Active Devices Sensing and Secure NOMA Assisted mMTC Wireless Networks

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Abstract—In this paper, a network model for visible light communication (VLC) using new delta-orthogonal multiple access (D-OMA) scheme is proposed under coordinated multipoint (CoMP) transmission environment. In this model, CoMP structure allows coordination among the group of access points (APs), thereby each user will receives the strong signal including cell edge user. Moreover, the D-OMA allows the partial overlapping among sub-bands of the non-orthogonal multiple access (NOMA) clusters such that it increases the massive access in the low power wireless communications. Closed form expression for the bit error rate (BER) of the proposed network is derived. Also, downlink transmission power optimization is performed using Karush-Kuhn Tucker (KKT) conditions. Numerical results demonstrate that the performance of the proposed CoMP based D-OMA-VLC network outperform the massive in-Band NOMA and OMA schemes.

Index Terms—D-OMA, in-band NOMA, VLC and 6G.

I. INTRODUCTION

Sixth generation (6G) is expected to be breaks many of the shortcomings of the existing wireless networks such as coverage issues, poor signals and network unavailability. 6G provides the ultra reliable communication, ultra low latency and massive accessibility. Recently, smart devices play a major role in the real time wireless services which leads heavy data traffic flow, therefore the current wireless networks may not be completely supported by the available technologies [1]. To overcome such issues, 6G is proposed to support the new spectrum and new energy-efficient transmission techniques. Multiple access schemes always kickoff in the development of large scale wireless networks [2]. With that motivation, a promising multiple access scheme known as non-orthogonal multiple access (NOMA) scheme has been proposed to provide the high spectrum efficiency and massive connectivity. NOMA scheme serve the multiple users with same resources in terms of time and frequency. Power-domain NOMA (PD-NOMA) is a subclass of NOMA scheme which allows users to convey their signals using different power levels and it is termed as superposition coding. Similarly, the successive interference cancellation (SIC) technique is applied at the receiver for the decoding of the NOMA signal. Indeed, power distribution scheduling enhance the performance of the NOMA based wireless network [3], [4].

In the recent years, to achieve a secure communication which is a critical issue over wireless networks the field of physical layer security (PLS) over different scenarios has taken an important interest as a means to provide reliable secure communications, relaxing the complexity and complementing the performance of the required cryptographic technologies. [5] PLS was proposed by Wyner to improve the security of the network as a complementary approach to the cryptographic techniques. [6] Physical-layer security protect the information by exploiting the intrinsic characteristics of the communications medium, is a promising wireless security. [7] The authors [8] have considered the physical-layer security for NOMA-based networks to investigate the physical layer security in a NOMA system for the single antenna and the multiple-antenna networks under the stochastic geometry concept. Primarily, with information theory fundamentals PLS is mainly focus on the secrecy capacity of the propagation channel. PLS makes use of physical layer properties of the communication system such as noise, interference and time-varying property of fading channels. [9] The basic idea behind PLS is to reduce the signal characteristics of the intended receiver (IR) for the Eavesdropper. [10] Due to the broadcast nature of the wireless networks, transmission between authorised users can easily be overheard by an eavesdropper for interception. This makes wireless transmission highly endangered to eavesdropping attacks. In order to achieve confidential transmission, existing communications systems typically adopt the cryptographic techniques to prevent an eavesdropper from tapping data transmission between legitimate users. The issue of active eavesdropper or multiple eavesdroppers in heterogeneous networks is addressed in [11], [12], [13], [14]. The challenges and opportunities on the use of physical-layer parameters to obtain device fingerprinting are given to provide a detailed treatment on developing novel wireless security solutions using device fingerprinting techniques [15]. An overview of threats and challenges in cyber-security can be found in [16], while a conceptual, generic, and expandable framework for classifying the existing PLS techniques against wireless passive eavesdropping can be found in [17]. The use of PLS for authentication and possible ways of invoking physical-layer authentication to reduce both the complexity and latency of the security processes in complex heterogeneous networks with the aid of the proposed physical security context sharing is discussed in [18], [19], including real implementation difficulties. The fading channels can strengthen the transmission of confidential information and that a secure communication can be achieved even when the channel to the eavesdropper is better than the main channel. An overview of PLS techniques with imperfect
channel information is given in [20]. A comprehensive review of the PLS techniques toward IoT applications is discussed [21], followed by the survey of the existing PLS techniques, the characteristics of IoT are identified, based on which the challenges faced by PLS protocol design are summarized, while [22], [23] provide a review of error-coding for PLS. In general, PLS authentication techniques can exploit randomness of the wireless channel in time, in frequency and in space domains [24]. In this paper, the author consider the physical layer security for non-orthogonal multiple access (NOMA)-based uplink massive machine type communication (mMTC) networks. [25] mMTC is proposed by ITU to provide a large scale of connectivity services through cellular networks for billions of machine-type communications devices (MTCDs). As a part of the new radio technology, non-OMA (NOMA) applied in mMTC has attracted attention of industrial communities [26]. mMTC has been viewed as a promising technology to innovate thoroughly with numerous smart sensors immerse with machine learning techniques and intelligence. [27] To meet the challenging demand of massive connectivity mMTC focuses on the uplink communication of a massive number of low-rate devices requires a completely different set of technologies than those designed to support human-type communications in previous communication systems [28]. mMTC has the characteristic of random access that users transmit small data packets. However, the signaling overheads for coordination are proportional to the number of users in the network. Because of this a transmission methodology is highly expected in uplink NOMA systems, in which a small number of active users can randomly transmit data at any time slot without any trembling process. [29]. Thus, the multiple distribution of active users inspires us to formulate multi-user detection problem under the compressive sensing (CS) framework. Compressive sensing (CS) is a novel sampling paradigm to reconstruct a sparse physical signal that samples signals in a much more efficient way than the established Nyquist sampling theorem. [30]

