Resource Allocation in Visible Light Communication Networks NOMA vs. OFDMA Transmission Techniques

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Presentation Agenda

1.	Introductory Remarks
2.	Paper Contribution
3.	VPANs Topology and System Model
4.	OFDMA vs. NOMA
5.	Optical Access Point Selection
6.	Utility Functions
7.	Problem Formulation and Solution Approach
8.	NOAPRA Algorithm
9.	Numerical Results
10.	Takeaways

Presentation Agenda

Introductory Remarks

Distributed Approach

- Not centrally determined: the decision lies at the mobile terminals

Visible Light Communications Personal Area Networks (VPANs)

- The communication signal is encoded on top of the illumination light
- Energy saving – "green" communication
- High Speed Connectivity Potential
- No health hazards, reduced interference and low transmission power at almost no cost

Resource Allocation

- Optimal **OAPs' Selection** within the users, **Resource Blocks (RBs)** and **Uplink Transmission Power** allocation based on Maximum Gain Policy and Utility Maximization

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Paper Contribution

Self Optimization

- The users optimally determine their transmission parameters irrespective of the selected transmission technique

Topology Optimization and Optimized User Transmission

- OAP selection
- Uplink Transmission Power Allocation

Power Allocation in the Uplink of VPANs

- One of the first approaches in literature, so far only downlink transmission was examined

NOMA

- Presentation of NOMA (Non Orthogonal Multiple Access) as a new promising transmission technique for resource allocation in the 5G networking era

Extensive Comparisons

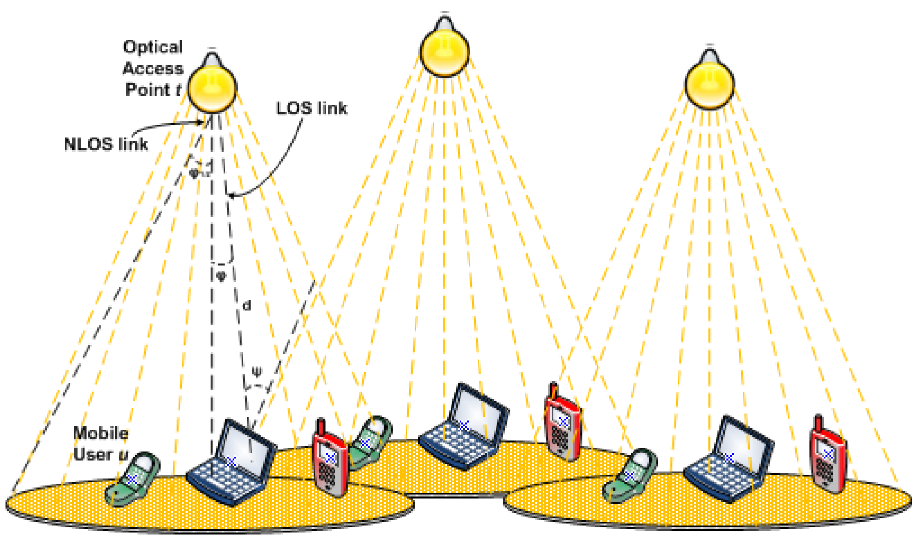
- NOMA is in depth compared with OFDMA (Orthogonal Frequency Division Multiple Access) – Advantages and Disadvantages - Conclusions

Presentation Agenda

VPANs Topology & System Model

- Multi-cell VPAN network consisting of
  - T OAPs $\mathcal{T} = \{t = 1, 2, ..., T\}$
  - U Mobile Users $\mathcal{U} = \{u = 1, 2, ..., U\}$
- A spectrum of total bandwidth W is devoted to each OAP

Simple VPAN topology



- Each user u communicates with an OAP t via a communication link $l = \{u, t\}$
- Line of Sight (LOS) between the user and the OAP:

$$H_{u,t} = \begin{cases} \frac{(m+1)A}{2\pi d^2} \cos^m(\varphi) T_s(\psi) g(\psi) \cos(\psi), & 0 \le \psi \le \psi_c \\ 0, & otherwise \end{cases}$$

A: photodetector area
φ: irradiance angle
$T_s(\psi)$: signal transmission coefficient of an optical filter
ψ: angle of incidence
m: order of Lambertian emission
g(ψ): gain of an optical concentrator
d: distance between the OAP and the user

