D2D user respectively. According to the results of the data from Table 2, the greedy algorithm with SB1SB2 has an average power efficiency value of 90.11 bps/mW. While the average value of the greedy algorithm is 81.62 bps/mW. The results show that the greedy algorithm with SB1SB2 has an average yield of 10.40% higher power efficiency compared to the greedy algorithm. This happens because the transmit power used is different in the two algorithms. This occurs because the transmit power required by the two algorithms differs. The greedy algorithm with SB1SB2 incorporates SB transmit power, whereas the greedy algorithm does not. With the addition of SB transmit power, the power allocation for each user will be more optimal in the process of data transmission. So that the use of power will be more efficient and cause the

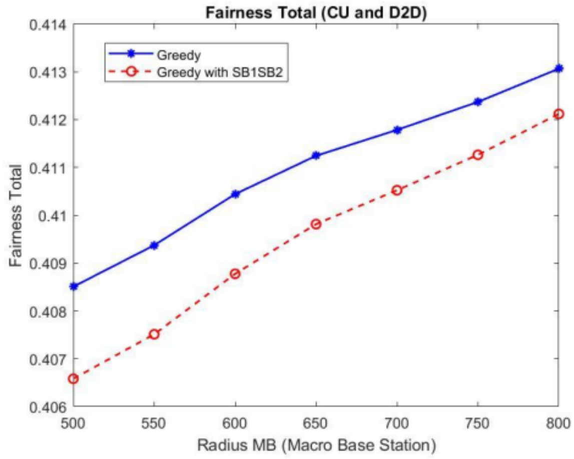

Fig. 7. Result of Fairness Total Simulation

results of power efficiency to be higher than those that do not use the addition of SB transmit power.

3.5. *Total Fairness (CU and D2D*

The value of fairness can be calculated using eq. (12) [9].

$$FI = \frac{(\sum_{i=1}^{n} Xi)^2}{n \cdot \sum_{i=1}^{n} Xi^2} \tag{12}$$

where n is the total number of the user (CUs and D2D Pairs), and Xi is the i-th user capacity.

The average total fairness results in scenario 2 can be seen in Table 2. Greedy algorithm with SB1SB2 gets an average value of 0.4095 in total fairness. While the greedy algorithm gets a value of 0.4110 on total fairness. From these data, the greedy algorithm with SB1SB2 obtains a total fairness value that is 0.37% lower than the greedy algorithm. This is because the total capacity values in the greedy algorithm with SB1SB2 are smaller than the greedy algorithm. So that the fairness value obtained by the greedy algorithm with SB1SB2 became lower.

4. Conclusion

In this study, resource allocation was carried out using a greedy algorithm. The system model used is HetNet by adding two SB in the MB area. The results analyzed are the greedy algorithm with SB1SB2 compared to the algorithm greedy without the addition of SB. The greedy algorithm with SB1SB2 has a better value in power efficiency than the greedy algorithm with the value of 90.11 bps/mW. On the other hand, the greedy algorithm produces better values at a sum rate of 1.64 x 10^8 bps, Spectral efficiency of 9.10 bps/Hz, and Total fairness of 0.4110. The results of power allocation using the greedy algorithm with S1SB2 are better than the greedy algorithm. However, resource allocation in both algorithms is not the best solution. So that the resulting performance parameters are less than optimal.

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