A Simple User Grouping and Pairing Scheme for Non-Orthogonal Multiple Access in VLC System

Esam M. Almohimmah[1], Mohammed T. Alresheedi[1], Ahmad F. Abas[1], and Jaafar Elmirghani[2]
[1]Department of Electrical Engineering, King Saud University, Riyadh, Saudi Arabia,
[2]School of Electronic and Electrical Engineering, University of Leeds, Leeds, UK
E-mail: malresheedi@ksu.edu.sa

ABSTRACT

In this paper, a simple user grouping and pairing scheme is proposed for non-orthogonal multiple access (NOMA) and is applied for the downlink visible light communication (VLC) system. The proposed scheme is a mix of both NOMA and the conventional orthogonal multiple access (OMA) schemes. In the proposed scheme, every two users are paired using NOMA and all pairs are allocated with conventional OMA. The performance of the proposed scheme is compared to the performance of the conventional OMA in terms of the maximum sum rate. Simulation results show that the proposed scheme provides higher sum rate compared with the OMA scheme.

Keywords: non-orthogonal multiple access (NOMA), visible light communication (VLC), user pairing, user grouping.

1. INTRODUCTION

Due to the revolution of smartphones and Internet of Things (IoT), there is a tremendous increase in the demand for wireless data communication. To meet this huge demand, 5G networks face many difficulties and challenges. One of these challenges is to increase the energy efficiency of the technologies to be used in 5G networks [1]. Recently, visible light communications (VLC) is considered as a promising candidate for 5G indoor wireless systems due to its energy efficiency and its potential to achieve high data rates [2]. In VLC, energy-efficient light emitting diodes (LEDs) are used for both illumination and data transmission communications while photodetectors (PDs) are used as receivers. Non-Orthogonal Multiple Access (NOMA), also known as Power Domain Multiple Access (PDMA), has been considered as a promising multiple access technique for 5G wireless networks due to its spectral efficiency [3].

NOMA utilizes the power domain for user multiplexing using superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at the receiver. During SC, users' signals are allocated different powers and superposed together. In SIC, high interference signals are detected first and then eliminated in a successive fashion until detecting the desired signal. As the number of users increases, the complexity of SIC increases due to the increase of interference signals. Hence, NOMA systems are considered as interference-limited systems. Based on that, it is not practical to implement NOMA for all users. Alternatively, orthogonal multiple access (OMA) can be applied to multiple groups and within each group, NOMA can be implemented for pairing a small number of users.

There are many techniques for user grouping and pairing proposed in the literature. In [4], the authors proposed a user pairing scheme in which the network coverage area is divided into two regions, near region and far region. Then each far user is paired with a near user. The problem with this scheme is that the number of unpaired users becomes high when the users in one region are greater than the users in the other region. Hence, this scheme does not exploit the capacity gain of NOMA efficiently. In [5], the authors proposed a virtual user pairing scheme in which multiple users with similar gains are paired with a single user in non-overlapping frequency bands. This scheme shows a significant increase in the capacity, however, the complexity of SIC implementation was increased.

In this paper, we propose a hybrid user grouping and pairing scheme of NOMA and OMA schemes. We evaluate the performance of the system in a downlink visible light communication system. The performance of the proposed scheme is compared to the performance of the conventional OMA in terms of the maximum sum rate using numerical simulation.

2. SYSTEM MODEL

In this paper, we consider a VLC cell with single LED (transmitter) serving K users (photodetectors or simply, receivers). A line of sight (LOS) downlink channel model for is considered. The effects of reflections and shadowing are ignored. We also assume a perfect SIC at the receiver.

2.1 LOS Channel Gain in VLC

The LOS channel gain of the k^{th} user is given by [6]:

$$h_k = \begin{cases} \frac{(m+1)A_k}{2\pi d_k^2}\cos^m(\phi_k)\,T(\psi_k)g(\psi_k)\cos(\psi_k)\,, & 0 \le \psi_k \le \Psi_k \\ 0\,, & \psi_k > \Psi_k \end{cases} \tag{1}$$

where A_k is the area of the k^{th} receiver; d_k is the distance from the LED to the k^{th} user; ψ_k and ϕ_k are the incidence and the irradiance angles, respectively; $m = -1/\log_2(\cos(\Phi_{1/2}))$ is the order of Lambertian emission; Ψ_k and $\Phi_{1/2}$ are the k^{th} receiver field of view (FOV) and the LED semi-angle at half power, respectively; $T(\psi_k)$ is the optical filter gain; and $g(\psi_k) = (n/\sin\Psi_k)^2$ is the optical concentrator gain and n is the refractive index. Assuming the receivers always face the ceiling, the LOS channel gain can be expressed as:

$$h_k = \left(\frac{(m+1)A_k T(\psi_k)g(\psi_k)}{2\pi}\right)\frac{L^{m+1}}{(L^2 + r_k^2)^{\frac{m+3}{2}}} \tag{2}$$

where L is the vertical distance between the LED and the receiving plane and r_k is the horizontal distance from the center point to the k^{th} user.