A. Motivation

Although CoMP based NOMA-VLC networks improve the QoS of the CEC user’s, the demand on massive access in the low power wireless communications is still a open problem [?]. For example, in the autonomous vehicle and the intelligent transportation systems, several hundreds of devices/nodes are involved to provide the reliable communications.

- Proposal of novel CoMP based D-OMA-VLC network to enhance the massive access in the indoor environment and it is one of the major requirement called as massive machine type communication (mMTC) in 6G.
- Transmission power optimization under QoS, dimming control constraints. It ensure the QoS of the each NOMA users within the clusters.
- Closed form analytical expressions for the BER of the proposed CoMP based D-OMD-VLC networks.

II. SYSTEM MODEL

The proposed cellular network consist of one base station, M near users and N far users and they are distributed randomly in the presence of the Eve as shown in Fig. 1. The density of the distribution of the legitimate users are modelled according to the homogeneous poisson point process (HPPP). It is assumed that the M near users are distributed within the inner circular region with radius of r and N far users are distributed in the annular region (i.e., intersection of inner and outer circular region) with its outer radius of rf. In this model, the user pair is formed by combining one near user and one far user and they are communicated with each other using NOMA and PLNC schemes. Further, it is assumed that the Eve is located beside the near user to trace the confidential information. Therefore to safeguard from the Eve, the near user is operating with full-duplex (FD) mode and emits the AN while receiving the message from the base station in order to confuse the Eve.

Consider a multi cell VLC communication network in a atto-cell environment where LED transmitters are mounted on the ceiling of the room and only three LED transmitters are shown in Fig. 1. Assume each LED lights cover only small circular region with radius rL on the floor where NL number of user’s are distributed randomly within a visible region of the LED L. In this model, D-OMA is applied as MA method to serve massive number of user’s simultaneously. In D-OMA scheme, the entire system bandwidth W (same bandwidth is assumed for all LEDs) is divided into NL sub bands and each sub band is allocated to a NOMA cluster as depicted in Fig. ?? Thus, the number of sub bands are equal to the number of NOMA clusters. Since, the partial overlapping in the D-OMA scheme, the number of user’s working with D-OMA scheme is always greater than the non-overlapping massive in-Band NOMA scheme.

![Fig. 1: NOMA Based mMTC Wireless Networks](image-url)
frequency is allocated for the NOMA cluster which includes the CoMP users of adjacent cells. We referred these sub bands as CoMP-DOMA clusters.

