User Clustering and Optimum Bandwidth allocation for Down link Multi-carrier NOMA

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***Abstract*—Multi-carrier Non Orthogonal Multiple Access system is considered a promising technique for future wireless communication systems. MC-NOMA system divides transmission bandwidth into sub-bands and multiple users in each sub-band are served based on power-domain NOMA. This work attempts to find the best clustering scheme that can provide the maximum sum rate for NOMA with unequal bandwidth allocation. We try to improve the system performance by tuning the bandwidth allocated to different clusters to find the best clustering scheme. The analytical results compared and validated using the golden search method reveal that pairing up the best channel gain user with the next best channel gain user with optimal bandwidth allocation gives a better sum rate compared to competitive schemes available in the literature.**

***Index Terms*—Non-Orthogonal Multiple Access(NOMA), Multi-carrier Non Orthogonal Multiple Access (MC-NOMA), Superposition coding (SC), Successive interference cancellation(SIC).**

I. Introduction

NOMA (Non-Orthogonal Multiple Access) is a 5G technique that helps to achieve enhanced spectral efficiency, low latency, and high connectivity [1]. In NOMA, each user operates in the same band and at the same time and the users are distinguished by their power levels which is called as power domain NOMA. In NOMA, users are divided into groups called clusters based on their channel gains. Power is allocated in such a way that the near user, which has better channel gain in the cluster, gets a smaller fraction of power compared to the far user [2]. The signals from the near and far users, which are allocated with different power levels at the transmitter end are multiplexed through a transmission technique called superposition coding. At the receiver end, the successive interference cancellation (SIC) decoding method is employed, where each receiver sequentially decodes and cancels the signals transmitted at the highest power to retrieve the desired signal [3]. The performance of NOMA systems experiences a notable degradation when the signal retrieval process fails during successive interference cancellation (SIC). This outcome is heavily influenced by the power allocation scheme employed among the users in the cluster.

Multi-carrier NOMA (MC-NOMA) is the combined system of Non orthogonal multiple access(NOMA) and Orthogonal frequency division multiple access(OFDMA) [4]. In the MC-NOMA system, the transmission bandwidth is divided into sub-bands, and multiple users in each sub-band are served based on power-domain Non Orthogonal Multiple Access (NOMA). In single carrier NOMA, as the number of users sharing the same transmission increases, error due to decoding also increases. Hence the users are divided into multiple clusters based on their channel conditions. Bandwidth is divided into several orthogonal subbands in such a way that the users in the same cluster share the same sub band.In the context of the NOMA (Non-Orthogonal Multiple Access) system, the two key performance metrics that are commonly evaluated are the sum rate and the success probability. The sum rate is the sum of achieved rates of all the users. The success probability is defined as the probability that all the users decode their requested data successfully [5]. In a conventional NOMA two users are paired to form a cluster. When the number of users served in a cluster increases interference also increases causing a drop in performance. When there are more than two users, the users can be paired in multiple ways for two-user NOMA. As per the results available in the literature [6] the sum rate can be maximized if the best channel gain user is paired up with the worst channel gain user. Existing literature shows that equal bandwidth allocation degrades system performance so there is a need for optimal bandwidth allocation. The novelty in our approach compared to the previous work is that prior studies on sum rate maximization in NOMA have focused on user clustering considering equal bandwidth allocation, whereas our proposal tries to maximize the sum rate by tuning the user clustering and bandwidth allocation without much drop in the success probability. Summarizing the significant contributions of this work, we have the following key highlights:

- Developed a user pair clustering scheme with optimal bandwidth allocation to maximize the sum rate of MC-NOMA system.
- We showed that the user pair clustering scheme with optimal bandwidth allocation maximizes the sum rate of MC-NOMA system without much drop in the success probability compared to the schemes in the literature through analytical results and plots.

II. Related works

This section presents a comprehensive overview of existing research highlighting the necessity of optimal bandwidth allocation in the context of MC-NOMA systems.

In [6], the authors have shown that pairing up the best channel gain user with the worst channel gain user improves the overall sum rate of the users for a given power. So pairing them as one cluster and allocating more fraction of power to the worst channel gain user and less fraction of power to the best channel gain user can be done to achieve the target rate. Target rate can vary according to the requirement of the user's application.