2.2 NOMA Concept

Consider K users in a VLC cell and those users are sorted ascendingly according to their channel gain, i.e. $h_1^2 \le h_2^2 \le \cdots \le h_K^2$. The power allocated to the sorted users will be in the reverse order, i.e. $P_1 \ge P_2 \ge \cdots \ge P_K$. This means users with bad channel conditions are allocated more power than those with good channel conditions. Then, user signals are superposed together. This process is known as the superposition coding (SC). The total electrical signal (the current that drives the LED) is given by:

$$x = \sum_{k=1}^{K}\sqrt{a_k P_t}\,s_k \tag{3}$$

where s_k is the k^{th} user signal, a_k is the power allocation factor for the k^{th} user and P_t is the total electrical power which should be fixed since the LED is used for both illumination and communication. At the receiver side, the received photocurrent at the k^{th} user can be expressed as [7]:

$$y_k = \mathcal{R}h_k\eta x + n_k \tag{4}$$

where $\mathcal{R}$ is the responsivity of the photodetector (Amps/Watt); h_k is the optical channel gain; η is the efficiency of the LED (Watts/Amp) and n_k denotes zero-mean additive white Gaussian noise (AWGN).

2.3 Maximum Sum Rate in NOMA and OMA

In NOMA systems, the signal to noise ratio (SNR) of the k^{th} user is affected by the interference from the signals of the users with higher channel gains, therefore the signal to interference and noise ratio (SINR) for the k^{th} user can be calculated by:

$$SINR_k = \frac{a_k P_t(\mathcal{R}h_k\eta)^2}{P_t(\mathcal{R}h_k\eta)^2\sum_{i=k+1}^{K}a_i + BN_0} \tag{5}$$

where B is the bandwidth and N_0 is the noise power density. The maximum sum rate in NOMA systems is given by [8]:

$$R_{sum}^{NOMA} = \sum_{k=1}^{K} B\log_2\left(1 + \frac{a_k P_t(\mathcal{R}h_k\eta)^2}{P_t(\mathcal{R}h_k\eta)^2\sum_{i=k+1}^{K}a_i + BN_0}\right) \tag{6}$$

The maximum sum rate in OMA systems is given by [8]:

$$R_{sum}^{OMA} = \sum_{k=1}^{K} b_k B\log_2\left(1 + \frac{P_t(\mathcal{R}h_k\eta)^2}{BN_0}\right) \tag{7}$$

where b_K is the bandwidth splitting factor for the k^{th} user. In (7), we assume an optimal OMA case where the powers allocated to the users are proportional to the bandwidths allocated to each user. Also, we ignore the effect of Hermitian symmetry if any optical OFDM scheme is used for VLC system.

2.4 The Proposed User Grouping and Pairing Scheme

In this section, the proposed user grouping and pairing scheme is illustrated as follows. Assume K is the total number of users and U is the set of all scheduled users. The users in U are ordered ascendingly depending on their channel gains, i.e. $h_1^2 \le h_2^2 \le \cdots \le h_K^2 \to U = \{u_1, u_1, \cdots, u_K\}$. The users in U are divided into two groups

A and B. Group A contains the users with low channel gains, i.e. $A = \{u_1, u_1, \cdots, u_{K/2}\}$, while group B contains the users with high channel gains, i.e. $B = \{u_{K/2+1}, u_{K/2+2}, \cdots, u_K\}$. Each user in A is paired with the corresponding user in B. In case of K is an odd number, the middle user is left unpaired. Then, NOMA is applied to each paired users and all pairs are allocated with conventional OMA. The proposed user grouping and pairing scheme is depicted in Fig. 1 when K in an odd number.

In this scheme, the maximum number of unpaired users is reduced to one, which is the case when K is an odd number only. Moreover, in our proposed scheme the user with high channel gain need to cancel the interference from only one user whereas other proposed schemes in literature may require cancelling the interference from more than one user in different bands simultaneously [5].