Presentation Agenda

OFDMA vs. NOMA

Orthogonal Frequency Division Multiple Access (OFDMA)

- The bandwidth of each Optical Access Point is divided into subcarriers, organized into Resource Blocks
- Each Resource Block is reserved for one user within the OAP, and reused among different OAPs
- Co-channel interference caused by reuse of RBs from different OAPs

Non-Orthogonal Multiple Access (NOMA)

- Users within the same OAP simultaneously exploit the whole bandwidth, leading to considerable achievable rate enhancements
- Each user decodes only the signals of other users with better channel gain (SIC interference cancellation technique)
- Interference from users with worse channel gain is treated as noise

SINR (γ)

$$\gamma_{u,t}^{(\mathrm{r})} = \frac{R_{PD} H_{u,t} P_{u,t}^{(r)}}{\sum_{u'=1, u' \neq u, t \in \mathcal{T}}^{U} H_{u',t} P_{u',t}^{(r)} + \xi}$$

R_{PD}: photodiode responsitivity
$H_{u,t}$: line of site path gain between user and the OAP
$P_{u,t}$: user's uplink transmission power
ξ: cumulative noise power

$$\gamma_{u,t} = \frac{R_{PD} H_{u,t} P_{u,t}}{\sum_{u' > u, t \in \mathcal{T}}^{U} H_{u',t} P_{u',t} + \xi}$$

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Optical Access Point Selection

- **A mobile user may reside within multiple OAPs**
- **Maximum Gain Selection (MGS) Policy:**
  Each user within the VPAN select the OAP that provides the highest path Gain H between him and the OAP
- **Near Optimal Solution:**
  Each user achieves the best feasible channel conditions based on the line of sight channel gain H, Channel gain diversity
- **Perfect path gain knowledge necessary**

$$\boldsymbol{H}(u,t)=\begin{bmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,T} \\ H_{2,1} & H_{2,2} & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ H_{U,1} & H_{U,2} & \cdots & H_{U,T} \end{bmatrix} \Rightarrow l^{*}=\{u^{*},t^{*}\}=\arg\max_{t\in\mathscr{T}} \boldsymbol{H}(u,t)$$

Users within an OAP vary with time, thus the MGS problem for OAP selection should be solved periodically per time slot

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Utility Functions

- Reflect users' degree of satisfaction as a result of their actions
- A user targets at transmitting with low uplink transmission power:
  - ⇒ Enhanced battery life
  - ⇒ Less interference in the multi-cell VPAN environment
- Satisfaction increases with high transmission data rate and lower transmission power values
- Utility functions show the trade-off between the among parameters

Utility Functions

$$OFDMA: \quad U_{u,t}^{(r)} = \frac{W \cdot f_u\left(\gamma_{u,t}^{(r)}\right)}{N_t \cdot P_{u,t}^{(r)}}$$

$$NOMA: \quad U_{u,t} = \frac{W \cdot f_u\left(\gamma_{u,t}\right)}{P_{u,t}}$$

N_t: number of users within the OAP
W: OAP's bandwidth
$f_u(\cdot)$: efficiency function - represents the probability of successful packet transmission

Presentation Agenda

Problem Formulation and Solution Approach (1/2)

Objective

Each user acting selfishly targets at maximizing his overall perceived satisfaction (utility) through an optimally determined transmission power value via a distributed approach

Uplink Power Allocation Problem Formulation

$$OFDMA: \quad \max_{P_{u,t}^{(r)}} U_{u,t}^{(r)}\left(P_{u,t}^{(r)}, \boldsymbol{P}_{\textbf{-u,t}}^{(r)}\right) \qquad s.t. \quad 0 \prec P_{u,t}^{(r)} \leq \frac{P_{u,t}^{Max}}{R_{u,t}}$$

$$NOMA: \quad \max_{P_{u,t}} U_{u,t}\left(P_{u,t}, \boldsymbol{P}_{\textbf{-u,t}}\right) \qquad s.t. \quad 0 \prec P_{u,t} \leq P_{u,t}^{Max}$$

⇒ The first approach towards uplink transmission power allocation in VPANs alongside QoS provisioning