In [7], an optimal power allocation factor for two user NOMA systems is derived by considering bandwidth as unity. Their objective was to maximize the success probability without much drop in sum rate.

In [8] the authors show that OFDMA system can be used to divide the bandwidth of transmission into several sub-bands, such that different groups of users in different sub-bands are served simultaneously with the power-domain NOMA which is referred to as Multi-carrier NOMA.

In MC-NOMA system previous works show that equal bandwidth allocation degrades the performance of MC-NOMA [8]. So there is a need for opportunistic bandwidth allocation along with power.

When the number of users exceeds two there can be more clustering scenarios. In this work we considered a scenario with four users U_1, U_2, U_3, U_4 with distances($d_1 < d_2 < d_3 < d_4$). This implies there are different possibilities for clustering that can be considered as follows:

- (U_1, U_2) (U_3, U_4)
- (U_1, U_3) (U_2, U_4)
- (U_1, U_4) (U_2, U_3)

The primary goal of this work is to find the best clustering scheme with optimal bandwidth allocation that maximizes the sum rate without adversely affecting the success probability for MC-NOMA.

III. Proposed System

Consider a multi carrier NOMA system with K users under the range of transmitting base station (BS). The system model of this work considers the NOMA system with only two users per cluster. Thus the users in the range of BS are paired to form $K/2$ disjoint clusters. Let B be the total bandwidth budget and is divided into $K/2$ orthogonal sub channels. Let B_i, $i \in \{1, 2, ..K/2\}$ be the bandwidth allocated to cluster C_i, then, $\sum_{i=1}^{k/2} B_i = B$. The set of multiplex users on i^{th} sub channel is given I_i, $i \in \{1, 2, ..K/2\}$. The MC-NOMA system uses OFDMA scheme to divide the bandwidth of transmission into several sub-bands. Then $I_i \cap I_j = \phi$ ∀ i, j $\in \{1, 2, ..K/2\}$ Consider S_i as the signal transmitted to cluster C_i. If $0<\alpha_i<0.5$ is the power allocation factor to C_i, then

$$S_i = \sqrt{\alpha P} s_{n_i} + \sqrt{(1-\alpha)P} s_{f_i}, \tag{1}$$

where P is the power transmitted per cluster. The signals corresponding to the far and near user in cluster C_i are denoted by s_{f_i} and s_{n_i} respectively. The power allocation factor α_i is determined based on the channel gains of users in the cluster and their target rate requirements. Let $g_{f_i} < g_{n_i}$ be the channel gains of the far and near user in cluster C_i. Assuming the transmission channel is a Rayleigh distribution with a path loss exponent of $k \geq 2$, the channel gains can be exponentially distributed as $d_{f_i}^{-k}$ and $d_{n_i}^{-k}$, where d_{f_i}, d_{n_i} are the distances for the far user and the near user respectively. Let Z_{f_i} and Z_{n_i} be the signal received by the far user and the near user in i^{th} cluster. Then

$$Z_{f_i} = \sqrt{g_{f_i}} S_i + n_o \tag{2}$$

$$Z_{n_i} = \sqrt{g_{n_i}} S_i + n_o \tag{3}$$

Where n_o is additive white Gaussian noise with zero mean and variance σ^2.

Then the achievable rates for far and near users are given by

$$R_{f_i} = B_i log_2 \left(1 + \frac{g_{f_i}(1-\alpha)P}{g_{f_i}\alpha P + B_i \sigma^2} \right) \tag{4}$$

$$R_{n_i} = B_i log_2 \left(1 + \frac{g_{n_i}\alpha P}{B_i \sigma^2} \right), \tag{5}$$

where σ^2 is the additive white Gaussian noise power at users in cluster C_i. The sum rate for the considered MC-NOMA system is calculated as

$$R_{sum} = \sum_{i=1}^{k/2} (R_{f_i} + R_{n_i}). \tag{6}$$

In this study, we make a simplifying assumption by setting $K = 4$ and using C_i, where $i = \{1, 2\}$. Under this configuration, we create a technique for resource allocation and user clustering that aims to maximize the sum rate. Furthermore, this approach can be expanded to accommodate multiple clusters with varying numbers of users in each cluster. We consider B as the total available system bandwidth with βB as the fraction of bandwidth allocated to cluster C_1, $(1-\beta)B$ as the fraction of bandwidth allocated to cluster C_2.

