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Performance Analysis of MIMO-NOMA Systems Based on Dynamic User Pairing Scheme

Shady A Deraz, Mohamed R M Rizk, Shawky Shaaban, and Karim H Moussa

Abstract. Multiple input multiple output (MIMO) structure can enhance the total capacity of the modern communication systems without using consuming excess power or bandwidth. Non-orthogonal multiple access (NOMA) configuration is a good nominee to accommodate with MIMO structure to fulfill the demands to extra user data rates and enriched spectral efficiencies. The dynamic uniform channel gain difference (DUCGD) user pairing technique plays an important role to maximize the capacity of all the paired and served users. The DUCGD is implemented by calculating the channel gain of every prospected user and sorting it in descending order to pair ones with the highest difference in channel gains to be functioned together. In this paper, the performance analysis of MIMO-NOMA systems by means of DUCGD is presented. The numerical analysis showed that, the increase of the number of users leads to an increase in the systems’ gain and the total achieved sum rates. This improvement is shown to be due to using DUCGD and an increased number of transmitting and receiving antennas, jointly.

1. Introduction

User pairing in non-orthogonal multiple access (NOMA) enables more than one user to share their resources using superposition coding (SC) in the power domain. Where each user can take a proportion of the transmitted power according to a sharing factor called power coefficient [1], it plays a promising procedure in the next mobile generation due to its higher spectral capacities [2][3]. The uniform channel gain difference (UCGD) pairing technique depends on fixed power coefficient and neglects channel gain differences between users. This UCGD maximizes the capacity of the selected paired users [4], consequently channel gain calculated at every frame to decide which users can be paired to obtain maximize the capacity of all paired and served users.

In 5G wireless communication system, its' main target is getting the largest number of users and the fastest data speeds with good bit-error-rates (BER). The multiple-input multiple-output (MIMO)-NOMA has been a hopeful technique to fulfil this targets due to its superior spectral efficiency (SE) and higher capacities without consuming excess power or bandwidth [5][6]. To utilize the user pairing (UP) manner in MIMO-NOMA procedure, the base station (BS) supposed to pick which users thought
to be paired to share the similar band in advance, since the clustered users should have a major variance between their channel gains to raise the systems’ whole rate [2].

In [7], The influence of the pairing techniques on the feasible sum rates of NOMA has been practiced with stationary power allocation but not a dynamic one. A new algorithm advances to acquire extraordinary properties of the interference signal cancellation at NOMA method studied in [8]. In [9], traditional NOMA apportions more power to the served users with low channel gains to escalate their throughput. The closed-form globally-optimal solution in [10] acquired to fix user pairing and power allocation problem with least rate compel for each user in NOMA scheme. In [11], an extra consideration about UP in the cognitive radio applications inspired from NOMA scheme is presented, where the achievable sum rate could be amplified with a costumed matched distributed algorithm. In [12], a user pairing and pair scheduling for massive MIMO-NOMA schemes expanded the throughput by alleviating the inter-pair interference. The issue of ergodic capacity expansion MIMO-NOMA systems with the Rayleigh fading channel is illustrated in [13], and submit both optimal and suboptimal power allocation schedule to settle this optimization problem. Finally, in [14] the new algorithm for power allocation can improve the achieved overall rate of NOMA method.

In this paper, the performance of different types of MIMO-NOMA pairing schemes were compared by calculating their total sum rate at various cases. The study considered a constant users’ number and utilizing 2, 4 and 8 transmitting (Tx) and receiving (Rx) antennas. When DUCGD pairing scheme is utilized, the system resulted highest sum rates with increasing of the number of utilized antennas. As well as, the cumulative distribution function (CDF) investigation proved that the probability of higher total sum rate is greater than the probability of lower ones at various user’s number in the same mentioned case. When the number of utilized MIMO antennas is fixed, the gain due to NOMA pairing schemes is increased with the increase of number of users. Due to the benefits of DUCGD over conventional schemes, it suggested to utilize it in MIMO-NOMA systems with increased numbers of users and massive numbers of antennas.

This paper is structured as follows. Second section portrayed user pairing in MIMO-NOMA. Third section explains the considered MIMO-NOMA system model. Furthermore, the results of the simulation and considerations are executed in the fourth Section. Finally, the conclusion is presented in fifth section.

