An Adaptive User Pairing Strategy for Uplink Non-Orthogonal Multiple Access

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***Abstract*—Non-orthogonal multiple access (NOMA) is considered an important candidate for the next-generation cellular networks to address the issue of exponentially growing data traffic from technologies like the Internet of Things (IoT). Efficient user pairing between multiple users is needed to enhance the capacity of uplink NOMA systems, and this paper investigates a user pairing strategy that enhances the capacities of a cell for uplink NOMA. In general, NOMA separates nodes into two equally-sized groups where half of nodes with the best channel conditions are allocated to one group, while the other half of nodes are allocated to the other group. Then, NOMA pairs each node in one group with another node in the other group. First, we investigate an efficient pairing scheme that maximizes the sum capacity for the uplink NOMA system, with an even number of nodes, i.e. when there is an equal number of cellular users in each group. An additional problem arises when there is an odd number of nodes, and the number of users in one group is thus one larger than in the other, leaving one node potentially unpaired. Instead of using regular OMA for the unpaired node, we propose an efficient adaptive user pairing strategy where the unpaired node is allowed to pair with one of the other pairs, forming a cluster of three nodes. The objective of our proposed scheme is to find the best pair of nodes to serve the unpaired node in order to increase the overall sum capacity. Moreover, the impact of perfect and imperfect successive interference cancellation (SIC) is studied on the user pairing strategy for uplink NOMA systems. Numerical results verify the effectiveness of our proposed adaptive user pairing strategy over the user pairing scheme utilizing conventional NOMA and OMA schemes.**

***Index Terms*—NOMA, User pairing, Uplink, Sum capacity, Adaptive, Internet of Things.**

I. INTRODUCTION

The exponential growth in the data traffic resulting from technologies like the Internet of Things (IoT) has been phenomenal over the last decade [1]. It is expected that the global data traffic will reach up to 175 trillion gigabytes, and more than 80 billion IoT devices will be connected to the Internet by 2025 [2]. Therefore, the next-generation of cellular networks are confronted with a challenge to support massive data traffic and connectivity requirements of the devices [3]. To support these requirements, non-orthogonal multiple access (NOMA) is being considered as a promising candidate for the next-generation of cellular networks [4] [5]. NOMA can support multiple users to transmit data using the same frequency, time, and code [6]. Specifically, in power domain NOMA, multiple user signals are superposition coded with different power levels, and they can transmit data using the same frequency band. The users with better channel conditions perform successive interference cancellation (SIC) of the weak channel users to decode their own signals [7]. Users can usually be divided into multiple clusters, and each cluster can be composed of several users. Users implement NOMA within each cluster, while orthogonal bandwidth resources are allocated to different clusters [8]. These users in a cluster are in a pair forming a two-user cluster.

An efficient user pairing strategy between the two users in a cluster is needed to enhance the capacity of NOMA systems. Usually, a high capacity gain can be achieved if the two users in a cluster have a significant disparity in channel gain [9]. For an even numbers of the users around the base station (BS), two users can form a cluster for user pairing. However, a problem arises in user pairing when there are an odd numbers of users around the BS. In such a scenario, if pairing between the two users is performed then, one user will remain unpaired.

A user pairing algorithm with SIC in a NOMA system is proposed in [10]. The authors presented the channel state sorting pairing and the user difference selecting access algorithm. However, the unpaired user is assigned resources individually in their proposed algorithms. Furthermore, the work in [11] presents a uniform channel gain difference pairing and hybrid pairing scheme in which the cell mid users are accommodated by maintaining a relatively uniform channel gain difference between in-pair users of all pair. A fast proportional fairness (PF) scheduling based user pairing and a power allocation algorithm are proposed in [12]. The idea is to form user pairs around the users with the highest PF metrics with a fixed power allocation. Two user pairing algorithms based on neighbor search methods, specifically the hill climbing and the simulated annealing, are proposed in [13]. However, [11], [12] and [13] considered even number of users in their proposed algorithms. For a non-uniform distribution of users, a virtual pairing scheme in the NOMA system is proposed in [14]. The authors considered that a cell-centered user could be paired with two cell edge users provided they have similar channel gain. The authors in [15] extend the model presented in [14] to multi-user multiple inputs multiple out downlink channels. The authors in [16] proposed a user pairing strategy where the performance of a cell edge user is improved with the help of pairing with two cell center users.