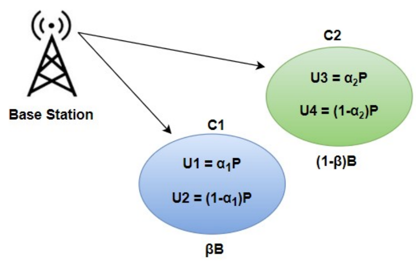

Fig. 1: MC-NOMA with four users, where users U_1 and U_2 are paired to form cluster C_1, U_3 and U_4 are paired to form cluster C_2

A. Optimal Power Allocation to maximize Success Probability

We have introduced a modification to the optimal power allocation factor (α) derived in [7], which maximizes success probability when the bandwidth is fixed to unity. This modification incorporates a bandwidth allocation factor (β) that is now considered and allocated to users within the clusters.

The condition for α_1 to satisfy the target rate requirement for the far user can be derived as follows:

$$R_{f_1} \geq R_{f_1}^{th}$$
$$\Rightarrow \alpha_1 \leq \frac{Pg_{f_1} - \gamma_{f_1}\beta B\sigma^2}{Pg_{f_1}(1+\gamma_{f_1})} \tag{7}$$

The condition for α_1 to satisfy the target rate requirement for the near user can be derived as follows:

$$R_{n_1} \geq R_{n_1}^{th}$$
$$\Rightarrow \alpha_1 \geq \frac{\gamma_{n_1}\beta B\sigma^2}{Pg_{n_1}} \tag{8}$$

where $\gamma_{f_1}^{th} = 2^{R_{f_1}^{th}/(\beta B)} - 1$, $\gamma_{n_1}^{th} = 2^{R_{n_1}^{th}/(\beta B)} - 1$.
Equations (7) and (8) show that the channel gain and target data rate requirements for far users determine the upper bound of α_1, while the channel gain and target rate requirements for near users determine the lower bound of α_1.

Here $R_{f_1}^{th}$ and $R_{n_1}^{th}$ are the target data rates of far and near users in cluster 1.
The expression for the success probability for the far user in cluster 1 is given by:

$$P_{f_1} = P\big(R_{f_1} \geq R_{f_1}^{th}\big)$$
$$= P\left(g_{f_1} \geq \frac{\beta B\sigma^2\gamma_{f_1}}{(P - \alpha_1 P(1+\gamma_{f_1}))}\right) \tag{9}$$

Assuming the transmission channel follows a Rayleigh distribution with a path loss exponent of $k \geq 2$, the channel gain can be modeled as an exponential distribution. In this case, the success probability for the far user in cluster 1 can be expressed as:

$$P_{f_1} = e^{-\Gamma_{f_1}}, \tag{10}$$

where $e^{-\Gamma_{f_1}} = \frac{\beta B\sigma^2\gamma_{f_1}}{d_{f_1}^{-k}(P-\alpha_1 P(1+\gamma_{f_1}))}$.

$$R_{fn_1} = \log_2\left(1 + \frac{(1-\alpha_1)Pg_{n_1}}{\alpha_1 Pg_{n_1} + \beta B\sigma^2}\right). \tag{11}$$

R_{fn_1} is the achievable rate at which near user decodes far user data in cluster 1.
The expression for the success probability for the near user in cluster 1 is given by:

$$P_{n_1} = P\big(R_{fn_1} \geq R_{f_1}^{th}, R_{n_1} \geq R_{n_1}^{th}\big)$$
$$= P\left(g_{n_1} \geq \max\left(\frac{\beta B\sigma^2\gamma_{f_1}}{P - \alpha_1 P(1+\gamma_{f_1})}, \frac{\beta B\gamma_{n_1}}{\alpha_1 P}\right)\right), \tag{12}$$

The success probability of near user in cluster 1 is

$$P_{n_1} = e^{-\Gamma_{n_1}}, \tag{13}$$

where $e^{-\Gamma_{n_1}} = \max\left(\frac{\beta B\sigma^2\gamma_{f_1}}{d_{n_1}^{-k}(P-\alpha_1 P(1+\gamma_{f_1}))}, \frac{\beta B\sigma^2\gamma_{n_1}}{d_{n_1}^{-k}\alpha_1 P}\right)$

