Resource Allocation for Multicarrier-Low Density Sequence-Multiple Access

Linda Meylani[1], Nur Andini[2], Desti Madya Saputri[3], Iswahyudi Hidayat[4]

Abstract*—Multicarrier low-density sequence multiple access (MC-LDSMA) is a code domain type of non-orthogonal multiple access (NOMA) in a multicarrier system. Each user in this multiple access scheme has a non-orthogonal code to one another. Each user is only allowed to access d_v from the available N resources and there are only d_c users from the total of J users accessing the same resource. The non-orthogonal nature causes the MC-LDSMA system to have a higher overloading factor than other orthogonal multicarrier systems. This condition causes MC-LDSMA to become one of the multiple access techniques used in underlay cognitive radio communication systems, where secondary users (SUs) are permitted to access resources owned by primary users (PUs). This paper proposed a resource allocation algorithm for MC-LDSMA in an underlay cognitive radio system. The proposed algorithm aims to increase the number of SUs accessing PUs resources while maintaining the SUs quality factor. The system built consisted of I PUs and J SUs. PUs in the system was assumed to be orthogonal so that they did not interfere with each other. At the same time, some J SUs simultaneously accessed resources owned by PU using the MC-LDSMA multiple access schemes. The proposed algorithm considered several factors, including the parameters d_c, d_v, SU target signal-to-noise ratio (SNR), and the interference tolerance limit desired by PU. Performance parameters were indicated by the outage probability (OP), the throughput of PU and SU, and the ratio of the number of SUs that were allocated less than d_v resources. The simulation results suggest that all performance parameters are affected by the number of resources accessed by each user, d_v, the target SNR of SU, and the interference limit determined by PU.

***Keywords*—MC-LDSMA, Underlay, Cognitive Radio, NOMA, Resource Allocation.**

I. INTRODUCTION

The spectrum sharing scheme in the cognitive radio system is considered capable of increasing the efficiency of spectrum use. There are two user definitions in this scheme, namely primary (PU)/licensed user and secondary user (SU)/cognitive user (CU)/unlicensed user. SU is obtained to access the spectrum owned by PU in three dynamic access schemes, one of which is underlay.

In the underlay scheme, SUs are allowed to carry out transmission simultaneously with PU on the condition that the interference level caused by SUs to PUs is still below the predetermined interference limit/threshold. A large number of access requirements by unlicensed users (SUs) need the existence of multiple access schemes that can increase the efficiency of spectrum use as well as manage the multi-user interference.

Multicarrier low-density signature multiple access (MC-LDSMA) is a non-orthogonal multiple access (NOMA) code domain multiple access schemes [1], [2]. As in low-density sequence orthogonal frequency division multiplexing (LDS-OFDM) [3], in MC-LDSMA, each user will spread the transmitted symbol on a d_v number of subcarriers, and a number of d_c users can access each subcarrier. Resource allocation in MC-LDSMA and LDS-OFDM systems, was carried out, but neither of them discussed resource allocation in cognitive radio communication systems [2], [4].

Studies on resource allocation in cognitive radio communication systems in underlay schemes have been carried out previously [5]-[11]. References [5], [6] allocated resources for SUs in orthogonal frequency-division multiple access (OFDMA) systems. Therefore, the SUs did not interfere with each other. Reference [7] performed resource allocation by assuming the multiple access scheme used by SU was code-division multiple access (CDMA). In comparison, references [8]-[10] performed resource allocation on the LDS-OFDM system. References [8] and [9] allocated resources based on the interference limit; in addition, reference [9] also considered the metric fairness parameter in the resource allocation process. Suppose references [8] and [9] selected a subcarrier for the SU, reference [10] allocated power to the SU to increase the average throughput of the SU. Reference [11] proposed resource allocation in the NOMA multicarrier system under conditions of cognitive radio underlay. The allocation of resources in a multi-channel underlay cognitive radio system using deep neural network (DNN) has also been carried out [12].