2. User pairing in NOMA

SC used in the NOMA systems to make numerous users sharing the mutual bandwidth with their information by giving each user a part of transmitting power. This process makes these users in a pair. The channel gains are a way to treat M users selected randomly in a cell $|h_1|^2 < |h_2|^2 < ... < |h_M|^2$ where $h_m$ implying the Rayleigh fading channel gain between the BS and the coordinated $m$th user and their allocated powers are in the arrangement $a_1 > a_2 > ... > a_M$. The transmitted signal with SC when $P$ denotes total transmitting power is $x_s = \sum_{m=1}^{M} \sqrt{a_m} s_m$, where $s_m$ and $a_m$ are message signal and the power allocation factor of the $m$th users respectively. We suppose that each user can detect other users’ information. Each $m_{th}$ user receives a combined signal $y_m = h_m \sum_{i=1}^{M} \sqrt{a_i} s_i + n_m$, where $n_m$ is the additive white Gaussian noise (AWGN). For all $|h_m|^2 > |h_i|^2$, the $m_{th}$ user has to perform SIC for perceiving and eliminating the inter-user interference from $i_{th}$ users. Reciprocally, the interference cancellation for each $i_{th}$ user doesn’t implement because it comes first in the decoding order and treats all $m_{th}$ users signals as noise. As per the principle of NOMA, $a_1 > a_m$ since $|h_1|^2 > |h_m|^2$. The achievable rates of the paired users are provided for Toward (1), (2)
\[ R_i = \log_2(1 + \frac{a_i |h_i|^2 \rho}{a_m |h_i|^2 \rho + 1}) \tag{1} \]

\[ R_m = \log_2(1 + a_m |h_m|^2 \rho) \tag{2} \]

respectively, where \( \rho \) represents the transmit signal to noise ratio (SNR). The total achievable data rate of NOMA is calculated by (3)

\[ R_{\text{NOMA}} = \log_2(1 + \frac{a_i |h_i|^2 \rho}{a_m |h_i|^2 \rho + 1}) + \log_2(1 + a_m |h_m|^2 \rho) \tag{3} \]

The \( m_{th} \) user can achieve \( R_m \) permanently. The sum data rate of an orthogonal MA technique is calculated by (4)

\[ R_{\text{OMA}} = \frac{1}{2} \log_2(1 + |h_m|^2 \rho) + \frac{1}{2} \log_2(1 + |h_i|^2 \rho) \tag{4} \]

2.1. Pairing techniques

Figure 1. a. clarifies dynamic traditional near–far users (DCU) pairing technique in NOMA. To anatomicize DCU pairing in NOMA, the discussion is restricted to use two users per pair for simplification. Combining users from the cell centre (high CQI) and cell edge (low CQI) into pairs can achieve ultimate channel gain difference between them. The difference in the channel gain of the cell mid users (CMU) is very less if they are paired with each other. The likelihood that superior capacity of these pairs are lower than MA systems is studied in [7]. The nearness in the channel gains and the power coefficients lead to the increasing of noise at lower channel gain users and the deficiencies of SIC at higher channel gain users which are the main reasons of decreasing the capacity in these CMU pairs [15]. Therefore, if the CMU are paired, their sum rates could be lower than MA and the small mobility made the difference in gain neglected.

For those reasons, dynamic uniform channel gain difference (DUCGD) pairing is used to accommodate the CMU by preserving comparatively DUCGD between paired users of all pairs as shown in Figure 1. b. The user's channel gains which existing in the cell are split into two combinations by median \( \tilde{h} \), pursued by inter-group pairing in such a way that CMU are well adapted. Consider the channel gains of \( L \) users in a cell as \(|h_1|^2, |h_2|^2, \ldots, |h_L|^2, |h_{L+1}|^2, \ldots, |h_{2L}|^2\). The channel gain of users are arranged such that \(|h_1|^2 < |h_2|^2 < \ldots < |h_L|^2\), group 1 (G1) \(|h_1|^2, |h_2|^2, \ldots, |h_{L/2}|^2\) is below the median \( \tilde{h} \), while group 2 (G2) \(|h_{L+1}|^2, |h_{L+2}|^2, \ldots, |h_{2L}|^2\) is above it. \( \tilde{h} \) will be an average of gains \(|h_{L/2}|^2\) and \(|h_{L+1}|^2\) as in (5). The DUCGD can find the users of CMU which can be paired with either the higher channel gain or the lower channel gain users. This implies each time the minimum gain users of each gathering are matched with others, trailed by blending next least clients of the two clusters, etc. The power allocation factor in this method depends on the channel gain as in (6)
\[ \tilde{h} = \frac{|h_{L/2}|^2 + |h_{L/2+1}|^2}{2} \quad (5) \]

\[ a_z = \frac{|h_z|^2}{|h|^2 + |h_z|^2}, \quad \text{and} \quad a_i = 1 - a_z \quad (6) \]

In this technique, the submitted procedure solved the main reasons of decreasing the capacity in these CMU pairs which discussed previously, that way allowing them to take advantage of MIMO-NOMA pairing techniques by getting higher capacity gain and minimizing the SIC performance issue.

\[ \text{U1Gain} > \text{U2Gain} > \ldots > \text{U8Gain} \]

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3. System model
A solitary circular cell MIMO-NOMA broadcast is Imposed scheme with radius R, the BS at the centre serving a total M user [12]. In which every user of the cell has K receiving antennas and BS is supplied with N antennas. Here, \( M > 2N \) is expected to confirm that 2N users are chosen from all the users and everyone should have the same frequency band with its paired client. The user terminal (UT) should have a number of antennas greater than that of BS as the required system. The accurate channel state information's (CSIs) of all the users are known for both UTs and BS [12].