The expression for the success probability of two users in cluster 1 is given by

$$P_{success_1} = P_{f_1} \times P_{n_1} = e^{-\left(\Gamma_{f_1} + \Gamma_{n_1}\right)} \tag{14}$$

To get the optimal value of α_1 which maximizes the success probability, it is required to first differentiate $P_{success_1}$ with respect to α_1 and equalize it to zero.

$$\frac{d}{d\alpha_1}P_{success_1} = 0$$
$$\frac{d}{d\alpha_1}e^{-\left(\Gamma_{f_1} + \Gamma_{n_1}\right)} = 0 \tag{15}$$

From equation (15) we get a quadratic equation and the roots of the equation is considered as the expression for optimal power allocation factor for cluster 1 as

$$\alpha_1 = -a_1 \pm \sqrt{{b_1}^2 + a_1 b_1} \tag{16}$$

where $a_1 = \frac{\gamma_{n_1}^{th} d_{f_1}^{-k}}{\gamma_{f_1}^{th} d_{n_1}^{-k} - \gamma_{n_1}^{th} d_{f_1}^{-k}(1+\gamma_{n_1}^{th} d_{f_1}^{-k})}$,
$b_1 = \frac{1}{1+\gamma_{f_1}^{th}}$,
$\gamma_{f_1}^{th} = 2^{R_{f_1}^{th}/(\beta B)} - 1$,
$\gamma_{n_1}^{th} = 2^{R_{n_1}^{th}/(\beta B)} - 1$.

Similarly, for cluster 2, we are allocating $(1-\beta)B$ bandwidth then the expression for optimal power allocation factor for cluster 2 is given by

$$\alpha_2 = -a_2 \pm \sqrt{{b_2}^2 + a_2 b_2} \tag{17}$$

where $a = \frac{\gamma_{n_2}^{th} d_{f_2}^{-k}}{\gamma_{f_2}^{th} d_{n_2}^{-k} - \gamma_{n_2}^{th} d_{f_2}^{-k}(1+\gamma_{n_2}^{th} d_{f_2}^{-k})}$,
$b = \frac{1}{1+\gamma_{f_2}^{th}}$,
$\gamma_{f_2}^{th} = 2^{(R_{f_2}^{th}/((1-\beta)B)} - 1$,
$\gamma_{n_2}^{th} = 2^{(R_{n_2}^{th}/((1-\beta)B)} - 1$.

d_{f_1}, d_{n_1} be the distance of far user and near user of cluster 1 and d_{f_2}, d_{n_2} be the distance of far user and near user of cluster 2 respectively.
The total success probability is denoted as $P_{success}$ is the average success probability of both clusters C_1 and C_2. The power allocation factors, α_1 is allocated to near user and (1-α_1) is allocated to far user in cluster 1. Similarly, α_2 is allocated to near user and (1-α_2) is allocated to far user in cluster 2.

B. Optimal Bandwidth allocation to maximize sum rate

The rate expressions in equations (4) and (5) after considering both optimal power allocation within the two clusters and optimal bandwidth allocation to the two clusters are modified as follows:

The achievable rates of far and near users in cluster 1 are

$$R_{f_1} = \beta B log_2\left(1 + \frac{(1-\alpha_1)Pg_{f_1}}{\alpha_1 Pg_{f_1} + \beta B\sigma^2}\right), \tag{18}$$

$$R_{n_1} = \beta B log_2\left(1 + \frac{\alpha_1 Pg_{n_1}}{\beta B\sigma^2}\right). \tag{19}$$

The sum rate of cluster 1 is given by

$$R_{sum_1} = R_{f_1} + R_{n_1}. \tag{20}$$

The achievable rates of far and near user in cluster 2 are

$$R_{f_2} = (1-\beta)Blog_2\left(1+\frac{(1-\alpha_2)Pg_{f_2}}{\alpha_2 Pg_{f_2}+(1-\beta)B\sigma^2}\right), \quad (21)$$

$$R_{n_2} = (1-\beta)Blog_2\left(1+\frac{\alpha_2 Pg_{n_2}}{(1-\beta)B\sigma^2}\right). \quad (22)$$