These works mainly concentrated on the user pairing for downlink NOMA. There are considerably fewer published studies of user pairing in uplink NOMA. In downlink NOMA, the strong channel users achieve throughput gains by successively decoding and cancelling the messages of the weak channel users, prior to decoding their own signals. However, in uplink NOMA, the BS successively decodes and cancels the messages of strong channel users before decoding the signals of weak channel users to enhance the throughput of weak channel users [17]. A comprehensive difference between uplink and downlink NOMA is given in [18]. A user pairing scheme based on channel quality indicator for uplink NOMA is presented in [19]. A framework to analyze multi-cell uplink NOMA systems is presented in [20]. A user selection and power allocation for the uplink NOMA beamforming system is presented in [21]. However, these models all considered an even number of $2N$ users in their system model. When there is an odd number of $2N+1$ users around the BS, we will end up with one user who will remain unpaired. Such unpaired users cannot be paired in another cluster as it will create an inter-set interference from the low/weak channel gain user. Usually, the unpaired user can be served through orthogonal multiple access (OMA). Using the conventional NOMA (C-NOMA) technique, the unpaired user can be grouped together in a cluster, if two users can be paired and served through NOMA, while the other user will be served through OMA. It is obvious that the performance of the latter is better in terms of capacity as compared to using only OMA. The objective of this paper is to propose and analyze a scheme that will be able to serve the unpaired user by adapting it into one of the paired clusters and thereby increase the overall capacity. Moreover, finding the right cluster for the unpaired user is also important so that the overall capacity can be increased. Therefore, to address these issues, we propose an adaptive user pairing scheme for uplink NOMA systems.

The principal contributions of this paper are as follows:

- First, a fundamental study of user pairing strategy that enhances the capacities of a cell for uplink NOMA is investigated for even numbers of users around the BS.
- Then for uneven distribution of users around the BS, an efficient Adaptive user pairing strategy for uplink NOMA systems is proposed in order to accommodate the unpaired user into the formed clusters. Our proposed scheme finds the right paired cluster to serve the unpaired user by accommodating it so as to increase the overall sum capacity.
- We also study the effect of perfect SIC (pSIC) and imperfect SIC (ipSIC) on the proposed Adaptive user pairing strategy for uplink NOMA systems.
- We demonstrate the effectiveness of our proposed Adaptive user pairing strategy over the user pairing scheme using conventional NOMA and OMA schemes.

The remainder of this paper is as follows. In Section II, we present the system model. User Pairing in Uplink NOMA for the even distribution of users in the group is studied in Section III. Our proposed Adaptive user pairing strategy for uplink NOMA is explained in Section IV. Simulation results and discussions are presented out in Section V. Finally, Section VI concludes the paper along with future work.

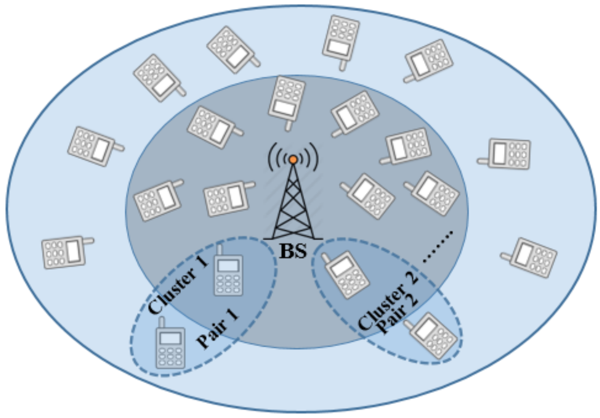

Fig. 1: Generic Reference System Model for User Pairing in Uplink NOMA

II. System Model

A generic reference system model for user pairing in uplink NOMA is shown in Fig. 1. It consists of a single cell uplink NOMA system in a circular cellular region of radius R with a base station (BS) at the center. In this uplink scenario, there are a total number of N users communicating with the BS. Note that, N can be even or odd. We assume that each of the users is equipped with a single antenna. We have also assumed that the channel state information (CSI) is perfectly known. All the wireless channels are subject to the independent Rayleigh flat fading plus additive white Gaussian noise (AWGN). We have also assumed that each user is ordered according to their channel quality, i.e., $|h_1|^2 > |h_2|^2 > |h_3|^2 > .....|h_N|^2$ with $|h_1|^2$ representing the cell center user with the highest channel gain. Here, h_1, h_2, $h_3 \dots h_N$ are denoted as channel coefficients where $h_i \sim CN(0, \lambda_{h_i} = d_i^{-v})$, d_i is the distance between BS and i^{th} user in the cell, λ_{h_i} is the variance and v is the path loss exponent, $i = 1, 2, \dots N$.