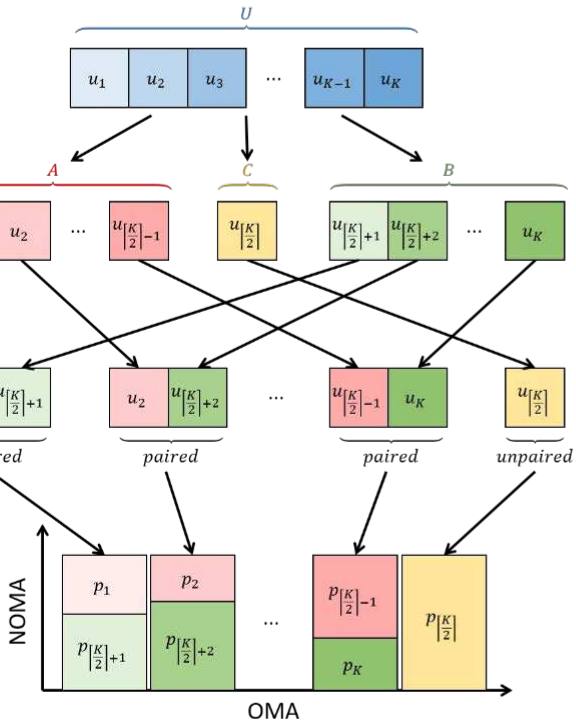


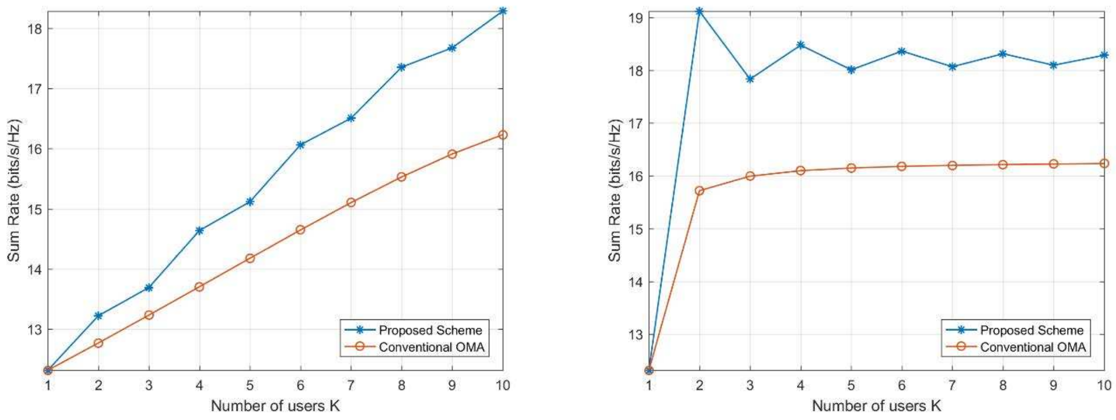
Figure 1. The concept of user grouping and pairing when K is an odd number.

3. SIMULATION RESULTS AND DISCUSSION

In this section, the maximum sum rate of the proposed scheme is compared with conventional OMA using numerical simulation. The parameters used in the simulation are as follows. P_t = 1 watt; $\eta = 1$; $\Phi_{1/2} = 60°$; A = 1 cm^2; $\Psi = 60°$; $\mathcal{R} = 1$; $T = 1$; n =1.5; $N_0 = 10^{-15}$ A^2/Hz and L = 2 m. The horizontal distances of the users are assumed to be equally spaced in the range [0-3m]. The users channel gains are computed using (2) and fixed power allocation (FPA) is used [9].

Figure 2 shows the maximum sum rate of our proposed scheme and the conventional OMA when the number of users varies from 1 to 10 users. In Fig. 2a, the users' distribution is based on the minimum difference in the horizontal distances. For example, when $K = 2$, $r_1 = 3$ m and $r_2 = 2.66$ m. When $K = 3$, $r_1 = 3$ m, $r_2 = 2.66$ m and $r_3 = 2.33$ m and so on. In Fig. 2b, the users' distribution is based on the maximum difference in the horizontal distances. For example, when $K = 2$: $r_1 = 3$ m and $r_2 = 0$ m. When $K = 3$: $r_1 = 3$ m, $r_2 = 1.5$ m and $r_3 = 0$ m and so on.

Simulation results show that our proposed scheme outperforms the conventional OMA scheme. There is a reduction in the maximum sum rate of proposed scheme when the total number of users is odd number. This result is expected due to the effect of the unpaired user. Pairing users with a higher difference in the horizontal distances will increase the sum rate of the system especially when the number of users is small.



(a) (b)

Figure 2. Sum-rate of the proposed scheme and OMA scheme when pairing the users with (a) minimum difference in the horizontal distances, (b) maximum difference in the horizontal distances

4. CONCLUSIONS AND FUTURE WORK

In this paper, we propose a simple user grouping and pairing scheme for non-orthogonal multiple access in a downlink visible light communication system. The proposed scheme is a mix of both conventional non-orthogonal multiple access and the conventional orthogonal multiple access schemes. In the proposed scheme, every two users are paired using NOMA and all pairs are allocated with conventional OMA. The performance of the proposed scheme is compared to the conventional OMA in terms of the maximum sum rate. Simulation results show that the proposed scheme increases the capacity gain of the system compared to the OMA scheme. Moreover, pairing users with a high difference in their horizontal distances will increase the sum rate of the system.

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