The sum rate of cluster 2 is given as

$$R_{sum_2} = R_{f_2} + R_{n_2}. \quad (23)$$

The sum rate of both the clusters is given as

$$R_{sum} = R_{sum_1} + R_{sum_2}. \quad (24)$$

C. Optimal user Clustering to maximize sum rate

Without loss of generality consider the channel gains of users from the base station as $g_1 > g_2 > g_3 > g_4$. In [6], authors discuss the conventional clustering that maximizes the sum rate, which is pairing the best user with the worst user under the range of a base station. But the authors have considered equal bandwidth allocation among the clusters. In this work, we are considering optimal bandwidth allocation as discussed in Section IIIB. We try all the possible combinations of clustering which are

- **CASE 1:** Users U_1 and U_2 are paired to form cluster C_1, Users U_3 and U_4 are paired to form cluster C_2.
- **CASE 2:** Users U_1 and U_3 are paired to form cluster C_1, Users U_2 and U_4 are paired to form cluster C_2.
- **CASE 3:** Users U_1 and U_4 are paired to form cluster C_1, Users U_2 and U_3 are paired to form cluster C_2.

Through detailed analysis, we derive the best clustering scheme for optimal bandwidth allocation that maximizes the sum rate. The proposed scheme is compared with conventional schemes existing in the literature to validate the improved performance in terms of sum rate and success probability.

IV. Results

In this section, we assess the performance of a four-user downlink MC-NOMA system by analyzing its sum rate and success probability. We present analytical results that demonstrate the performance improvement achieved through the proposed optimal bandwidth allocation. Here, we considered three cases for the difference of distance between the users(ΔD=50, 100, 150) from the base station to analyse the above three cases as follows:

- d_1=100m, d_2=150m, d_3=200m, d_4=250m
- d_1=100m, d_2=200m, d_3=300m, d_4=400m
- d_1=100m, d_2=250m, d_3=400m, d_4=550m

Total bandwidth(B)=10 MHz, equal power(P)=500mWatts is allocated to both the clusters. Target rates of 1Mbps is taken for both near and far users in clusters 1, 2.

A. Illustration of performance improvement by optimal alpha

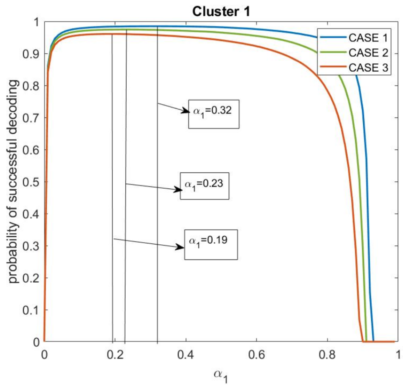

Fig. 2: Success Probability Vs α_1 for three cases of clustering for ΔD=100

In Fig. 2, for cluster 1 the maximum Success probability is obtained at α_1=0.32, 0.23, 0.19 for three cases.

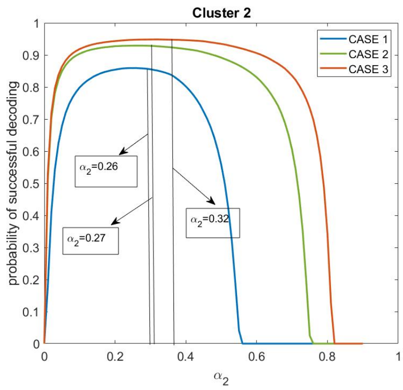

Fig. 3: Success Probability Vs α_2 for three cases of clustering for ΔD=100

In Fig. 3, for cluster 2 the maximum Success probability is obtained at α_2=0.26, 0.27, 0.32 for three cases.

TABLE I: Comparison of α_1, α_2 values obtained from plots and calculations for ΔD=100

Cases	α_1 from plots	α_1 from calculations	α_2 from plots	α_2 from calculations
Case 1	0.32	0.316	0.26	0.2608
Case 2	0.23	0.235	0.27	0.276
Case 3	0.19	0.187	0.32	0.347

From Table I it can be observed that the power allocation factors of cluster 1 and cluster 2 obtained from plots and calculated using equations (16) and (17) are almost the same.