The Tx signal for the paired users have with SC at the BS can be shown as (7)

\[ s = [\sqrt{a_{1,1}}s_{1,1} + \sqrt{a_{2,1}}s_{2,1}, \ldots, \sqrt{a_{1,N}}s_{1,N} + \sqrt{a_{2,N}}s_{2,N}]^T \]

\[ s = [s_1, \ldots, s_N]^T \quad (7) \]

where \( s_{1,i} \) and \( s_{2,i} \) indicate the first and second client's signals in the \( i_{th} \) pair \( (i = 1, 2, \ldots, N) \), \( a_{1,i} \) and \( a_{2,i} \) denote the equivalent power allocation coefficients, \( a_{1,i} + a_{2,i} = 1 \) [12]. Thus, the received signal \( y_{n,i} \in \mathbb{C}^{i+1} \), \( n = \{1, 2\} \) of the \( n_{th} \) user in the \( i_{th} \) pair can be represented as (8)
\[ y_{n,i} = H_{n,i} s_i + \sum_{j=1,j\neq i}^{N} H_{n,j} s_j + n_{n,i} \]  

where \( H_{n,i} \in \mathbb{C}^{k \times N} \) represents the channel state matrix of the \( n \)th user in the \( i \)th pair, and \( H_{n,j} = \bar{H}_{n,j} i \sqrt{1+d_{n,j}^2} \). The elements in \( \bar{H}_{n,j} \in \mathbb{C}^{k \times N} \) obey the quasi-static Rayleigh block fading channel, which implies that the channel state changes from one frame until the following frame yet stays steady inside one frame. Moreover, the factor \( d_{n,j} \) is the distance between the \( n \)th user in \( i \)th pair and BS. \( V \) is the large scale fading coefficient \( n_{n,i} \in \mathbb{C}^{k \times 1} \) indicates the noise vector, wherein its components comply with the zero-mean unit-variance Gaussian distribution \( n_{n,i} \sim \mathcal{CN}(0,I) \). Consequently for each pair with its user gains \( |\mu_{n,i}| \) and \( |\mu_{n,j}| \), \( a_{n,i} = \frac{\|\mu_{n,i}\|^2}{\|\mu_{n,j}\|^2} \) and \( a_{n,j} = 1-a_{n,i} \). Following the essential rule of NOMA [2], the power allocation coefficients Can be customized as \( a_{n,i} < a_{n,j} \). Within a pair, fragmentary transmit power was utilized to characterize \( a_{n,i} \) and \( a_{n,j} \), so that, the principal user can recognize the subsequent user’s signal effectively, and afterward subtracts it from the superposition coded signal by means of the SIC procedure [2]. The sum rate of MIMO-NOMA schemes can be indicated as (9)

\[
R_{\text{NOMA}} = \sum_{i=1}^{N} E\{ \log_2 (1 + \frac{a_{n,i} |H_{1,i}|^2 \rho}{a_{n,j} |H_{1,j}|^2 \rho + 1}) + \log_2 (1 + a_{n,j} |H_{2,j}|^2 \rho) \} \tag{9}
\]

As a correlation, the sum rate of traditional MIMO-OMA frameworks can be expressed as (10)

\[
R_{\text{OMA}} = \frac{1}{2} \sum_{i=1}^{N} E\{ \log_2 (1 + a_{n,i} |H_{1,i}|^2 \rho) \} + \frac{1}{2} \sum_{i=1}^{N} E\{ \log_2 (1 + a_{n,j} |H_{2,j}|^2 \rho) \} \tag{10}
\]

Through sensibly distributing the transmitting power coefficients \( a_{n,i} \) and \( a_{n,j} \), we can make sure

\[ R_{\text{NOMA}} > R_{\text{OMA}}. \]

4. Simulation results

We use 4, 8 and 16 users, the simulation done when each user has 2, 4 and 8 antennas, as well the BS is accommodated with 2, 4 and 8 antennas. The distance between BS and user1, BS and user 2 is standardized to be unity. Further, we consider \( v = 4, B = 1\text{ MHz} \), SNR varies from 0 to 30 dB, and normalized power per pair is 1. We assume \( H_{1,i} > H_{2,j} \) so that, \( a_{n,i} < a_{n,j} \) based on \( a_{n,i} + a_{n,j} = 1 \) [4].

Figure 2 illustrates the performance of different types of MIMO-NOMA pairing schemes. Here, different number of Tx and Rx antenna are simulated, in case of using 8 users. DCU is better than OMA, also DUCGD is the highest sum capacity for all utilized antenna.