The research in this paper continues the previous research [8] and [9] in which the resource allocation algorithm pays attention not only to the limit on the number of SUs that are allowed to access the same resource (d_c) and the interference limit determined by the PU but also to the quality factor. The expected SU, in this case, is expressed by the SU target SNR. It aims to ensure that each SU remains capable of carrying out transmission by maintaining quality.

The rest of this paper is organized as follows: the system model and problem formulas are presented in Section II. Section III discusses the proposed resource allocation. Section IV discusses the simulation results. Finally, Section V presents the conclusions of this study.

II. SYSTEM MODEL

In this research, SUs and PUs were assumed to be in the same geographical environment. PUs were assumed to use the

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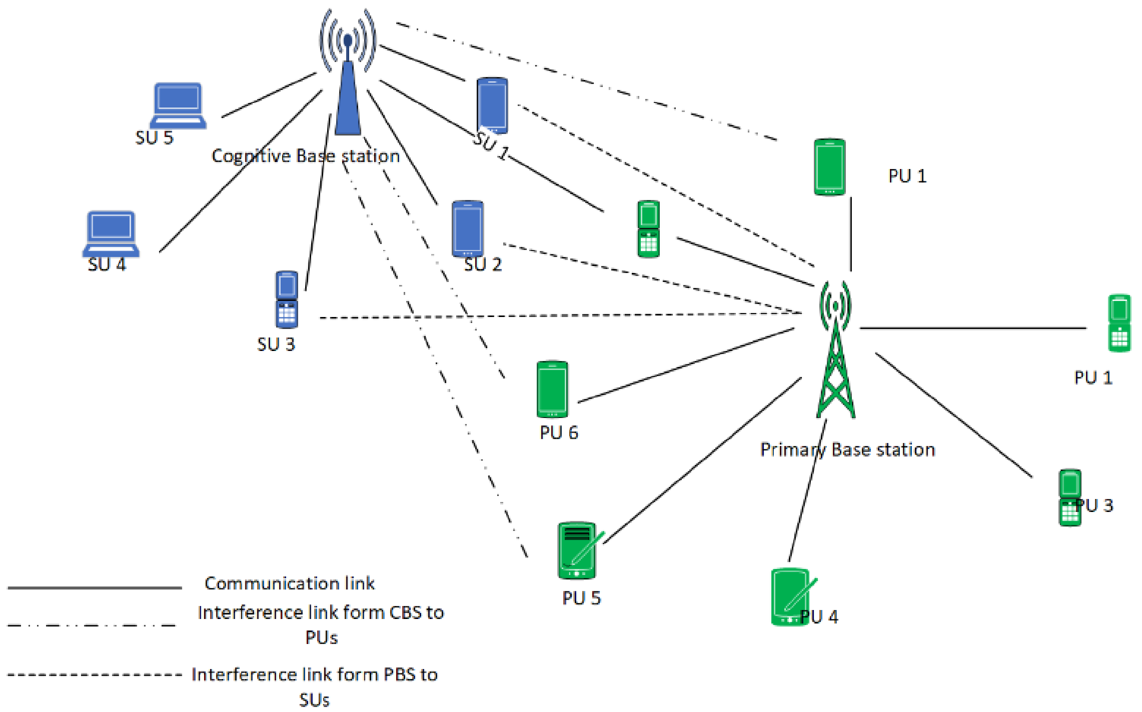

Fig. 1 System model.

OFDMA multiple access schemes; therefore, each PU would access its subcarrier and did not interfere with each other. On the other hand, SU used the MC-LDSMA multiple access schemes. This study assumed that the CR system had knowledge of the PU channel condition and utilized it for the resource allocation process. The system model in this study is shown in Fig. 1.

MC-LDSMA, like LDS-OFDM, has low-density properties in its spreading code. This system allows each subcarrier on the system to be accessed by several d_c users from the total of existing J users. It also allows each user to access several d_v subcarriers from the total N subcarriers on the system. In this research, the spreading code of each user was not generated directly, but codes were generated based on the resource allocation obtained by each user and influenced by the d_c and d_v parameters.