B. Sum rate Maximization

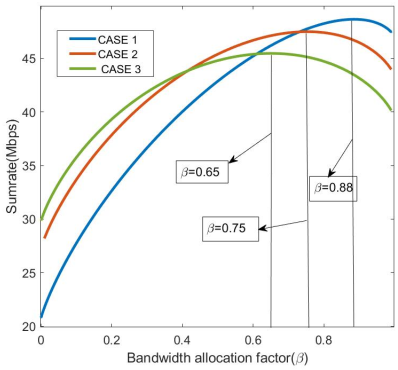

Fig. 4: Sum rate of users Vs β for three cases of clustering for ΔD=100

In the Fig. 4 the maximum sum rate obtained at β=0.88, 0.75, 0.65 for three cases.

TABLE II: Comparison of β values obtained from plots and golden search optimization method for ΔD=100

Cases	β from plots	β from golden search method
Case 1	0.88	0.876
Case 2	0.75	0.761
Case 3	0.65	0.643

We performed the golden search optimization method to find the optimal solution for maximizing the sum rate to validate our optimal bandwidth allocation factor. From Table II it can be observed that the band allocation factor obtained from the analytical plot and golden search optimization method are almost the same.

TABLE III: Case 1 Clustering

	α_1	α_2	β_{opt}	R_{sum}	Rates of Individual Users			
					U_1	U_2	U_3	U_4
ΔD=50	0.3761	0.3490	0.79	52.61	32.97	10.87	6.33	2.44
ΔD=100	0.3162	0.2808	0.88	48.6	31.74	11.18	3.84	1.82
ΔD=150	0.2722	0.2223	0.92	46.28	30.54	11.6	2.5	1.6

TABLE IV: Case 2 Clustering

	α_1	α_2	β_{opt}	R_{sum}	Rates of Individual Users			
					U_1	U_2	U_3	U_4
ΔD=50	0.3110	0.3242	0.68	52.56	26.64	12.17	9.13	4.3
ΔD=100	0.2359	0.2765	0.75	47.5	25.78	8.2	10.05	3.42
ΔD=150	0.1896	0.2536	0.78	43.02	24.22	6.36	9.49	2.93

TABLE V: Case 3 Clustering

	α_1	α_2	β_{opt}	R_{sum}	Rates of Individual Users			
					U_1	U_2	U_3	U_4
ΔD=50	0.2661	0.3745	0.63	51.85	23.66	14.84	4.52	8.88
ΔD=100	0.1876	0.3478	0.65	45.5	21.72	11.06	4.2	8.53
ΔD=150	0.1447	0.3344	0.654	40.6	19.69	9.11	3.89	7.89

In Tables III, IV, and V the values of α_1 and α_2 are obtained from the equations (16) and (17). The values of β_{opt} are obtained from analytical plots as shown in Fig. 2. We can observe that sum rate of case 1 clustering is better than case 2 and case 3 clustering.

We are considering three more cases of difference of distance between the users((ΔD=25, 50, 75) from the base station as follows:

- d_1=50m, d_2=75m, d_3=100m, d_4=125m
- d_1=50m, d_2=100m, d_3=150m, d_4=200m
- d_1=50m, d_2=125m, d_3=200m, d_4=275m

Here we reduced the initial distance from the base station in order to understand the trend.

TABLE VI: Case 1 Clustering

	α_1	α_2	β_{opt}	R_{sum}	Rates of Individual Users			
					U_1	U_2	U_3	U_4
ΔD=25	0.3761	0.3490	0.8	72.36	47.41	10.65	11.38	2.90
ΔD=50	0.3164	0.2699	0.89	68.04	47.18	13.33	5.56	1.94
ΔD=75	0.2723	0.2021	0.93	66.45	46.85	14.95	3.14	1.48

TABLE VII: Case 2 Clustering

	α_1	α_2	β_{opt}	R_{sum}	Rates of Individual Users			
					U_1	U_2	U_3	U_4
ΔD=25	0.3113	0.3227	0.68	71.01	39.75	16.35	10.03	4.88
ΔD=50	0.2364	0.2694	0.78	67.18	39.5	11.45	12.5	3.73
ΔD=75	0.1901	0.2417	0.82	65.89	38.7	9.52	14.5	3.16