The CDF at figure 3, shows the performance of various types of MIMO-NOMA pairing ways, which proved that DUCGD get better performance of MIMO-NOMA with the raise of antenna numbers. At figure 4, we employed 8 antennas at transmitter and receiver with different number of users so it provided that, while the users’ number increases, the aggregate scheme capacity increases correspondingly.
5. Conclusion
In this paper a new proposed method for improving the gain of MIMO-NOMA pairing techniques has been used. The simulation results of this new method has been showed that the gain due to the DUCGD pairing scheme is improved with the increase of Tx and Rx antennas. It is noticed that higher SNR leads to decrease the gain of DUCGD pairing system. The probability of achieving higher total sum rates in accordance with employing the DUCGD is superior by increasing number of transmitted and received antennas, also the spectral efficiency enhancing proportional to number of users especially for lower values of the SNR. The previous analysis proved that DUCGD suggested to utilize in MIMO-NOMA schemes with increased numbers of users or antennas. Through this paper, it was found that it is possible to use the DUCGD pairing techniques to take the advantage of the features which provided in 5G techniques.
6. References
[1] Nguyen V D, Tuan H D, Duong T Q, Poor H V and Shin O S Dec. 2017 “Pre-coder design for signal superposition in MIMO-NOMA multi cell networks,” IEEE Journal on Selected Areas in Communications vol. 35, no. 12, pp. 2681–2695.
[2] Islam SR, Avazov N, Dobre O A, and Kwak K S Second quarter 2017 “Power domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges.” IEEE Communications Surveys & Tutorials, vol. 19, no. 2, pp. 721–742.
[3] Wu Z, Lu K, Jiang C and Shao X 2018 “Comprehensive study and comparison on 5G NOMA schemes”. IEEE Access 6, pp. 18511–18519.
[4] Shahab MB, Irfan M, Kader MF, and Shin S Y 2016 "User pairing schemes for capacity maximization in non-orthogonal multiple access systems." Wireless Communications and Mobile Computing 16, no. 17, pp. 2884-2894.
[5] Wong V W S, Schober R, Ng D W K and Wang L 2017 "Key Technologies for 5G Wireless Systems." Cambridge University Press.
[6] Xiao Z, Zhu L, Choi J, Xia P and Xia X G May 2018 “Joint power allocation and beamforming for non-orthogonal multiple access (NOMA) in 5G millimeter wave communications,” IEEE Transactions on Wireless Communications, vol. 17, no. 5, pp. 2961-2974.
[7] Ding Z, Fan P and Poor V August 2016 “Impact of user pairing on 5G non-orthogonal multiple access downlink transmissions,” IEEE Transactions on Vehicular Technology, vol. 65, no. 8, pp. 6010–6023.
[8] Sun P, Yuan W, and Cheng H 2018 "A Novel Successive Interference Cancellation Arithmetic Based on NOMA System." In 2018 International Conference on Network, Communication, Computer Engineering (NCCE 2018). Atlantis Press.
[9] Huang Y, Zhang C, Wang J, Jing Y, Yang L, and You X 2018 “Signal processing for MIMO-NOMA: Present and future challenges” IEEE Wireless Communications, 25(2), pp.32-38.
[10] Zhu L, Zhang J, Xiao Z, Cao X, and Oliver D W 2018 "Optimal user pairing for downlink non-orthogonal multiple access (NOMA)." IEEE Wireless Communications Letters 8, no. pp. 328-331.
[11] Liang W, Ding Z, Li Y, and Song L Dec 2017 “User pairing for downlink non-orthogonal multiple access networks using matching algorithm,” IEEE Transactions on Communications, vol. 65, no. 12, pp. 5319–5332.
[12] Chen X, Gong F K, Li G and Song P November 2017 "User Pairing and Pair Scheduling in Massive MIMO-NOMA systems". IEEE Communications Letters, vol. 22, no. 4, pp. 788 - 791.
[13] Sun Q, Han S, Chin-Lin I and Pan Z 2015" On the Ergodic Capacity of MIMO NOMA Systems”. IEEE Wireless Communications Letters, vol. 4, pp. 405 - 408.
[14] Erpek T, Ulukus S and Sagduyu YE 2019 "Interference Regime Enforcing Rate Maximization for Non-Orthogonal Multiple Access (NOMA)." In 2019 International Conference on Computing, Networking and Communications (ICNC), pp. 950-994. IEEE.
[15] Saito K, Benjebbour A, Kishiyama Y, Okumura Y and Nakamura T 2015 "Performance and design of SIC receiver for downlink NOMA with open-loop SU-MIMO "In 2015 IEEE International Conference on Communication Workshop (ICCW), London, UK, pp.1161–1165.