The system in this research has been built by a number of I PUs and J SUs. Each PU would access different subcarriers; hence, they did not interfere with each other. Meanwhile, SU applied the MC-LDSMA multiple access scheme with specific d_c and d_v parameters, where $d_c < J$ and $d_v < N$. Assume each PU's subcarrier will be accessed by a number of d_c SUs, the equation for receiving a signal at the PU base station on the nth subcarrier is expressed as follows:

$$y_n(t) = c_{pu\,i,n} \cdot h_{pu\,i,n} + \sum_{j \in S_l} c_{su\,j,n} \cdot g_{su\,j,n} + v_n \quad (1)$$

where $y_n(t)$ is a received signal at the PU base station, $c_{pu\,i,n}$ and $c_{su\,j,n}$ are transmitting symbols of PUs and SUs at nth subcarrier, respectively. $h_{pu\,i,n}$ and $h_{su\,j,n}$ is a channel gain of PUs and SUs nth subcarrier, respectively. v_n is additive white Gaussian noise (AWGN). Meanwhile, S_l is a group of SU accessing nth subcarrier. The interference limit determined by PU is denoted by I_l. Therefore, the allowed total interference in nth subcarrier is expressed as follows

$$I_{total,n} = \sum_{j \in S_l} p_{su\,j,n} \cdot \left|g_{j,n}\right|^2 \leq I_l \quad (2)$$

where $p_{su\,j,n}$ is a transmitting power of jth SU at the nth subcarrier. Resource allocation index, $x_{n,i}$, is used to formulate allocation subcarrier for SU. If SU is allocated to the nth subcarrier, then $x_{n,i} = 1$; if SU is not allocated to the nth subcarrier, then $x_{n,i} = 0$ and vice versa.

At the proposed resource allocation, each SU has the same SNR target that is defined as follows.

$$SNR_{j,n} = \frac{p_{su\,j,n} \cdot |h_{su\,j,n}|^2}{\sigma^2 W_n + p_{pu\,i,n} \cdot |g_{pu\,i,n}|^2 + \sum_{k \neq j, k \in S_l} p_{su\,k,n} \cdot |h_{su\,k,n}|^2}. \quad (3)$$

The throughput of SU is represented as

$$R_{j,n} = \log_2 \frac{p_{su\,j,n} \cdot |h_{su\,j,n}|^2}{\sigma^2 W_n + p_{pu\,i,n} \cdot |g_{pu\,i,n}|^2 + \sum_{k \neq j, k \in S_l} p_{su\,k,n} \cdot |h_{su\,k,n}|^2} \quad (4)$$

on the condition that

$$p_{su\,j,n} = \frac{P_{su\,j}}{d_v} \quad (5)$$

$$P_{su\,j} \leq P_{su,max}, j \in J \quad (6)$$

$$p_{su\,j,n} \leq 1, j \in J \; dan \; n \in N \quad (7)$$

$$x_{\,j,n} \in \{0,1\}, \; j \in J \; dan \; n \in N \quad (8)$$

$$\sum_{j \in S_l} x_{\,j,n} \leq d_c, n \in \mathcal{N} \quad (9)$$

$$\sum_{n \in \mathcal{N}_l} x_{\,j,n} \leq d_v, j \in J \quad (10)$$

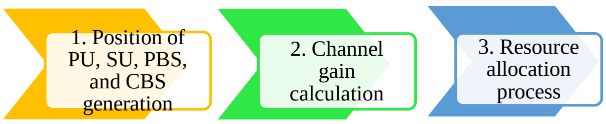

Fig. 2 Resource allocation process.

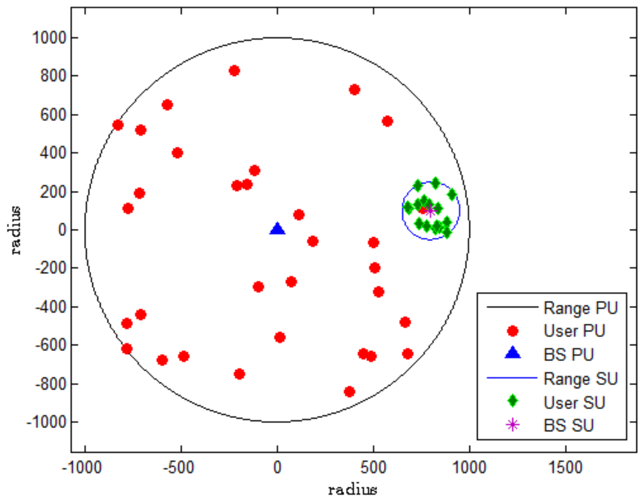

Fig. 3 Generation of PBS and CBS with 32 PUs and 16 SUs.

