Optimization Technique of Indoor-Outdoor User Pairing in DL-NOMA System

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***Abstract*—This work investigates the user pairing issue of indoor and outdoor users for a cellular downlink NOMA system, where a less complex algorithm called least and most cost method (LMCM) is proposed to maximize the achievable data rate and obtain high fairness. Furthermore, the proposed algorithm mainly depends on the diversity of the channel gains of indoor and outdoor users, where the most and least cost matrix techniques are applied. Moreover, we discuss the channel path loss for the case of indoor and outdoor users by proposing to apply particular and empirical propagation models. In addition to that, different performance metrics such as achievable data rate and fairness index are analysed to measure the efficiency of the proposed algorithm. The simulation results show that the proposed algorithm outperforms a random user pairing in terms of different performance metrics.**

***Index Terms*—Non-orthogonal multiple access (NOMA), User Pairing, Indoor-Outdoor NOMA Users**

I. Introduction

THE enormous growth in the demand for exchanging massive data within milliseconds of time is dramatically increased due to the revolution of smart devices. These instruments concurrently exchange huge traffic of data over limited radio resources, which need to be skilfully administered. Therefore, very advanced technologies such as 5G can fulfil their requirements by efficiently offering several useful solutions. To illustrate, frequency radio resource is considered as one of the major challenges in the wireless communication field. Thus, a new multiple access technique such as non-orthogonal multiple access (NOMA) technology becomes a strong candidate in the literature to enhance the spectral efficiency. Unlike OFDMA, NOMA can offer better use of radio resources, but with high cost of interference and receiver complexity. Therefore, to straightforwardly overcome these challenges, the successive interference cancellation (SIC) technique is employed. According to the principle of power domain NOMA, the transmit signals are multiplexed based on particular levels of power, where all assigned users simultaneously occupy the same resource blocks. To attain a high spectral efficiency, resource allocation such as user pairing needs to be carefully addressed.

There is a large volume of published studies investigating NOMA, for example, the fundamental concept of NOMA described in [1] and [2], the cooperative NOMA system in [3], and performance analysis of conventional NOMA in [4], [5]. Moreover, the authors in [6] proposed a new approach of vertical pairing structure that contributes in establishing a pair of users based on their channel gain. They also examined the sum rate maximization problem of NOMA over a frequency selective fading channel. The results show that this approach of user pairing and allocating power overcomes other current techniques and offers a comparable performance with the optimal solution. Another research study carried by Zhu *et al.* in [7] identifies the user pairing and power allocation problem to optimize the achievable sum rate. Results demonstrate that proposed optimal user pairing significantly enhances the system performance of NOMA comparing with other alternative methods such as random pairing. Recent study at user pairing of NOMA system with practical SIC is presented in [8]. The authors of that study proposed an adaptive user pairing (A-UP) algorithm for enhancing the sum rate performance of the paired users. Much of the recent research has focused on identifying and evaluating the user pairing and power allocation of NOMA for the scenario of SISO system. On the other hand, Chen *et al.* [9] studied the user pairing for massive MIMO-NOMA, where the authors proposed a user pairing and pair scheduling algorithm. The proposed algorithm assures that paired users are aimed to contribute in a greatest achievement of sum data rate. Another study provided by Nguyen *et al.* [10] investigates the user pairing problem for MISO-NOMA Networks With SWIPT to maximize the overall energy efficiency (EE) and spectral efficiency (SE) restricted to some requirements of user quality of service (QoS). The authors proposed a novel hybrid user pairing algorithm to solve the optimization problem.

However, to the best of the author's knowledge, there is no work that carries out the study of indoor and outdoor user pairing. Therefore, we propose a straightforward algorithm, which is based on the channel gains of indoor and outdoor users, that maximizes the sum data rate of paired users and offers a high fairness index. The channel gains of indoor and

978-1-6654-8550-0/22/$31.00 ©2022 IEEE

outdoor users are calculated differently due to the nature of the signal path between the transmitter and receiver. Therefore, various empirical propagation models are also proposed to overcome this issue.

The rest of this paper is organized as follows. Section II presents the system model of this work. Section III provides the maximization problem that includes the discussion of the proposed algorithm. The results are explicitly discussed in Section IV. The conclusion of this research is provided in Section V.