The information signal received by the BS is given by:

$$y = \sum_{i=1}^{N} \sqrt{a_i P} H_i s_i + n_i \tag{1}$$

where P is the total transmit power, a_i is the NOMA power allocation coefficient in the range [0 1] such that $\sum_{i=1}^{n} a_i = 1$, $n_i \sim CN(0, \sigma^2)$ represents the complex AWGN with zero mean and variance σ^2 of the i^{th} user, H_i is the channel matrix of the i^{th} user and s_i is the message signal of the i^{th} user.

III. User Pairing in Uplink NOMA

Without the loss of generality, we have assumed that two users form a pair, as shown in Fig. 1, forming a number of $L = \frac{N}{2}$ user pairs, i.e. $Cluster_1, Cluster_2 \dots Cluster_L$. If the available bandwidth for the system is B, then the bandwidth B is divided into $\frac{B}{L}$ parts and allocated to each L user pairing clusters.

The information signal received by the BS is given by:

$$y_{BS} = (H_1 x_1 + H_2 x_2) + n \tag{2}$$

where $H_1 = [h_{1,1}, h_{2,1}, \dots h_{L,1}]$ are the channel matrices and $x_1 = [\sqrt{a_{1,1}} s_{1,1}, \sqrt{a_{2,1}} s_{2,1}, \dots \sqrt{a_{L,1}} s_{L,1}]$ are the signal vector of the users having strong channel conditions with $a_{1,1}, a_{2,1}, \dots a_{L,1}$ being the power allocation factors. Similarly, $H_2 = [h_{1,2}, h_{2,2}, \dots h_{L,2}]$ are the channel matrices and $x_2 = [\sqrt{a_{1,2}} s_{1,2}, \sqrt{a_{2,2}} s_{2,2}, \dots \sqrt{a_{L,2}} s_{L,2}]$ are the signal vector of the users having weak channel conditions with $a_{1,2}, a_{2,2}, \dots a_{L,2}$ being the power allocation factors.

In the uplink NOMA, the received signal power, which corresponds to the user with strongest channel condition, is likely to be the strongest at the BS. Hence, this signal is first decoded at the BS, and it experiences interference from all users having comparatively weaker channels in the cluster. The transmission of the highest channel gain user experiences interference from all of the users within its cluster, while the transmission of the lowest channel gain user experiences zero interference from the users in its cluster in the case of perfect SIC (pSIC).

Assuming pSIC and considering $R_{u,1}$ and $R_{v,2}$ are the data rate of u^{th} user in the strong set and v^{th} user in the weak set, then the achievable data rate can be calculated respectively as:

$$R_{u,1}^{pSIC} = \frac{B}{L} \log_2 \left(1 + \frac{a_{u,1}|h_{u,1}|^2}{a_{v,2}|h_{v,2}|^2 + \frac{1}{\rho}}\right) \tag{3}$$

$$R_{v,2}^{pSIC} = \frac{B}{L} \log_2 \left(1 + a_{v,2}\rho|h_{v,2}|^2\right) \tag{4}$$

where $\rho = \frac{P}{\sigma^2}$ represents the transmit SNR, $a_{u,1}$ and $a_{v,2}$ represents the power allocation coefficient of the u^{th} and v^{th} user respectively.

The total achievable data rate of the system under pSIC can be calculated by:

$$R_{sum}^{pSIC} = \sum_{u=1}^{L} R_{u,1}^{pSIC} + \sum_{v=1}^{L} R_{v,2}^{pSIC} \tag{5}$$

In uplink NOMA, the BS is believed to be able to correctly decode and cancel near user signal as explained by Equations 3 and 4. However, due to different factors such as bad pairing between the users, hardware limitation, channel estimation, and power allocation of the paired users causes interference on the SIC process. Thus, in such a scenario, the achievable data rate under imperfect SIC (ipSIC) can be calculated as [19]:

$$R_{u,1}^{ipSIC} = \frac{B}{L} \log_2 \left(1 + \frac{a_{u,1}|h_{u,1}|^2}{a_{v,2}|h_{v,2}|^2 + \frac{1}{\rho}}\right) \tag{6}$$

$$\begin{aligned} R_{v,2}^{ipSIC} &= \frac{B}{L} \log_2 \left(1 + \frac{a_{v,2}|h_{v,2}|^2}{\frac{1}{\rho} + \xi}\right) \\ &= \frac{B}{L} \log_2 \left(1 + \frac{\rho a_{v,2}|h_{v,2}|^2}{1 + \rho\xi}\right) \end{aligned} \tag{7}$$