III. Proposed Resource Allocation

The general process of allocation resources in this research is shown in Fig. 2. The followings are steps in the resource allocation process.

1) Randomly Generated a Number of I PUs and J SUs, the Primary Base Station, and Cognitive Base Station: This research assumed that primary base station (PBS) has a wider range than cognitive base station (CBS). As shown in Fig. 3 and Table I, it can be seen that the radius of PU is wider than SU.

2) Calculation of Channel Gain: The channel gain calculation is based on the Cost 231-WI channel model.

3) Resource Allocation Process: Resource allocation for SU is conducted by considering the quality expected by SU. In this research, the minimum SNR expected by SU is assumed to be 10 dB.

In this paper, two resource allocation algorithms were compared. At the first step, the algorithms allocated PUs at their subcarrier without interference with each other. The first resource allocation algorithm (RA-1) allocated resource SU based on its quality target (SNR). RA-1 checked the interference caused by PU and chose a d_v subcarrier with lower interference. After SUs obtained the subcarrier allocation, the interference value would be updated and compared with the minimum SNR target of SU. The process continued until all SUs had the opportunity to be allocated or the requirements had been met, where each resource had been accessed by d_c SU.

The second resource allocation algorithm (RA-2) allocated resources for SU based on the SU target SNR and considered the interference limit (I_L) determined by PU. The interference limit (I_L) is related to the PU target. Table I presents the parameter simulation of this research.

TABLE I
SIMULATION PARAMETER

Parameter	Information
Total subcarriers	128
The number of PUs	4
The number of SUs	2-32
PBS coordinate	(0,0)
CBS coordinate	(700,20)
Radius of PU	800 m
Radius of SU	150 m
Noise power spectral density	-174 dBm/Hz
Channel model	Cost 231-WI
Maximum of PU's power	23 dBm
Maximum of SU's power ($P_{su,\,max}$)	30 dBm
SU's power in the subcarrier	$P_{su,\,max}/d_v$
Multiple access for PU	OFDMA
Multiple access for SU	MC-LDSMA

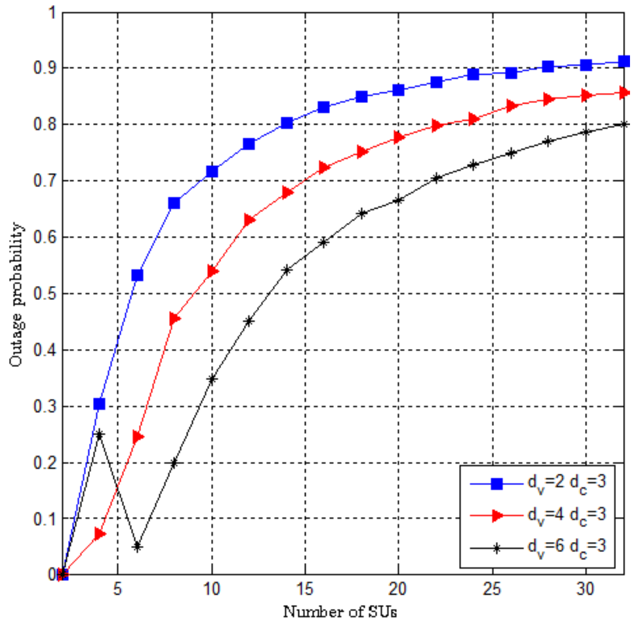

Fig. 4 Outage probability.

