Proceedings Paper:

Aljohani, MK, Alsulami, OZ, Alazwary, KD orcid.org/0000-0003-2823-6958 et al. (4 more authors) (2020) NOMA Visible Light Communication System with Angle Diversity Receivers. In: 2020 22nd International Conference on Transparent Optical Networks (ICTON). 2020 22nd International Conference on Transparent Optical Networks (ICTON), 19-23 Jul 2020, Bari, Italy. IEEE ISBN 9781728184234

https://doi.org/10.1109/icton51198.2020.9203212

NOMA Visible Light Communication System with Angle Diversity Receivers

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ABSTRACT

In this paper, a non-orthogonal multiple access (NOMA) visible light communication (VLC) system is investigated. The system uses angle diversity receivers (ADRs) to provide high data rates. The ADR has 4 branches, each directed to a different direction. An 8m × 4m sized room is modelled to study the resource allocation to users according to their channel conditions to maximize the data rate. The results show that using ADRs improves the data rate by an average of 35% compared to a system using wide FOV receivers.

Keywords: Visible Light Communication (VLC), Non-Orthogonal Multiple Access (NOMA), Angle Diversity Receivers (ADRs).

1. INTRODUCTION

Demand for higher data rates has always been one of the main challenges in telecommunications. Researchers have been working on developing new approaches to provide high data rates for different applications. In Visible Light Communication (VLC), obtaining high data rates is one of the main challenges due to the limitations caused by the conventional transmitter and receiver technologies [1]-[11]. Other challenges include Inter Symbol Interference (ISI) and Co-Channel Interference (CCI) caused by the existence of multiple transmitters and multipath propagation. Laser diodes (LDs) are proposed to replace Light Emitting Diodes (LEDs) as transmitters because of their high modulation bandwidth which provides high data rates of up to several gigabits per second [12]-[14].

Different techniques were considered to enhance optical wireless communication systems including beam adaptation [15]–[17], spot diffusing approaches [18] – [23] and diversity techniques including angle diversity receiver (ADR) [24] - [27]. The use of code division multiple access (CDMA) schemes including pulse position modulation (PPM) CDMA, and multi-carrier CDMA (MC-CDMA) was investigated for multi-user communication [28] - [30]. Resource allocation in multi-user systems was investigated in [31] – [36].

To guarantee higher data rates, receivers such as Angle diversity receiver (ADR) are used [13], [17], [21] – [24]. An ADR is a combination of narrow Field of View (FOV) detectors that point to different directions to optimize the selection of the best and strongest optical signal. The use of ADRs aided in mitigating the effects of ambient light and pulse spread in optical wireless systems, as well as reducing the impact of interferences which improves the overall efficiency of the system [21]-[24]. Furthermore, ADRs can be used with other methods to improve the performance such as their use with relay nodes [37], fast adaptation techniques [38] – [40] and with beam steering in uplinks [41].

Non-Orthogonal Multiple Access (NOMA) in optical wireless systems operates by multiplexing all users' signals in the power domain then demultiplex them at the receiver end. It uses superposition coding for transmission and successive interference cancellation (SIC) at the receiving end. NOMA operates by allocating signal power according to the channel strength of each user; the higher their strength the lower the power assigned [42].

In this paper a NOMA system using ADRs with four branches is compared to a system using wide FOV receiver. Simulation models are developed to optimize the allocation of access point resources to users following our approach in [36]. The rest of the paper is organized as follows: The system model is introduced in Section 2. The simulation results and discussion are discussed in Section 3, while the conclusions are given in Section 4.

2. SYSTEM MODEL

The simulation models an empty room 8m long, 4m wide, and 3m heigh. Lambertian reflectors are used to model the walls and ceilings with a reflectivity coefficient of 0.8, without taking into consideration doors and windows [8], [9]. The signal is transmitted through multiple reflections from the walls and ceilings. Ray tracing is used for modelling the optical indoor channel similar to [11]-[13]. The reflective area is divided into several equal sized square shaped areas with area dA and reflection coefficient ρ. Reflections produced by surface elements reflecting the light emitted by a transmitter to the receiver are called first order reflections. The light reflected by a surface element can be further reflected by another surface element before reaching the receiver. This is called second order reflection. Reflections beyond the second order are insignificant due to their extremely low optical power [12]. The time resolution of the results is determined by the surface elements size. For first-order reflections, surface elements are of 5 cm × 5 cm while for second-order reflections, they are 20 cm × 20 cm. The dA values should be observed carefully due to their impact on the computation time.