Algorithm 1 User Pairing Scheme for Uplink NOMA

Input: N number of users around the BS. $N = 2L$ is even.
Output: User pairing with optimal cell capacities.
Calculate the channel gain of each of the user around the BS based on their distance.
if Number of users are even **then**
  Sort each of the users into the High Channel Gain User and Low channel Gain User group in descending order.
  Form a cluster of two users by pairing users from each group forming a L user pairs.
  Cluster can be formed by paring the first user of the High Channel Gain User group with the first user of Low Channel Gain User group, and so on through High-High channel gain users pairing scheme.
  Cluster can also be formed by paring the first user of the High Channel Gain User group with the last user of Low Channel Gain User group and so on through High-low channel gain users pairing scheme.
  Calculate total achievable rate for both High-High and High-low channel gain users pairing scheme for NOMA under pSIC and ipSIC using Equations 5 and 8.
end if
End of Algorithm 1

where ξ denotes the residual interference due to imperfect SIC.

The total achievable data rate of the system under ipSIC can be calculated by:

$$R_{sum}^{ipSIC} = \sum_{u=1}^{L} R_{u,1}^{ipSIC} + \sum_{v=1}^{L} R_{v,2}^{ipSIC} \tag{8}$$

A. High-High Channel Gain Users Pairing Scheme

In this scheme, first, the N randomly distributed users around the BS are sorted according to the channel quality which is based on the channel matrix and distance from the BS, i.e., $|h_1|^2 > |h_2|^2 > |h_3|^2 > .....|h_N|^2$ with $|h_1|^2$ representing the cell center user with the highest gain. Then the users are divided into two sets: High Gain Set and Low Gain Set such that each set gets the half number of users ordered by their channel gain i.e., High Gain Set $= [h_1, h_2, \dots h_{\frac{N}{2}}]$ and Low Gain Set $= [h_{\frac{N}{2}+1}, h_{\frac{N}{2}+2} \dots h_N]$. Note that in each of these set, users are sorted in descending order sequence where h_1 is representing the highest channel gain of the user in High Gain Set, whereas $h_{\frac{N}{2}+1}$ is representing the highest channel gain of a user in Low Gain Set. Now, the pairing is done between these High Gain Set and Low Gain Set by selecting the corresponding highest channel gain user from each set such that user with channel h_1 is paired with the users with channel $h_{\frac{N}{2}+1}$, a user with channel h_2 is paired with the user with channel $h_{\frac{N}{2}+2}$ and so on.

B. High-Low Channel Gain Users Pairing Scheme

Similar to High-High channel gain users pairing scheme as explained above, in this scheme, the pairing is done

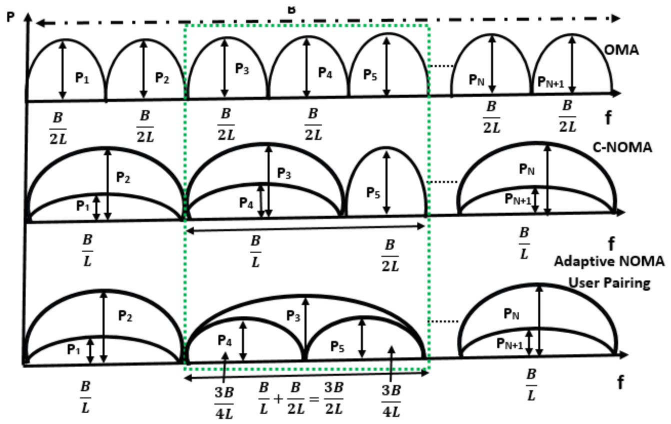

Fig. 2: Conventional OMA, NOMA and Proposed Adaptive User Pairing Scheme for Uplink NOMA

between these High Gain Set and Low Gain Set by pairing the highest channel gain user from the High Gain Set with the corresponding lowest channel gain user from the Low Gain Set such that user with channel h_1 is paired with the user with channel h_N, a user with channel h_2 is paired with the user with channel h_{N-1} and so on.

A pseudo-code for High-High channel gain users and High-Low channel gain users pairing scheme is given in Algorithm 1.

IV. Adaptive User Pairing Scheme for Uplink NOMA

In the above two pairing schemes, we considered that the pairing is done between two High-High channel gain users and High-Low channel gain users where the assumption is that the users are evenly distributed between those High-High channel gain user group and High-Low channel gain user group. However, the users around the BS may not be evenly distributed. In such cases, we will have users who will be left alone and thus cannot be paired. Such unpaired users cannot be paired in another cluster as it will create an inter-set interference from the low/weak channel gain user. The objective of our Adaptive user pairing scheme is to serve the unpaired user by adapting it into the paired cluster and increase the overall capacity. Also, finding the right cluster for the unpaired user is also important so that the overall capacity can be improved. Therefore, to address these issues, we propose an Adaptive user pairing scheme for uplink NOMA systems.