IV. Simulation Results

This section presents and discusses the simulation results of the proposed resource allocation. Parameter simulations in this research are shown in Table I. Parameter performance used was outage probability (OP), average throughput value of SU and PU, as well as the ratio of the number of SUs that did not obtain the d_v subcarriers. OP is a parameter representing the number of SUs that get resources.

Fig. 4 shows OP of the proposed allocation resource with the variation of d_v value. The resource allocation process considers the target SNR desired by the SU as the first requirement and the interference limit determined by the PU as the second requirement. The resource allocation began with the searching process for subcarriers that met SU requirements; when the system detected a number of d_v subcarriers, it would calculate whether the interference limit determined by PU could still be met. When both conditions were met, SU was allocated to the expected resource. However, SU would not obtain the expected

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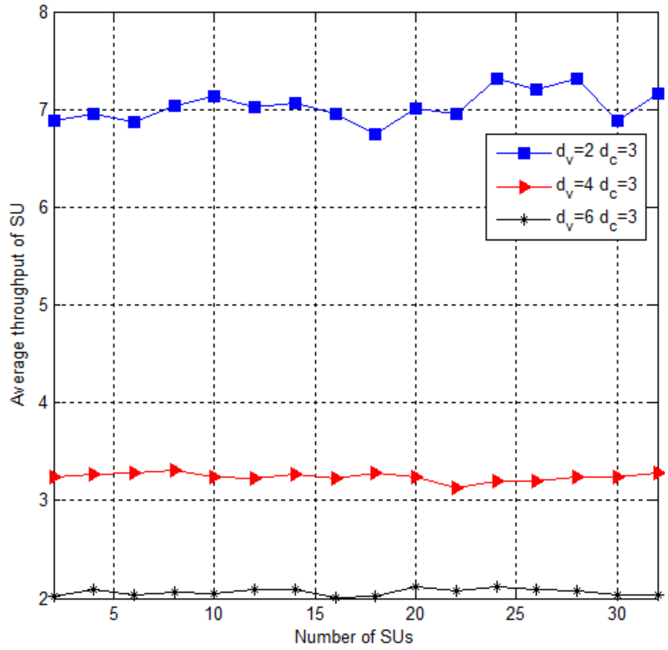

Fig. 5 Average throughput of SU.

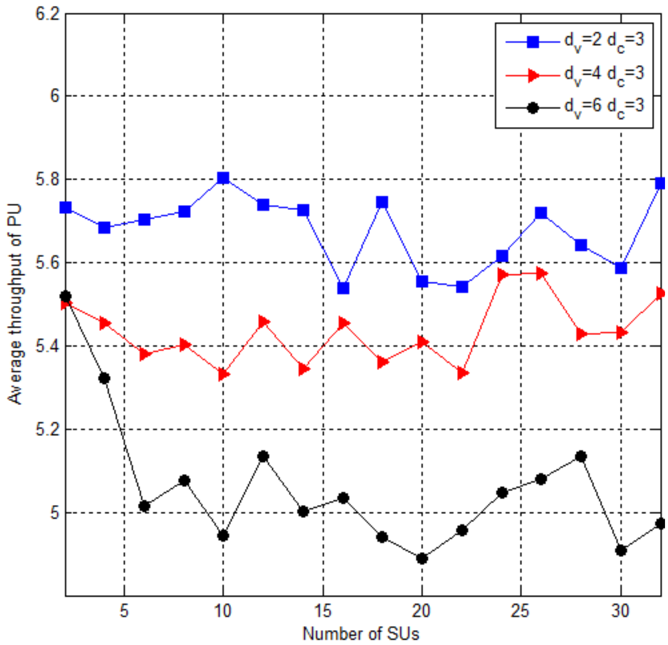

Fig. 6 Average throughput of PU.