TABLE VIII: Case 3 Clustering

	α_1	α_2	β_{opt}	R_{sum}	Rates of Individual Users			
					U_1	U_2	U_3	U_4
ΔD=25	0.2673	0.3684	0.66	70.51	36.88	17.82	4.67	11.13
ΔD=50	0.1889	0.3335	0.71	66.91	35.6	14.2	4.2	12.91
ΔD=75	0.1457	0.3191	0.73	63.05	33.92	12.33	3.95	12.85

From Table. VI, VII, and VIII we can observe the same trend as in Table. III, IV, V i.e. case 1 clustering shows a better sum rate than case 2 and case 3 clustering, and also the sum rate is more when the initial distance from the base station is reduced. This is because as the initial distance reduces channel gain increases. Thus, showing the improvement in system performance.

C. Comparison of three cases of clustering with optimal power allocation and bandwidth allocation with existing clustering scheme with equal bandwidth allocation

TABLE IX: Comparison of user clustering cases for ΔD=100

User clustering	α_1	α_2	B.W allocation factor(β)	R_{sum}	$P_{success}$
$(u_1, u_2)(u_3, u_4)$	0.3162	0.2608	β_{opt}=0.88	48.6	0.9212
$(u_1, u_3)(u_2, u_4)$	0.2359	0.2765	β_{opt}=0.75	47.5	0.9521
$(u_1, u_4)(u_2, u_3)$	0.1876	0.3478	β_{opt}=0.65	45.5	0.9553
Clustering in [6]	0.1840	0.3628	β=0.5	44.8	0.9572

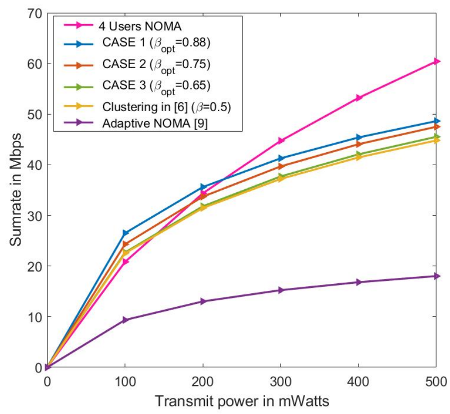

Fig. 5: Comparison of sum rate Vs power for three cases with existing clustering with equal bandwidth allocation, adaptive NOMA and 4 user NOMA for ΔD=100

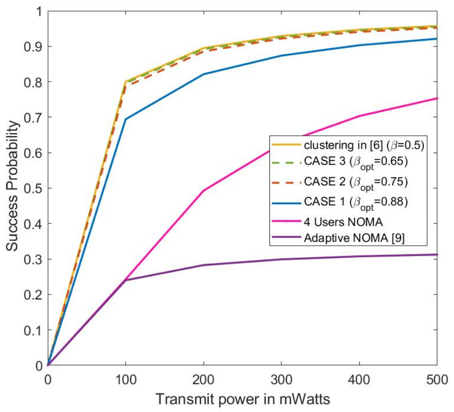

Fig. 6: Comparison of success probability Vs power for three cases with existing clustering with equal bandwidth allocation, adaptive NOMA and 4 user NOMA for ΔD=100 with target rate as 1Mbps

Fig. 5 and Fig. 6 show the sum rate and success probability at transmit power=500mWatts for each cluster and bandwidth=10MHz. From Table IX, Fig. 5, it can be observed that case 1 shows a better sum rate than the remaining cases. It is also observed that our proposed clustering scheme, i.e., case 1 with optimal bandwidth allocation, outperforms the existing clustering method with equal bandwidth allocation (β=0.5) for both clusters (C_1 and C_2) in terms of sum rate. But from Fig. 6, we can see that there is a drop in the probability of successful decoding for case 1 compared to clustering scheme in [6]. Though the success probability of case 1 is lower compared to other cases, it is meeting the target rate requirement of 1Mbps, i.e., the individual rates of all the users shown in Tables III, 1V, V, VI, VII and VIII are more than 1Mbps. Therefore, we can draw the conclusion that the clustering scenario can be selected based on the desired target rate.