In this work, we assumed that the communication between the LED and an user is carried through a line of sight (LOS) path. The LOS DC channel, $h_{mL,kL}$ between the BS and the user $U_{mL,kL}$ inside the atto cell is given by [7]

$$h_{mL,kL} = A_{mL,kL} R_0(\varphi_{mL,kL}) T(\phi_{mL,kL}, \sigma(\varphi_{mL,kL}), \mu) \cos(\phi_{mL,kL}),$$  \hspace{1cm} (1)

for $0 \leq \phi_{mL,kL} \leq \Phi_{mL,kL}$ and for $\phi_{mL,kL} > \Phi_{mL,kL}$, $h_{mL,kL} = 0$. $A_{mL,kL}$ is the field of view (FoV), $\Phi_{mL,kL}$ is the angle of incidence of the $U_{mL,kL}$, $d_{mL,kL}$ is the distance between the LED and user $U_{mL,kL}$, $v$ is the path loss exponent, $\varphi_{mL,kL}$ is the angle of irradiation of the transmitter LED, $T(\phi_{mL,kL}, \sigma(\varphi_{mL,kL}))$ is the Lambertian radiant intensity of the LED transmitter and can be expressed as

$$R_0(\varphi_{mL,kL}) = \frac{\mu + 1}{2\pi} \cos^\mu(\varphi_{mL,kL}),$$ \hspace{1cm} (2)

where $\mu$ denotes the order of Lambertian emission, $\mu = -\ln(2)/\ln|\cos(\varphi_{1/2})|$, where $\varphi_{1/2}$ denotes the transmitter LED semi-angle at the half power of the LED L. The gain of the optical concentrator of the PD, $G(\phi_{mL,kL})$ can be expressed as $G(\phi_{mL,kL}) = \nu^2 / \sin^2(\Phi_{mL,kL})$, where $\nu$ is the refractive index.

III. PERFORMANCE ANALYSIS

A. Achievable Rates

The transmitted optical signal at the BS can be given as

$$x(t) = P_{\text{LED}}[x(t) + I_{\text{DC}}]$$ \hspace{1cm} (3)

where $P_{\text{LED}}$ is the LED power all of BS in $W/A$, $I_{\text{DC}}$ is the added DC bias at the BS to obtain non negative signals, i.e. $x(t) + I_{\text{DC}} \geq 0$ and $x(t)$ is the transmit on-off keying (OOK) symbol. After removing the DC bias, the received signal at $U_{mL,kL}$ can be expressed as

$$y_{mL,kL} = \frac{y_{mL,kL}}{\text{Signal from LED L}} + \frac{y_{mL(kL)}}{\text{Signal from LED (L-1)}}$$ \hspace{1cm} (4)

Let us assume $\eta$ is the photo-detector responsivity in $A/W$, $g_{mL,kL}$ is the LoS VLC channel gain and $\omega_{mL,kL} \sim \mathcal{CN}(0, \sigma^2_{mL,kL})$ is AWGN at $U_{mL,kL}$ which is a combination of thermal and shot noise [7]. The signal to interference plus noise ratio (SINR) for decoding its own messages at $U_{mL,kL}$ can be given as

$$\sigma_{mL,kL} = \sigma_{mL,kL} (1 + \delta_{mL} + \delta_{mL}).$$

For users in LED L, the interference due to the signal of users in same cluster called as intra-cluster interference ($I_{\text{ICL}}$) and the interference due to the signal of users in neighbor clusters $I_{\text{ICL}(L-1)}$, respectively. These can be given as

$$I_{\text{ICL}} = \sum_{j=1}^{K_{mL}} \frac{(\eta P_{\text{LED}}|g_{mL,kL}|)^2 P_{mL,j}}{K_{mL}}$$ \hspace{1cm} (5)

$$I_{\text{ICL}(L-1)} = \sum_{j=1}^{K_{mL}} \left( \frac{(\eta P_{\text{LED}}|g_{mL(kL-1),kL}|)^2 P_{mL(j-1)}}{K_{mL-1}} \right)$$ \hspace{1cm} (6)

$$I_{\text{ICL}(L-1)} = \left( \frac{(\eta P_{\text{LED}}|g_{mL(kL-1),kL}|)^2}{K_{mL-1}} \right) \sum_{t=1}^{K_{mL-1}} \left( \sqrt{\delta_{mL}} + \sqrt{\delta_{mL-1}} \right)^2 + \sum_{y=1}^{K_{mL-1}} \left( \sqrt{\delta_{mL}} + \sqrt{\delta_{mL+1}} \right)^2 P_{mL(j-1),y}.$$ \hspace{1cm} (7)

Therefore, the lower bound the achievable rates of the users can be expressed as

$$R_{mL,kL} = \frac{B_{mL}}{2} \log_2 \left( 1 + \frac{e}{2\pi} \gamma_{mL,kL} \right), \hspace{1cm} kL = 1, ..., K_{mL}.$$ \hspace{1cm} (8)

B. Bit Error Rates

IV. TRANSMISSION POWER MINIMIZATION

In this Section, transmit power optimization of the LED L is analyzed under QoS requirements and dimming control.