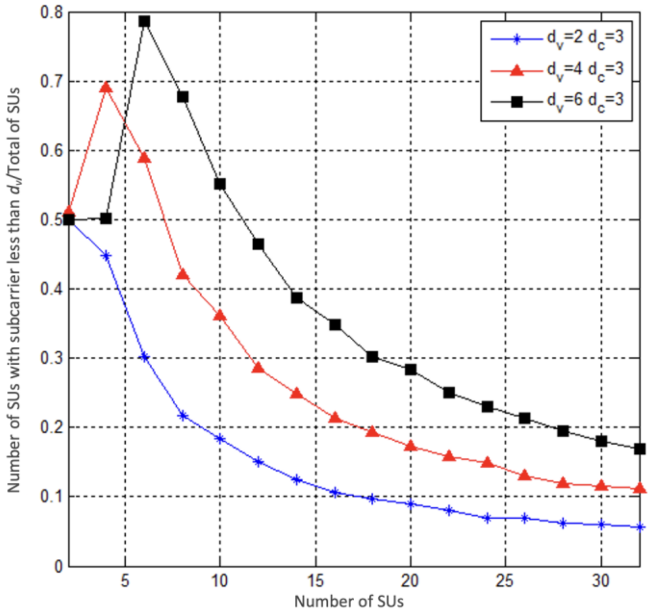

Fig. 7 Ratio of SU obtaining allocation less than d_v subcarrier.

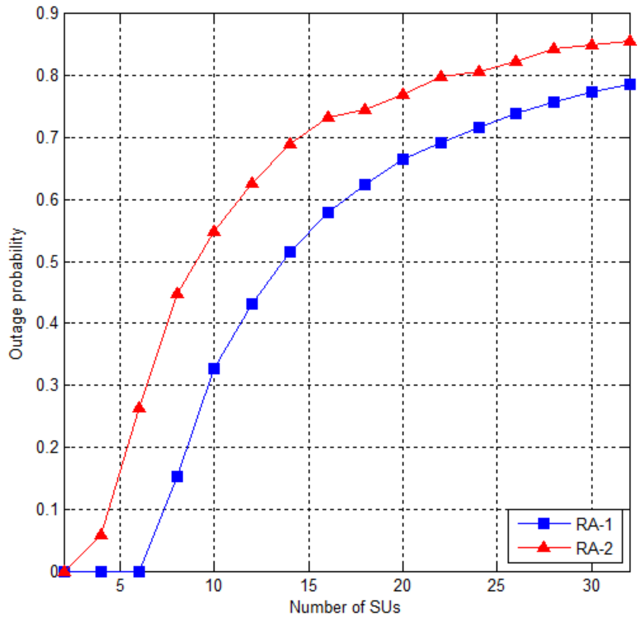

Fig. 8 Comparison of OP.

resources when the two main requirements were not eligible. Fig. 4 shows the effect of variation value of d_v to OP. When the system determined that the number of subcarriers that SU could access was small (marked by a small d_v value), then when SU obtained d_v subcarriers that matched the first requirement but did not meet the second requirement, SU would not obtain the resource allocation on the expected subcarrier. When the d_v value in the system was small, it had a lower chance of obtaining resources than the larger d_v value. Therefore, the small d_v has a higher OP value than the higher value of d_v.

The average throughput values of SU and PU are shown in Fig. 5 and Fig. 6, respectively. These figures show when the d_v parameter is low, the average throughput of PU and SU is higher. This finding is in accordance (4) where the calculation of the throughput value for SU is affected by interference from PU and others SUs accessing the same subcarrier. Although high d_v allowed SU to get resource allocation, the transmission power on each subcarrier used became smaller which was P_{su}/d_v. Hence, it lowered the interference from other SUs. It also applied to the calculation of throughput on the PU where interference would be caused by the SU accessing its subcarrier, but there was no interference from other PUs.