II. System Model

Consider a downlink NOMA system applied for multiple indoor and outdoor users served by a single base station (BS), in which all devices are equipped with a single antenna. The BS multiplexes a set of transmit signals and propagates them to a set of users $u = \{1, 2, ..., U\}$ through a subset of subcarries $s = \{1, 2, ..., S\}$. The multiplexed signals are allocated with different levels of power, where the total bandwidth (BW) is uniformly divided by the total number of subcarries S to form the dedicated bandwidth (W) of each subset of users, i.e., $W = \frac{BW}{S}$. In addition, each subcarrier S is assumed to be allocated by (U_s) users. Therefore, the total number of users can be found as $U = U_s \times S$. Furthermore, the channel state information (CSI) of each assigned links between BS and users are considered available. The transmit signal from BS to U_s users can be presented as $\sum_{u=1}^{U_s} \sqrt{\mathrm{P}_t \alpha_{s,u}} X_{s,u}$, where $\alpha_{s,u}$ is the allocated power of user u on subcarrier s, and P_t is the total transmit power. In addition, $X_{s,u}$ is the transmit signal sent to user u on subcarrier s. Moreover, the received signal of user u on subcarrier s can be observed as

$$y_{s,u} = h_{s,u} \sqrt{\mathrm{P}_t \alpha_{s,u}} X_{s,u} + \sum_{i=1 \neq u}^{U_s} h_{s,u} \sqrt{\mathrm{P}_t \alpha_{s,i}} X_{s,i} + n_{s,u} \tag{1}$$

where $h_{s,u}$ is known as the complex channel gain between BS and user u on subcarrier s, and $n_{s,u} \sim \mathcal{CN}(0, \sigma^2)$ is an additive white Gaussian noise (AWGN) with zero mean and variance σ^2. Each user can detect and decode its desired signal by applying the successive interference cancellation (SIC) technique, which is assumed to be perfect in this work. Without loss of generality, the channel coefficients between BS and all users u on subcarriers s are considered to be in ascending order as $h_{s,1} \leq h_{s,2} \leq \cdots \leq h_{s,u}$, where the effect of path loss and small scale fading are comprehend as $h_{s,u} = \frac{|h_{s,u}|^2}{\sqrt{PL_{s,u}}}$, [11]. According to NOMA principle, the user with the poor channel gain on a subcarrier s can decode its own signal with no need of SIC and treats other signals as noise. On the contrast, the user with the best channel gain on the same subcarrier s aims to apply SIC to retrieve its own message. It is done by firstly decoding other user's interference signal, and then subtract it from the original superimposed signal to finally recover its own desired signal with no cost of interference. The power allocation is distributed according to the channel gain of each paired users, so more power will be assigned to poor channel gain user and vice versa, i.e., $\alpha_{s,1} > \alpha_{s,2} > \cdots > \alpha_{s,u}$. With the respect of perfect SIC process, the received signal to noise ratio (SINR) for $U_{s,u}$ can be given as

$$\gamma_{s,u} = \frac{\alpha_{s,u} \mathrm{P}_t h_{s,u}}{\sum_{i=1}^{u-1} \alpha_{s,i} \mathrm{P}_t h_{s,i} + \sigma^2} \tag{2}$$

A. Path Loss Model

In the first scenario, the communication between BS and outdoor users occurs over the air-to-ground channel, which causes only outdoor transmission loss. These links are effected by the large scale path loss, where the free space path loss model is applied as in [12].

$$PL_{U^O} = 32.45 + 20\,\log(d_{sr}) + 20\,\log(f) \tag{3}$$

where d_{sr} is the Euclidean distance between the BS and the outdoor nodes, and f is the frequency. However, the propagated signals from BS to indoor users are fulfilled over the outdoor-to-indoor channels, where the large-scale path loss and the indoor transmission path loss are included. Therefore, we aim to apply an empirical propagation model known as COST 231 Building Penetration Loss, given in [12]. The indoor transmission path loss encompasses the building penetration loss (PL_B) and the indoor loss (PL_{in}). Thus, the total path loss for indoor users can be calculated as:

$$PL_{U^I} = L_{fs} + L_t + L_{in} \tag{4}$$

where L_{fs} indicates the free space path loss, and L_t represents the transmission propagation path loss that includes the parallel penetration loss L_{pt} and the perpendicular loss L_{pc}, presented as follows:

$$L_t = L_{pc} + L_{pt} \times (1 - \sin(\theta))^2 \tag{5}$$

where θ is the grazing angle between BS and the exterior building wall. Moreover, the indoor propagation path loss, L_{in}, is identified by the mean path loss determined from the internal side of the exterior wall to the indoor user, given as

$$L_{in} = \max\{n\ L_i, \chi(d_{in} - 2)(1 - \sin(\theta))^2\} \tag{6}$$

where n is the total number of internal walls, L_i defines the internal wall loss, and χ is the indoor path loss factor. Stander values of the indoor propagation model parameters are shown in Table I.