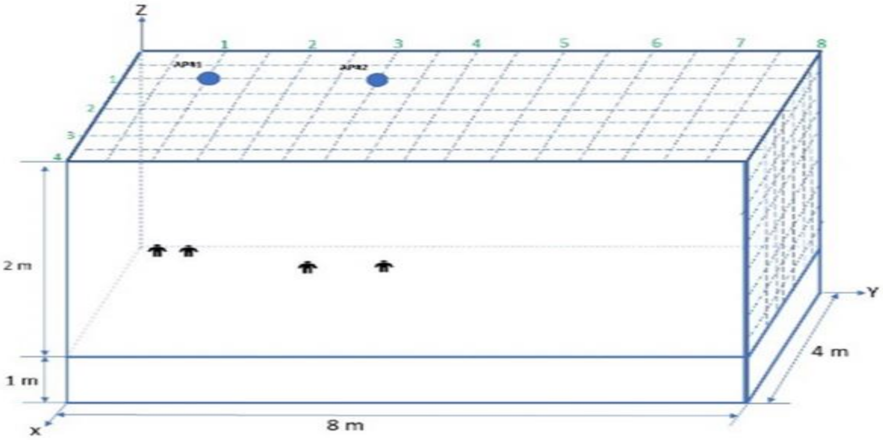

Figure 1. Modelled Room dimensions

To reduce interference, an ADR with 4 branches is used. Each branch has a photodetector that covers a different area based on the elevation and azimuth angles of the ADR faces, with the transmitter mounted in the ceiling. The elevation angles, El, of the four detectors are set at 70° whereas, the azimuth angles, Az, of the detectors are 45°, 135°, 225°, and 315°. The FOV of the four detectors is set to 25°. In addition, the area of each photodetector is 20 mm^2 with responsivity of 0.4 A/W [36].

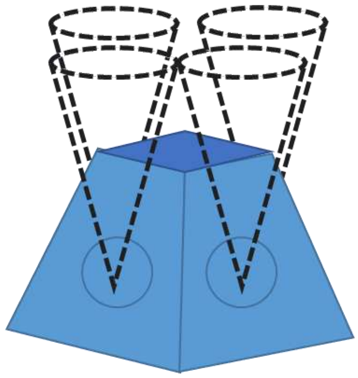

Figure 2. Angle Diversity Receiver (ADR).

We performed resource allocation to ensure that the sum SINR is maximized [36]. The power allocation coefficient for each user is similar to [43], [44]. The signal to interference ratio (SINR) for the NOMA system is given by:

$$SINR_k = \frac{(a_k P_t R h_k \eta)^2}{(\sum_{\substack{i=1 \\ i \neq k}}^{K} a_i P_t R h_k \eta)^2 + (BN_0 + 2q(I_d + R\, P_{bn})B)} \qquad (1)$$

where:

a_k	Power allocation coefficient
P_t	optical received power
R	Photodetector Responsivity
h_k	Optical channel gain
η	LD Efficiency
N_0	Noise power density
B	Receiver bandwidth
q	Electron charge
I_d	Dark background current
P_{bn}	Received background optical power

Table 1. shows a breakdown of all the system's configurations and characteristics, as well as the values used in the simulation and modelling of our design.

Table 1, System Parameters

Parameters	*Configurations*
Reflection coefficient of Walls and ceiling	0.8
Reflection coefficient of Floor	0.3
Reflections Count	1 2
Coverage Area	5 cm x 5 cm 20 cm x 20 cm
Reflection element angle	60°
Total transmit power	1.9 W

3. SIMULATION RESULTS AND DISCUSSION

We compare the performance of VLC NOMA system using four branch ADR to the performance of a NOMA system using wide FOV receiver considering the room setup described in Section 2. The users in the room setup mentioned above are located in close proximity to the access points. The access points were located at (1,1,3), (1,3,3) while the users were located at (0.5,0.5,1), (0.5,1.5,1), (1.5,2.5,1), (1.5,3.5,1).

Figure 3, Figure 4 and Figure 5 show that using an ADR receiver instead of a wide FOV receiver is effective in increasing the data rate per user. For users located in close proximity to the access point, using the ADR (Figure 4) provides a range of improvements between 29% and 40% with an overall data rate improvement by an average of 35% compared to the data rate achieved by the wide FOV receiver (Figure 5). In general, the data rate in the wide FOV receiver system is lower due to the low channel bandwidth.

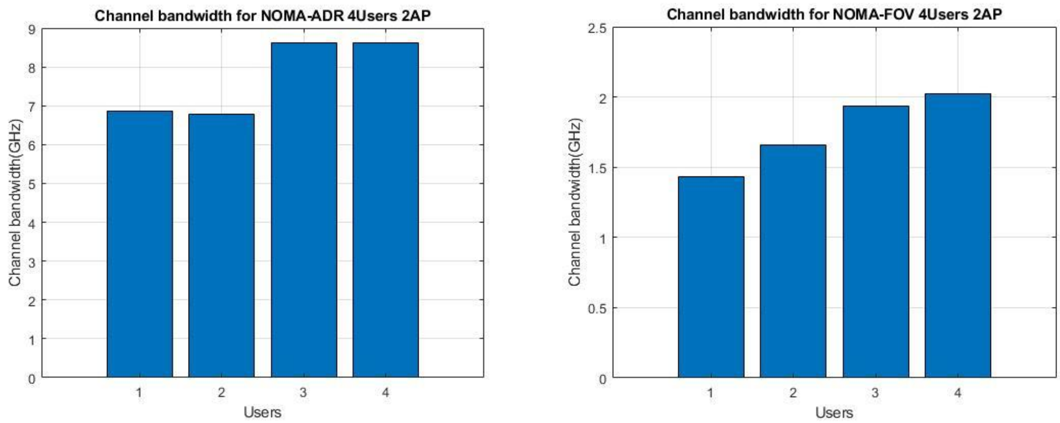

Figure 3. (a) Channel bandwidth (ADR). (b) Channel bandwidth (Wide FOV Receiver).