The curve in Fig. 7 shows the ratio of several SUs receiving an allocation which is less than d_v subcarrier to the total SU. In the simulation, a number of SUs accessing the same resource, $d_c=3$, were considered. Due to the fulfillment of the

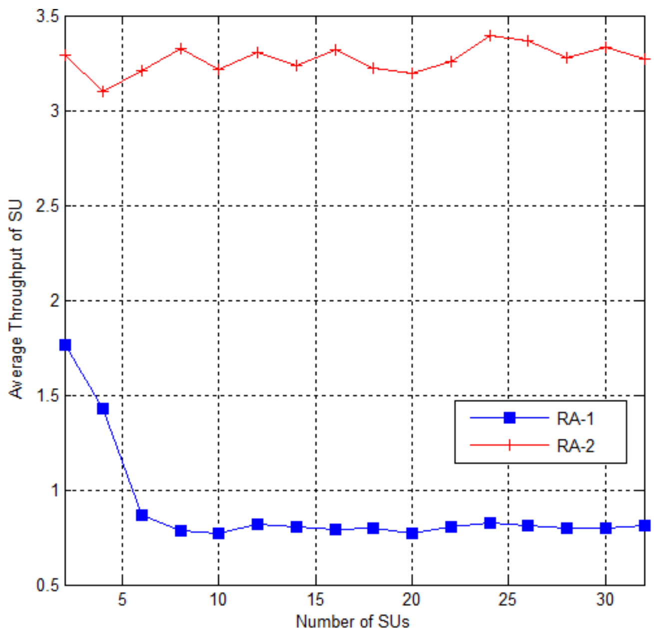

Fig. 9 Comparison of SU's throughput.

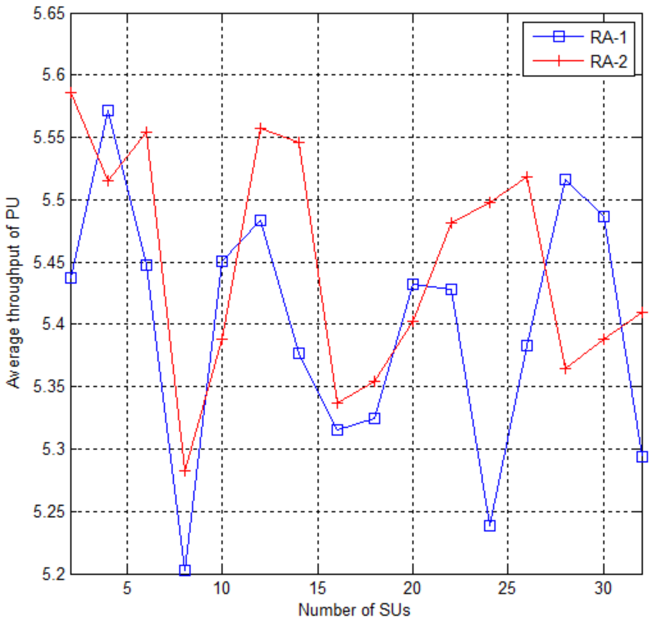

Fig. 10 Comparison of average PU's throughput.

requirements for the number of SU accessing the resource, it can be seen that the larger value of d_v, the greater number of SUs obtaining allocation which is less than the d_v subcarrier. However, referring to Fig. 4 which shows the OP value, it can be seen that the greater the d_v value, the higher the chance for SU to get resource allocation, indicated by a low OP value. This ratio parameter was also influenced by the determination of the d_c value, the amount of SU in the system, and the interference limit determined by the PU and the target SNR desired by the SU.

Fig. 8 shows the comparison of the OP values of the two resource allocation algorithms for $d_v = 4$ and $d_c = 3$. RA-1 is a resource allocation that only considers one requirement in the

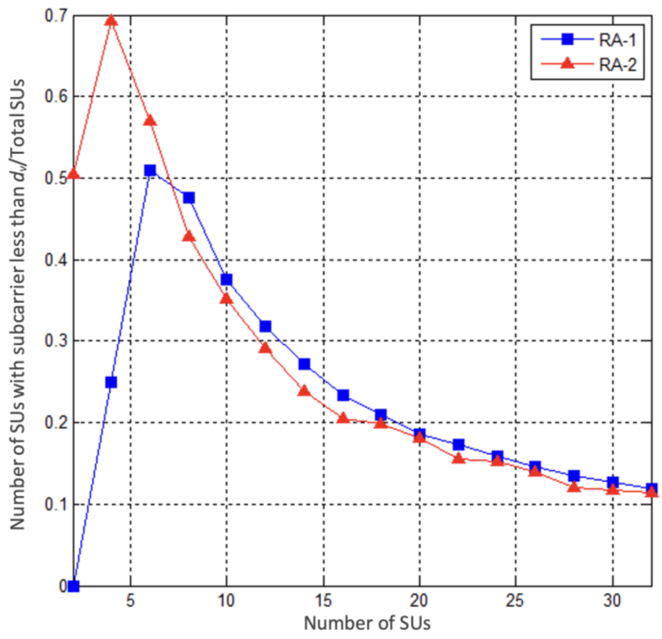

Fig. 11 Comparison of ratio number of SU accessing less than d_v subcarrier.