B. Performance Analysis

1) Achievable Data Rate: In a wireless communication system, the effective rate of successful signal transmission measured in bits per second (bps) is known as the achievable data rate. Therefore, to attain the individual data rate of NOMA users, the following formula is applied.

$$R_{s,u} = W \times \log_2 \left(1 + \frac{\alpha_{s,u} \mathrm{P}_t h_{s,u}}{\sum_{i=1}^{u-1} \alpha_{s,i} \mathrm{P}_t h_{s,i} + \sigma^2} \right) \tag{7}$$

Thus, the total achievable data rate can be calculated as follow.

$$R_{sum} = \sum_{s=1}^{S}\sum_{u=1}^{U} R_{s,u} \tag{8}$$

2) Fairness: The fairness metric shows the importance of power allocation and user pairing methods in the overall system performance. It can be done by applying Jain's fairness index [13].

$$F = \frac{\left(\sum_{u}^{U_s} R_{s,u}\right)^2}{U_s \times \sum_{u}^{U_s} \left(R_{s,u}\right)^2} \tag{9}$$

Jain's fairness has a value range of $0 \leq F \leq 1$. Thus, the fairness performance is considered high in case of F beings close to 1.

III. Problem Formulation

To describe the pairing association between users and subcarriers, we need to create a cost matrix $(M_{s,u})$ of the subcarrier-users assignment with the size of $(U \times S)$ to observe the best optimal user pairing, [14]. This can be formulated as follow.

$$M_{s,u} = \begin{bmatrix} m_{1,1} & ... & m_{1,u} \\ ... & ... & ... \\ m_{s,1} & ... & m_{s,u} \end{bmatrix} \tag{10}$$

where $m_{s,u}$ is a binary value, which is considered to be one when a subcarrier s is occupied, and zero when it is empty. Thus,

$$m_{s,u} = \begin{cases} 1, & \text{if subcarrier s is allocated} \\ 0, & \text{otherwise} \end{cases} \tag{11}$$

The values of $(m_{s,u})$ illustrate the channel gain of each user over each subcarrier. Hence, the main objective here is to maximize the total achievable data rate (R_s) as well as to enhance the fairness among indoor and outdoor users. Therefore, the optimization problem can be written as follow.

$$\text{maximize} \quad R_{sum} \tag{12a}$$

$$\text{subject to} \quad \sum_{s=1}^{S}\sum_{u=1}^{U} \alpha_{s,u} = 1 \tag{12b}$$

$$\sum_{u=1}^{U} m_{s,u} = U_s, \forall s \tag{12c}$$

$$\sum_{s=1}^{S} m_{s.u} = 1, \forall u, m_{s.u} \in \{0,1\} \tag{12d}$$

Constraint (12b) assures that the allocated power for paired users cannot exceed P_t. In addition, constraint (12c) validates that each subcarrier s is restricted to used by certain U_s users. However, constraint (12d) guarantees that each user can attain its data from a single subcarrier, and it shows the indicator value of the subcarrier assignment.

A. Proposed User Pairing Algorithm

In this approach, we assume that each indoor user is paired with an outdoor user. Since indoor users mostly suffer from path loss and non-line-of sight (NLOS) impacts, their channel gain may become insignificant. However, in the ideal scenario, outdoor users are supposed to exhibit less effects from the aforementioned issues, so their channel gains are considered better than the channel gains of indoor users. Therefore, we can apply a conventional user pairing approach based on NOMA system, in which the weak user is paired with the strong user, i.e., a subset of indoor users are aimed to pair with a subset of outdoor users in each particular subcarrier. The proposed algorithm of this particular method is mentioned in Algorithm I. To illustrate, we give an example of applying this algorithm as $U_s = 2$ and $S = 3$, where that total users can be calculated as $U = U_s \times S = 6$ users. Therefore, the cost matrix (cost function) can be given in table I, where the indoor and outdoor users are highlighted by red and blue color, respectively, as $\{U_1, U_2, U_3\}$ and $\{U_4, U_5, U_6\}$. Hence, this algorithm is valid when the conditions in Algorithm I are satisfied.