We named our scheme as an Adaptive user pairing scheme as in our scheme, the paired cluster is able to adapt or accommodate the unpaired user and hence forming a three user cluster from the two user cluster. The pseudo-code of our proposed algorithm is shown in Algorithm 2. In our scheme, if the number of users is even then the users are paired according to High-High channel gain users pairing scheme and High-Low channel gain users pairing scheme as explained in the previous section. If the total number of users is odd, then the two users form a pair or cluster first as $Cluster_1, Cluster_2 \dots Cluster_L$, and the remaining unpaired user will be grouped into a cluster where its channel gain difference is maximum compared to other grouped user in that cluster.

Assume that there are an odd number of users $(2L+1)$ around the BS. Thus, by following High-High channel gain users pairing scheme and High-Low channel gain users pairing scheme, each user can be grouped into $Cluster_1, Cluster_2 \dots Cluster_L$. The unpaired user will check or compare its channel gain to find where the difference is maximum to each of the paired users in the cluster. If the unpaired user finds that its channel gain difference in the $Cluster_i$ is maximum, then it can be adapted or accommodated to this cluster and thus forming a three user group cluster. It should be noted that in the $Cluster_i$, out of three users, one of the users will be high gain users, and the other two users will use the same power allocation. For the newly admitted user in the $Cluster_i$, we can serve two users by using NOMA and the third user by using OMA represented by C-NOMA, as shown in Fig. 2. The high gain user among these three users in the $Cluster_i$ will receive interference from this newly added user and from the other already paired user while performing SIC at the BS. Using our Adaptive NOMA user pairing strategy, the high channel gain user can be paired with low channel gain user and the newly added unpaired user in the $Cluster_i$ if they do not share a common bandwidth. Here, the high channel gain user can use the entire bandwidth that has been allocated to low channel gain user and newly added unpaired user in the $Cluster_i$.

For the convenience of explanation, as shown in Fig. 2, let us suppose that there are L user pairs where each cluster with two users is served through NOMA, and thus it is allocated $\frac{B}{L}$ bandwidth. Each user using OMA is thus allocated $\frac{B}{2L}$ bandwidth. After user pairing of High-Low channel gain users, there will be one unpaired user (let's say UE_5), which has to be accommodated in the already formed cluster. Now, the unpaired user UE_5 will check its channel gain difference with the other users in each of the cluster. Let us suppose that the unpaired user found that in $Cluster_2$ with users, let's say UE_3 and UE_4 (marked in a green box in Fig. 2); its channel gain difference is maximum with each of the user. Thus, the unpaired user UE_5 will be added to the $Cluster_2$ which has now a total number of three users with bandwidth $\frac{B}{L}$ allocated for UE_3 and UE_4 NOMA user pair and $\frac{B}{2L}$ for UE_5 unpaired user. Using conventional NOMA (C-NOMA) technique, the UE_3 and UE_4 can be served through NOMA, and UE_5 can be served through OMA. However, we still want to explore if adding such an unpaired user in the cluster can achieve capacity enhancement compared to C-NOMA. It should be noted that the total bandwidth allocated for the $Cluster_2$ is $\frac{3B}{2L}$ $(\frac{B}{L}+\frac{B}{2L})$. Using our Adaptive-NOMA user pairing scheme, a high gain user (lets say UE_3) can be paired with both of the users UE_4 and UE_5 in the $Cluster_2$ provided that these two user pairing do not share a common bandwidth i.e., $B_{3,4} \cap B_{3,5} = \varnothing$. However, UE_3 user can use the entire bandwidth, i.e. $\frac{3B}{2L}$ that has been allocated to the $Cluster_2$.

Now, the user pairs UE_3-UE_4 and UE_3-UE_5 can divide the resource block into two halves, i.e., $\frac{3B}{4L}$ considering the user fairness and use them accordingly.

For other paired clusters, the achievable data rate will be the same as discussed in Section III. We will now focus on the achievable data rate of the $Cluster_2$ with three users UE_3, UE_4, and UE_5.