TABLE II
COMPARISON OF RA-1 AND RA-2

Parameter of Simulation at 20 SUs	RA-1	RA-2
OP	0.66	0.77
Average throughput of SU	0.75	3.30
Average throughput of PU	5.43	5.40
The ratio of SU with allocated resource less than d_v subcarrier	0.19	0.18

resource allocation process, the SNR target by SU and does not heed the interference limit determined by PU. Meanwhile, RA-2 considers two requirements, namely the SNR target of SU and the interference limit required by PU. As shown in Fig. 8, using two requirements in RA-2 cause the outage probability to be higher, in other words, there are more SUs that do not obtain resource allocation for the same d_v and d_c values. Although SU has selected d_v subcarriers that meet the desired requirements, there is a possibility the subcarrier chosen does not meet the second requirement causing SU not to obtain the resource.

The throughput of SU and PU for the comparison of the two resource allocation algorithms is shown in Fig. 9 and Fig. 10, consecutively. The throughput of SU, shown in Fig. 9, suggests that RA-2 has a higher average throughput value for SU. In RA-2, the number of SUs allocated was less than RA-1. Consequently, interference caused by other SUs and perceived by SU was smaller. As for PU throughput, both RA-1 and RA-2 indicated relatively the same value due to the fulfillment of the interference limit requirements desired by PU and would indirectly maintain the value of PU throughput in a particular range.

Fig. 11 shows the comparison of the RA-1 and RA-2 algorithms to the ratio of SU obtaining a subcarrier allocation of less than d_v. According to this figure, in the range of two to seven users, RA-2 has higher number of users acquiring an allocation less than d_v resource. RA-2 has a slightly lower ratio value than RA-1 since the requirements that must be met by RA-2 are more than RA-1. Consequently, it would cause OP to be high while the ratio of the allocated SU was less than d_v, and the subcarrier also increased. As the number of SU in the system increased, RA-1 got lower OP in the end. However, SU was less than then d_v subcarrier.

The comparison between RA-1 and RA-2 is shown in Table II. The number of SU is 20 users, the OP in RA-1 is 0.66, meaning that 66% of the total users do not obtain resource allocation. Meanwhile, in RA-2, 77% of SUs do not get resource allocation. However, in the RA-2, SU has a higher throughput value than the RA-1.

V. CONCLUSION

Based on the simulation results, it can be concluded that resource allocation based on the SNR target of SU is possible for the MC-LDSMA multiple access schemes on the cognitive radio system. Parameter values d_v and d_c will affect the value of OP, average throughput of SU and PU. The increasing value of d_v parameter will decrease the value of OP, average throughput of SU, and PU as well as reduce the number of SU that obtain allocated resources. Combining the SNR target of SU parameters and the interference limit PU will increase the number of SUs that do not get the resource allocation (represented with high OP value) for the same d_c and d_v values.

CONFLICT OF INTEREST

There is no conflict of interest in this paper.

AUTHOR CONTRIBUTION

Conceptualization, Linda Meylani; methodology, Linda Meylani, Nur Andini; software, Linda Meylani, Desti Madya Saputri; validation, Linda Meylani, Nur Andini, Iswahyudi Hidayat; formal analysis, Linda Meylani; resources, Linda Meylani, Desti Madya Saputri; data curation, Linda Meylani; original draft writing, Linda Meylani, Iswahyudi Hidayat; writing-review and editing, Nur Andini; visualization, Desti Madya Saputri; supervision, Linda Meylani.

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