V. RESULTS AND DISCUSSION

In this section, BER and achievable rates of the proposed CoMP-based D-OMA-VLC is discussed. In all the simulations, LOS DC channel gain and OOK modulation is considered. The simulation parameters are listed in the Table. 1.

Fig.3 shows the BER performance of the proposed CoMP based D-OMA VLC network. In this simulation, far user only considered hence both $I_{\text{ICL}}$ and $I_{\text{ICL}(L-1)}$ are taken. The value of $I_{\text{ICL}}$ is 0 dB and the value of $I_{\text{ICL}(L-1)}$ is –10 dB. Assumed the near users perform perfect SIC operation hence the SIC residual error is neglected. Further, in massive in-Band NOMA the $I_{\text{ICL}}$ is zero. For the target BER of $10^{-3}$, D-OMA with single point transmission need 23 dB SNR whereas D-OMA with multi-point transmission need only 12 dB SNR that is 11 dB SNR gain is achieved by CoMP transmission. Also it is noted that D-OMA outperform the massive in-band NOMA even with the single point transmission.

The BER performance of the proposed CoMP based D-OMA-VLC network is shown in Fig. 4 for various $I_{\text{ICL}}$ values. It is noted that the effect of the $I_{\text{ICL}(L-1)}$ in the single point
### TABLE I: Simulation Parameters

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Distance between the NU and the BS</td>
<td>$d_1$</td>
<td>1 m, 2 m and 3 m</td>
</tr>
<tr>
<td>2.</td>
<td>Distance between the FU and the BS</td>
<td>$d_2$</td>
<td>4 m, 6 m and 8 m</td>
</tr>
<tr>
<td>3.</td>
<td>Path loss exponent</td>
<td>$\nu$</td>
<td>2</td>
</tr>
<tr>
<td>4.</td>
<td>Optical detection area</td>
<td>$A$</td>
<td>0.01</td>
</tr>
<tr>
<td>5.</td>
<td>FOV</td>
<td>$\phi_{FOV}$</td>
<td>60°</td>
</tr>
<tr>
<td>6.</td>
<td>LED semi-angle</td>
<td>$\phi_{1/2}$</td>
<td>40°, 60°</td>
</tr>
<tr>
<td>7.</td>
<td>Angle of irradiance</td>
<td>$\phi_1$, $\phi_2$</td>
<td>45°</td>
</tr>
<tr>
<td>8.</td>
<td>Angle of incidence</td>
<td>$\phi_1$, $\phi_2$</td>
<td>35°, 45°</td>
</tr>
<tr>
<td>9.</td>
<td>LED power</td>
<td>$P_{LED}$</td>
<td>20 W/A</td>
</tr>
<tr>
<td>10.</td>
<td>PD responsivity</td>
<td>$\eta$</td>
<td>0.4 A/W</td>
</tr>
<tr>
<td>11.</td>
<td>Refractive index</td>
<td>$\nu$</td>
<td>1.5</td>
</tr>
<tr>
<td>12.</td>
<td>Gain of the optical filter</td>
<td>$T(\phi_{FOV})$</td>
<td>1</td>
</tr>
</tbody>
</table>

*BS - base station, NU - near user, FU - far user

![Fig. 2: Comparison of BER performance with various multiple access techniques.](image)

Transmission is more however while operating with multi-point transmission its effect is considerably reduced. For the target BER of $10^{-3}$, D-OMA with single point transmission need 22 dB SNR when $I_{PCL} = -20dB$ whereas 27 dB SNR is required when $I_{PCL} = -13dB$. However, while operating with CoMP transmission the additional SNR requirement is only 2dB.

### VI. Conclusion

A CoMP based D-OMA-VLC network is proposed to enhance QoS of the CEC users and to increase the massive access in the indoor wireless communications which is one of the major requirements in the 6G wireless networks. Spatial diversity is virtually achieved using CoMP transmission in this VLC network. Power optimization is performed at the LED transmitter to allocate the fair power to each user thereby spectral efficiency of the proposed network is improved. Further, BER performance and the achievable rates of the proposed network is analyzed and compared with existing multiple access techniques. Numerical results conclude that BER performance of the D-OMA-VLC network is significantly improved when compared to the massive in-band NOMA network.

![Fig. 3: BER performance of the D-OMA-VLC network for the various photo detector areas.](image)

### ACKNOWLEDGMENT

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### REFERENCES


5


[27] “Six key features of machine type communication in 6G.”