A. Achievable Data Rate for Adaptive User Pairing Scheme

The achievable data rate of UE_4 of UE_3-UE_4 pair in the $Cluster_2$ with pSIC can be calculated as:

$$R_{UE_4}^{pSIC} = \frac{3B}{4L} \log_2 \left(1 + a_4 \rho |h_4|^2\right) \tag{9}$$

Similarly, the achievable data rate of UE_5 of UE_3-UE_5 pair in $Cluster_2$ with pSIC can be calculated as:

$$R_{UE_5}^{pSIC} = \frac{3B}{4L} \log_2 \left(1 + a_5 \rho |h_5|^2\right) \tag{10}$$

Now, the achievable data rate of UE_3 in $Cluster_2$ for UE_3-UE_4 pairing and UE_3-UE_5 pairing with pSIC can be calculated as:

$$R_{UE_3}^{pSIC} = \frac{3B}{4L} \log_2 \left(1 + \frac{a_3|h_3|^2}{a_4|h_4|^2 + \frac{1}{\rho}}\right) + \frac{3B}{4L} \log_2 \left(1 + \frac{a_3|h_3|^2}{a_5|h_5|^2 + \frac{1}{\rho}}\right) \tag{11}$$

The total achievable data rate of the $Cluster_2$ under pSIC can be calculated by:

$$R_{Cluster_2}^{pSIC} = R_{UE_3}^{pSIC} + R_{UE_4}^{pSIC} + R_{UE_5}^{pSIC} \tag{12}$$

The achievable data rate of UE_4 with ipSIC can be calculated as:

$$R_{UE_4}^{ipSIC} = \frac{3B}{4L} \log_2 \left(1 + \frac{a_4 \rho |h_4|^2}{1 + \rho \xi}\right) \tag{13}$$

Similarly, the achievable data rate of UE_5 with ipSIC can be calculated as:

$$R_{UE_5}^{ipSIC} = \frac{3B}{4L} \log_2 \left(1 + \frac{a_5 \rho |h_5|^2}{1 + \rho \xi}\right) \tag{14}$$

Now, the achievable data rate of UE_3 with ipSIC can be calculated as:

$$R_{UE_3}^{ipSIC} = \frac{3B}{4L} \left(\log_2 \left(1 + \frac{a_3|h_3|^2}{a_4|h_4|^2 + \frac{1}{\rho}}\right) + \log_2 \left(1 + \frac{a_3|h_3|^2}{a_5|h_5|^2 + \frac{1}{\rho}}\right)\right) \tag{15}$$

The total achievable data rate of the $Cluster_2$ under ipSIC can be calculated by:

$$R_{Cluster_2}^{ipSIC} = R_{UE_3}^{ipSIC} + R_{UE_4}^{ipSIC} + R_{UE_5}^{ipSIC} \tag{16}$$

Now, the total achievable data rate for our adaptive user pairing scheme for uplink NOMA under pSIC and ipSIC can be calculated respectively as:

$$R_{Ada}^{pSIC} = R_{sum}^{pSIC}{}_{L \notin 2} + R_{Cluster_i}^{pSIC}{}_{i \in 2} \tag{17}$$

$$R_{Ada}^{ipSIC} = R_{sum}^{ipSIC}{}_{L \notin 2} + R_{Cluster_i}^{ipSIC}{}_{i \in 2} \tag{18}$$

Algorithm 2 Adaptive User Pairing Scheme for Uplink NOMA

Input: N number of users around the BS. $N = 2L + 1$ is odd.

Output: Adaptive user pairing with optimal cell capacities.

if Number of users is odd **then**
    For $2N$ users, form a cluster of two users by pairing users from each group forming a L user pairs through Step 5 and Step 6 of **Algorithm 1** and keep the single left user unpaired.
    Compare and check the channel gain difference of the unpaired user with each of the users in L clusters.
    if Channel gain difference of the unpaired user is maximum in the $Cluster_i$ **then**
        Accommodate the unpaired user in the i^{th} cluster by forming a three user cluster.
        Out of three users, one user will be a high channel gain user, and two users will be low gain users.
        Pair the high channel gain user with low channel gain user and newly added user on a condition that they do not share a common bandwidth.
        Allow high channel gain user to use the entire bandwidth of the $Cluster_i$ and two other users to share the bandwidth among themselves based on user fairness.
        Calculate the achievable rate of the $Cluster_i$ under pSIC and ipSIC by using Equations 12 and 16.
        Calculate total achievable rate for Adaptive User Pairing Scheme for Uplink NOMA under pSIC and ipSIC by using Equations 17 and 18.
        Compare the results with conventional NOMA user pairing and OMA schemes.
    end if
end if
End of Algorithm 2

V. Simulation Results and Discussions

In this section, we present the simulation results for our proposed Adaptive user pairing scheme for uplink NOMA. We have used the simulation parameters listed in Table I unless stated otherwise. MATLAB is running the Monte-Carlo simulations by averaging over 10^5 random realizations of Rayleigh fading channels to get the simulation results. Users are randomly distributed around the BS. Each of the user's distance from the BS is normalized to unity.