In this study, we compared the proposed scheme with the conventional 4-user NOMA and adaptive NOMA-OMA scheme [9]. The adaptive NOMA-OMA scheme optimizes system performance by dynamically choosing users for NOMA or OMA transmission based on their channel conditions. Our approach outperforms the adaptive NOMA-OMA in sum rate and success probability. Based on the example scenario considered in this section, the scheme in [9] demands two OMA transmissions and a single two-user NOMA transmission. The increase in the number of transmissions leads to more subbands but reduced bandwidth per subband. However in conventional 4-user NOMA, the system's sumrate improves because of more available bandwidth per subband. But the success probability decreases due to SIC errors caused by more users per subband. For all these cases of NOMA systems that we discussed in this manuscript, channel state information, which is channel gain and noise, is required as feedback and signalling overhead.

V. CONCLUSION

In this paper, we present a novel approach to determining the optimal bandwidth allocation factor that maximizes the sum rate of a downlink Multi Carrier Non-Orthogonal Multiple Access (MC-NOMA) system, and its effectiveness is analytically validated. The performance of our proposed optimal bandwidth allocation factor is evaluated by comparing the achieved sum rate and the success probability with those obtained using the equal bandwidth allocation employed in the existing literature. Our findings indicate that our proposed scheme i.e., pairing up the best channel gain user with the next best channel gain user with optimal bandwidth allocation yields better system performance in terms of sum rate compared to pairing up the best channel gain user with the worst channel gain user with optimal bandwidth allocation and equal bandwidth allocation and also our proposed scheme outperforms adaptive NOMA system. Moreover, we observe that our proposed user clustering with optimal bandwidth allocation significantly improves the sum rate of the downlink MC-NOMA system while maintaining a satisfactory success probability level.

REFERENCES

[1] L. Dai, B. Wang, Y. Yuan, S. Han, I. Chih-lin, and Z. Wang, "Non-orthogonal multiple access for 5g: solutions, challenges, opportunities, and future research trends," *IEEE Commun. Mag.*, vol. 53, no. 9, pp. 74–81, 2015.

[2] Z. Ding, P. Fan, and H. V. Poor, "Impact of user pairing on 5g nonorthogonal multiple-access downlink transmissions," *IEEE Trans. Veh. Technol.*, vol. 65, no. 8, pp. 6010–6023, 2016.

[3] S. M. R. Islam, N. Avazov, O. A. Dobre, and K.-s. Kwak, "Power-domain non-orthogonal multiple access (noma) in 5g systems: Potentials and challenges," *IEEE Commun. Surveys Tut.*, vol. 19, no. 2, pp. 721–742, 2017.

[4] H. Al-Obiedollah, K. Cumanan, H. B. Salameh, G. Chen, Z. Ding, and O. A. Dobre, "Downlink multi-carrier noma with opportunistic bandwidth allocations," *IEEE Wireless Commun. Lett.*, vol. 10, no. 11, pp. 2426–2429, 2021.

[5] K. N. Doan, W. Shin, M. Vaezi, H. V. Poor, and T. Q. S. Quek, "Optimal power allocation in cache-aided non-orthogonal multiple access systems," in *2018 IEEE International Conference on Communications Workshops (ICC Workshops)*, 2018, pp. 1–6.

[6] M. S. Ali, H. Tabassum, and E. Hossain, "Dynamic user clustering and power allocation for uplink and downlink non-orthogonal multiple access (noma) systems," *IEEE Access*, vol. 4, pp. 6325–6343, 2016.

[7] D. Keerthi, S. P, and D. P. P, "Optimum power allocation for power efficient noma," in *2022 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT)*, 2022, pp. 1–6.

[8] F. Fang, H. Zhang, J. Cheng, and V. C. M. Leung, "Energy-efficient resource allocation for downlink non-orthogonal multiple access network," *IEEE Trans. on Commun.*, vol. 64, no. 9, pp. 3722–3732, 2016.

[9] R. Alhamad, "Adaptive noma/oma for wireless communications," *Signal, Image and Video Processing*, vol. 15, no. 7, pp. 1469–1475, 2021.