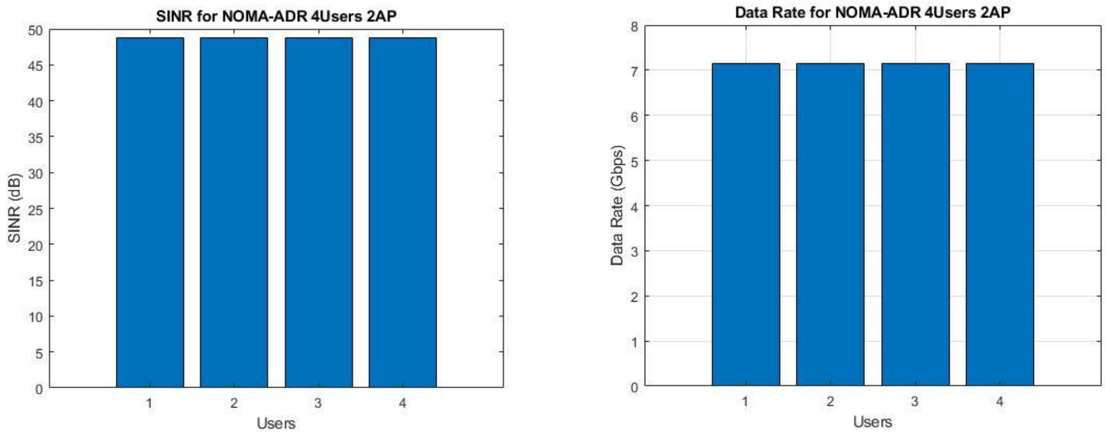

Figure 4. (a) SINR (ADR). (b) Data Rate (ADR).

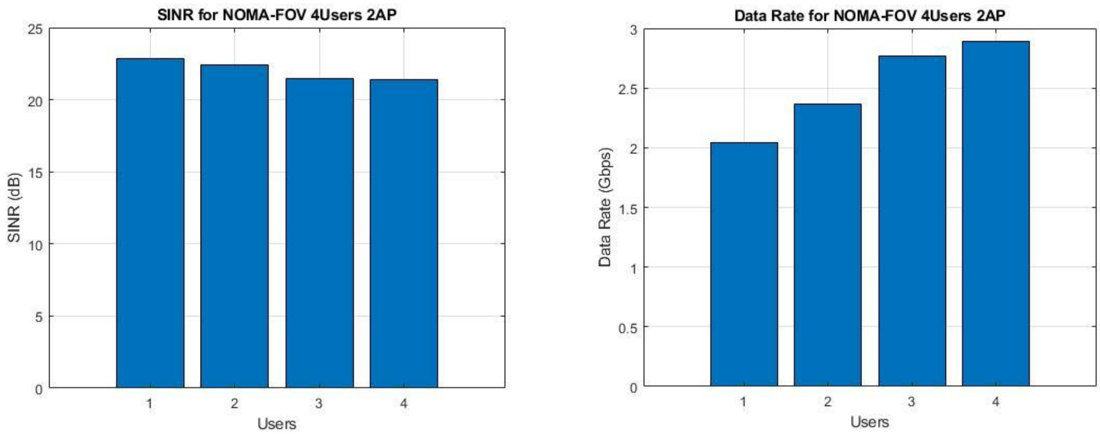

Figure 5. (a) SINR (Wide FOV Receiver). (b) Data Rate. (Wide FOV Receiver).

4. CONCLUSIONS

In this paper an ADR receiver with four branches was considered to enhance the data rate of a NOMA system. The performance of NOMA-VLC systems with an ADR is compared to a NOMA system with a wide FOV receiver in a room setup with two access points and multiple users in different locations. The simulation results revealed that using an ADR improves the data rate of the NOMA system by an average of 35% compared to a system with a wide FOV receiver.

ACKNOWLEDGEMENTS

The authors would like to acknowledge funding from the Engineering and Physical Sciences Research Council (EPSRC) INTERNET (EP/H040536/1), STAR (EP/K016873/1) and TOWS (EP/S016570/1) projects. The authors extend their appreciation to the deanship of Scientific Research under the International Scientific Partnership Program ISPP at King Saud University, Kingdom of Saudi Arabia for funding this research work through ISPP#0093. The first author would like to thank Taibah University, Kingdom of Saudi Arabia for funding her PhD scholarship. The second author would like to thank Umm Al-Qura University, Kingdom of Saudi Arabia for funding his PhD scholarship. All data is provided in the results section of this paper.

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