In Fig. 3, for $N = 20$ number of users in a cell where each pair consists of two users, i.e., $L = \frac{N}{2} = 10$, we see that the cell capacities is higher for the High-Low channel gain users pairing scheme than for the High-High channel gain users pairing scheme for both the pSIC and the ipSIC cases. However, the difference is not much. Clearly, it can be seen that the SIC imperfection has a dominant effect on the cell capacities of the UL NOMA system. For ρ greater than 20 dB, we observe that cell capacities for both the High-High,

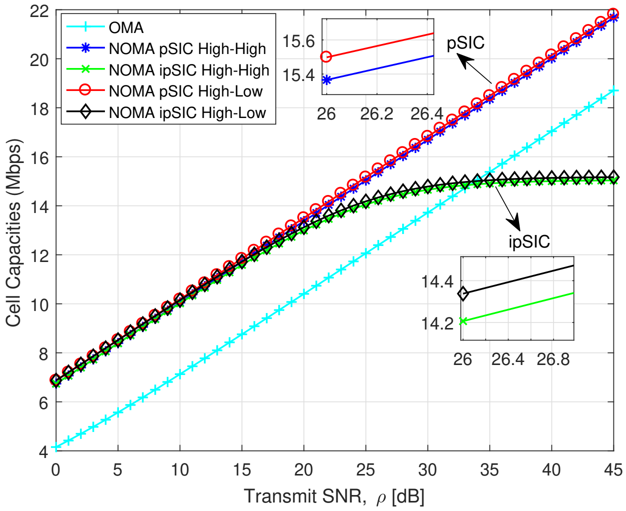

Fig. 3: Cell Capacities of User Pairing in Uplink NOMA

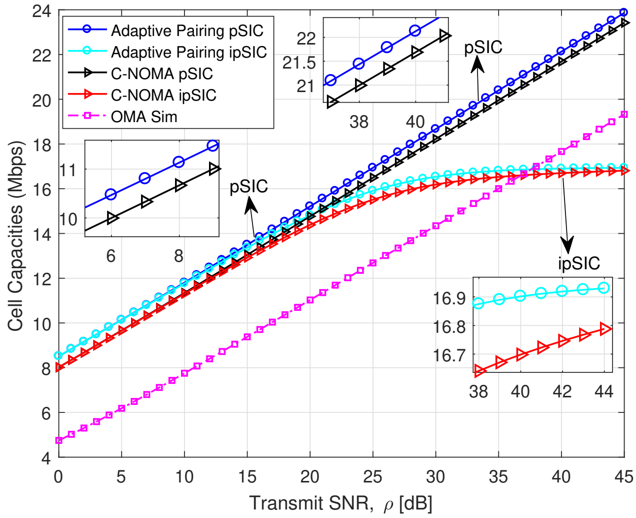

Fig. 4: Adaptive User Pairing with 21 Users for Uplink NOMA

and the High-Low channel gain users pairing schemes start deteriorating, and they remain saturated for ρ greater than 28 dB. Since SIC imperfection leads to capacity degradation, we can see that the cell capacities for OMA actually exceed the cell capacities for ipSIC NOMA for ρ greater than 33 dB.

Since the High-Low channel gain users pairing scheme has higher capacities compared to the High-High channel gain users pairing scheme, as shown in Fig. 3, we have used it for the initial pairing in our simulation in order to form the two-user clusters for our Adaptive user pairing scheme. In Fig. 4, for an uneven number of users in a cell, i.e., $N = 21$, we see that our Adaptive user pairing scheme has higher cell capacities than C-NOMA and OMA schemes for all values of ρ. Also, ipSIC tends to lower the cell capacities, and similar observations can be observed, as in Fig. 3. Our proposed Adaptive user pairing scheme finds the right cluster for the unpaired user and accommodates the unpaired user in that cluster so that the overall cell capacities is improved compared to the C-NOMA and OMA schemes.

The cluster$_i$ sum capacities for three user cluster when $N = 21$ as found through our Adaptive user pairing scheme is shown in Fig. 5. The difference in the overall $cluster_i$ sum capacity for the Adaptive user pairing scheme, C-NOMA, and OMA scheme is clearly visible against all ρ values. Since our proposed adaptive user pairing approach aims to find a suitable cluster to accommodate the unpaired user with the paired user, the sum capacity of $cluster_i$ is significant, which can contribute to the improvement of overall sum capacity for our proposed Adaptive user pairing scheme as shown in Fig. 4.