Algorithm 1 Least and Most Cost Method (LMCM)

```
i : Total number of indoor users
j : Total number of outdoor users
U^I ← {m_{1,1}, ..., m_{s,i}}, ∀s, i
U^O ← {m_{1,i+1}, ..., m_{s,j}}, ∀s, j
procedure PAIR(U^I, U^O)
    Build a channel gain matrix with size of (U × S)
    if (i==j) then
        for each item in U^I do
            for s ← 1 to S do
                Find: min(U^I), and reset its row
                and column values
            end for
        end for
        for each item in U^O do
            for s ← 1 to S do
                Find: max(U^O), and reset its row
                and column values
            end for
        end for
        Apply eq. (8) to show the paired users
    end if
    return
end procedure
```

Table I shows an example of the cost matrix that has been aggregated from the average channel gain of each user over each subcarrier. These values are captured by the simulation of both indoor and outdoor users according to the simulation parameters in table VI.

Table II is divided between indoor users (red color) and outdoor users (blue color). Each cell value indicates the

TABLE I
INITIAL COST MATRIX

s	U_1	U_2	U_3	U_4	U_5	U_6
1	0.016	0.006	0.006	0.12	1.7	0.06
2	0.048	0.11	0.046	0.05	0.6	0.11
3	0.05	0.15	0.04	0.06	0.2	1.5

TABLE II
INITIAL VALUES OF LEAST AND MOST COST MATRIX

s	U_1	U_2	U_3	U_4	U_5	U_6
1	0.016	0.006	0.006	0.12	1.7	0.06
2	0.048	0.11	0.046	0.05	0.6	0.11
3	0.05	0.15	0.04	0.06	0.2	1.5

average channel gain between BS over a particular subcarrier s and the designated user u.

TABLE III
SECOND LEAST AND COST MATRIX

s	U_1	U_2	U_3	U_4	U_5	U_6
1	0	1	0	0	1	0
2	0.048	0	0.046	0.05	0	0.11
3	0.05	0	0.04	0.06	0	1.5

According to Algorithm I, the least cost value of the first three columns among all indoor user's channel gains will be selected as an initial start point, as in Table II. Similarly, the most cost value of the remaining three columns is also chosen to start the second iteration loop. Once both selected points are found, then they become as reserved cells for user pairing and all rows and columns that include these cells are reset to zero.

TABLE IV
FINAL LEAST AND COST MATRIX

s	U_1	U_2	U_3	U_4	U_5	U_6
1	0	1	0	0	1	0
2	0.048	0	0	0.05	0	0
3	0	0	1	0	0	1

The previous procedures are repeated until all possible pairs are selected. Hence, in Table IV, the last applicable choices of max and min cost values are lifted to no more rows and columns. Therefore, we pause the iterations and assign them as allocated cells for user pairing purpose.

TABLE V
OPTIMAL SOLUTION OF USER PAIRING

s	U_1	U_2	U_3	U_4	U_5	U_6
1	0	1	0	0	1	0
2	1	0	0	1	0	0
3	0	0	1	0	0	1

Finally, the optimal selections of the cost matrix for both indoor and outdoor users are indicated by ones, which means that these users can be paired with the same subcarrier s, and the algorithm is ended here.

TABLE VI
SIMULATION PARAMETERS

Description	**Value**
Transmit power(P_t)	$\{-40$ - $40\}$ dBm
Frequency(f)	900 MHz
System bandwidth(BW)	1 MHz
Noise power(σ_j^2)	-174 dBm
Power allocation factor(α_1)	0.8
indoor distance(d_{in}) in meters	2
Perpendicular loss (L_{pc})	7 dB
The loss in the internal walls (L_i)	7 dB
Number of internal walls in meters (n)	0
Indoor path loss parameter (χ)	0.6 dB/m
Parallel penetration loss(L_{pt})	20 dB

IV. RESULTS AND DISCUSSION

In this section, we evaluate the performance of our proposed resource allocation algorithm through simulation. The system parameters applied to the simulations are given in Table VI. The fixed power allocation technique is applied in this work.

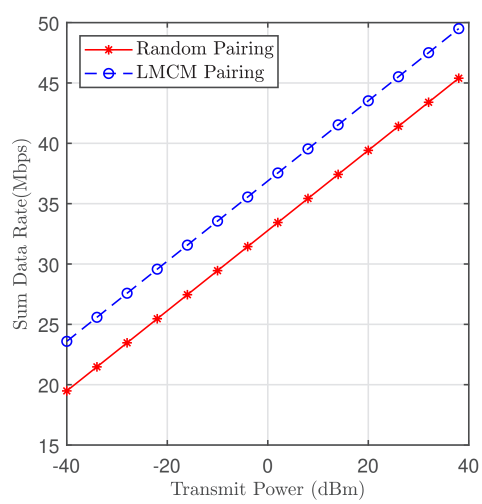

Fig. 1. Throughput performance of indoor-outdoor users versus SNR

Fig. 1 shows the sum data rate versus transmit power in dBm. It depicts the total achievable data rate of multiple paired indoor and outdoor users capturing two curves of the LMCM algorithm and the random user pairing. The figure indicates that the proposed algorithm outperforms the random user pairing method with a maximum increase of about 4.5 Mbps of the sum data rate. This amount of improvement attained by the proposed algorithm is consistently represented over the full range of transmit power.

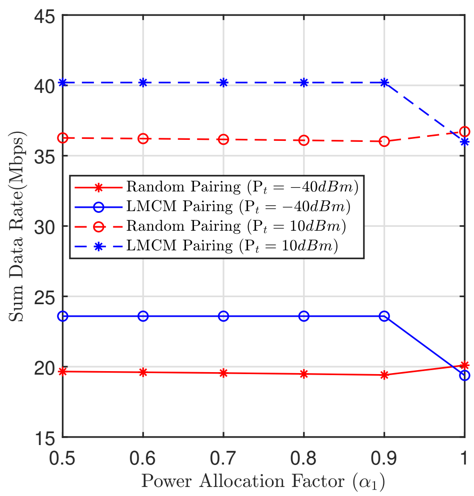

Fig. 2. Throughput performance of indoor-outdoor users versus power allocation factor α_1

Fig. 2 demonstrates the impact of fixed power allocation on the sum data rate of both user pairing approaches. The figure represents the two considered scenarios of the SNR values, i.e., $P_t \in \{-40, 10\}$ dBm, and measures the total achievement of data rate over different values of power allocation factor, α_1. To illustrate, the LMCM algorithm attains more data rate over both scenarios compared to the benchmark approach. Moreover, at high amount of α_1, the sum data rate performance of LMCM algorithm decreases while the performance of random pairing increases. In addition, both schemes attempt to behave similarly at both transmit power values within a high amount of α_1. Consequently, the LMCM algorithm maintains high sum data rate performance comparing with the random user pairing.

Moreover, fig. 3 shows the fairness index of each assigned paired indoor and outdoor users over a particular subcarrier s. To obtain more insights, we examine the fairness index over different SNR values, i.e., $P_t \in \{-40, 0, 40\}$dBm. The result shows that a high fairness index is attained by the proposed algorithm, particularly within all SNR values for $s = 3$. According to 3, the proposed algorithm contributes slightly high fairness achievement among the indoor and outdoor users at low SNR value with $s = 2$. However, random user pairing attains higher fairness rate than LMCM algorithm at low SNR

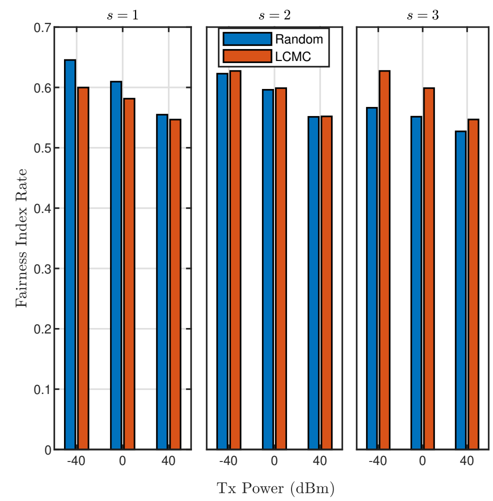

Fig. 3. Fairness of indoor-outdoor users versus SNR

with $s = 1$. To illustrate, on $s = 3$, the proposed algorithm attains about 0.2 fairness index more than random approach at low SNR values, and about 0.1 fairness rate at high SNR value. However, on $s = 1$, the fairness rate of random technique can exceed the proposed algorithm at low SNR with a rate of about 0.05.

V. Conclusion

This work investigates the user pairing problem of multiple indoor and outdoor users in a downlink NOMA system. The propagation path loss model for outdoor to indoor channel is discussed as well as the conventional case for outdoor users. Furthermore, we proposed an algorithm that addresses a new method of user pairing for this particular system model to maximize the sum data rate and fairness index. It provides a less complex solution that can enhance the system performance. Moreover, to obtain more insights, another alternative approach of user pairing called random user pairing is applied as a benchmark. The simulation results show that LMCM algorithm obtains comparable performance with the random pairing algorithm.

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