In Fig. 6, we intend to check the performance of our Adaptive user pairing scheme with more number of users. We observe that the overall cell capacities are improved with more number of users in a cell. However, the difference in capacities between our Adaptive user pairing and C-NOMA under both the pSIC and ipSIC cases is not much, since our scheme only targets one best cluster out of all clusters for the unpaired user. Moreover, one can see a significant improvement in cell capacities with more number of users for both Adaptive user pairing and C-NOMA user pairing schemes compared to the OMA scheme and ipSIC case.

TABLE I: Simulation Parameters

Path Loss Factor	v	4
Transmit SNR	ρ	0-45 dB
Residual Interfering Signal	ξ	-25 dB
Total Number of Users	N	20, 21, 25
Bandwidth	B	1 MHz
Power Factor for Strong NOMA Users	$a_{u,1}$	0.8
Power Factor for Weak NOMA Users	$a_{v,2}$	0.2

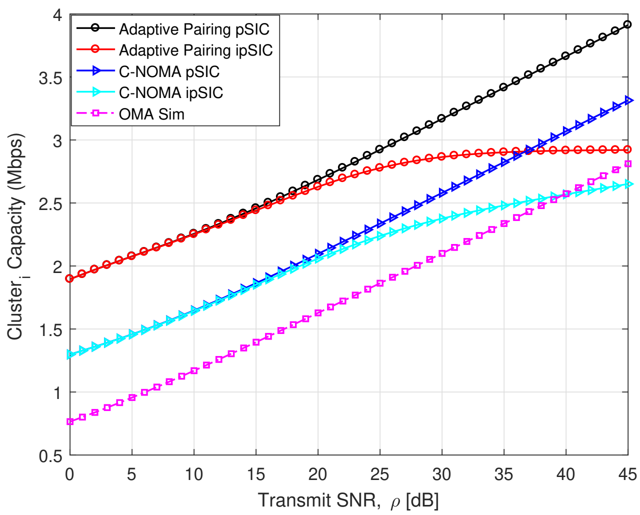

Fig. 5: Cluster$_i$ Sum Capacity for Uplink NOMA

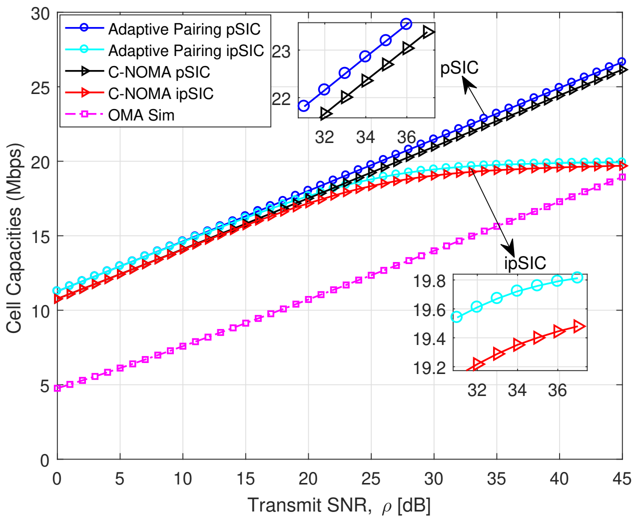

Fig. 6: Adaptive User Pairing with 25 Users for Uplink NOMA

VI. Conclusion and Future Work

In this paper, we investigated user pairing in uplink NOMA systems and proposed an Adaptive user pairing strategy for maximization of the sum capacity in such systems. We discussed the pairing issue and how two users in a cluster can be paired in uplink NOMA systems. We also discussed the problem of having an unpaired user when the total number users around the base station is an odd number. Then, to accommodate the unpaired user in a cluster, we showed how our proposed Adaptive user pairing strategy could find the right paired cluster to serve the unpaired user by accommodating it to form a three user cluster so as to increase the overall sum capacity. The effects of pSIC and ipSIC were also considered to examine how SIC imperfection affects the overall sum capacity. Simulation results showed that SIC imperfection affects the user pairing strategy greatly and can lead to sum capacity degradation. We also compared our Adaptive user pairing strategy with conventional NOMA and OMA schemes to show the effectiveness of our proposal with respect to sum capacity maximization of a cell in uplink NOMA systems.

For future work, we would like to derive closed-form analytical expressions to gain more insights into our proposed Adaptive user pairing strategy in uplink NOMA systems and compare it with downlink NOMA systems.

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