Optimization Solution Approach

First order derivative of the utilities:

$$\frac{\partial U_{u,t}^{(r)}}{\partial P_{u,t}^{(r)}} = 0 \Leftrightarrow \frac{\partial f_u\left(\gamma_{u,t}^{(r)}\right)}{\partial \gamma_{u,t}^{(r)}} \cdot \gamma_{u,t}^{(r)} - f_u\left(\gamma_{u,t}^{(r)}\right) = 0$$

$$\left(resp. \quad \frac{\partial U_{u,t}}{\partial P_{u,t}} = 0 \Leftrightarrow \frac{\partial f_u\left(\gamma_{u,t}\right)}{\partial \gamma_{u,t}} \cdot \gamma_{u,t} - f_u\left(\gamma_{u,t}\right) = 0 \right)$$

Problem Formulation and Solution Approach (2/2)

Unique Solution

Unique Solution due to sigmoidal form of f(γ) and "one-to-one" SINR function for both OFDMA and NOMA transmission techniques

$$OFDMA: \quad P_{u,t}^{(r)*} = \min\left\{ \frac{\gamma_{u,t}^{(r)*} \cdot \left(\sum_{\substack{u'=1 \\ u'\neq u \\ t\in \boldsymbol{T}}}^{U} H_{u',t} P_{u',t}^{(r)} + \xi \right)}{R_{PD} H_{u,t}}, \frac{P_{u,t}^{Max}}{R_u} \right\} \Rightarrow \boldsymbol{P}^{(r)*} = \left[P_{1,t}^{(r)*}, P_{2,t}^{(r)*}, \ldots, P_{u,t}^{(r)*}, \ldots, P_{U,t}^{(r)*} \right]$$

Optimal Uplink Transmission Power Vectors

$$NOMA: \quad P_{u,t}^{*} = \min\left\{ \frac{\gamma_{u,t}^{*} \cdot \left(\sum_{\substack{u'>u \\ t\in \boldsymbol{T}}}^{U} H_{u',t} P_{u',t} + \xi \right)}{R_{PD} H_{u,t}}, P_{u,t}^{Max} \right\} \Rightarrow \boldsymbol{P}^{*} = \left[P_{1,t}^{*}, P_{2,t}^{*}, \ldots, P_{u,t}^{*}, \ldots, P_{U,t}^{*} \right]$$

Presentation Agenda

NOAPRA Algorithm (1/2)

NOAPRA

- **N**on-Cooperative **OAP** Selection and **R**esource **A**llocation Algorithm:
- Decentralized, iterative, distributed, and low complexity - divided in two parts

OAP Selection Part

Based on Maximum Gain Selection Policy, the Matrix H(u,t) is created, given perfect knowledge of path gain information. Set $k=1$ and $U^{(0)}=\{1,2,\ldots,U\}$	Step A 1
Each user u* connects to the OAP t, via creating a communication link based on the highest path gain $H_{u,t}$ $$l^* = \{u^*, t^*\} = \underset{u^* \in \mathcal{U}, t^* \in \mathcal{T}}{\arg\max}\ \boldsymbol{H}(u,t)$$	Step A2
Delete user u* from the overall set of users: $$U^{(k+1)} = U^{(k)} - \{u^*\}$$	Step A3
If $U^{(k+1)} = \varnothing$ then stop. Otherwise go to Step 2	Step A4

NOAPRA Algorithm (2/2)

Resource Allocation Part

RB's Allocation (OFDMA)

Each OAP is aware of the number of users residing within it (i.e., *U*)	Step B1
If R=U: one Resource Block $r \in \mathcal{R}$ is allocated per user $u \in \mathcal{U}$	Step B2

Uplink Transmission Power Allocation

Each user within an OAP initially transmits with a randomly selected feasible uplink transmission power and set k=0: (OFDMA) $0 \prec P_{u,t}^{*(\mathrm{r})(0)} \prec \frac{P_{u,t}^{Max}}{R_{u,t}}$ (NOMA) $0 \prec P_{u,t}^{*(0)} \prec P_{u,t}^{Max}$	Step C1
The controller collects the information and each OAP announces the overall interference to the users. Each one user computes his sensed interference	Step C2
Given the overall interference, each user updates his uplink transmission power. Set k=k+1	Step C3
If $\left\|P_{u,t}^{*(\mathrm{r})(k+1)} - P_{u,t}^{*(\mathrm{r})(k)}\right\| \le \varepsilon$ (resp. $\left\|P_{u,t}^{*(k+1)} - P_{u,t}^{*(k)}\right\| \le \varepsilon$), e.g., $\varepsilon = 10^{-5}$ then Stop Otherwise go to step 2.	Step C4

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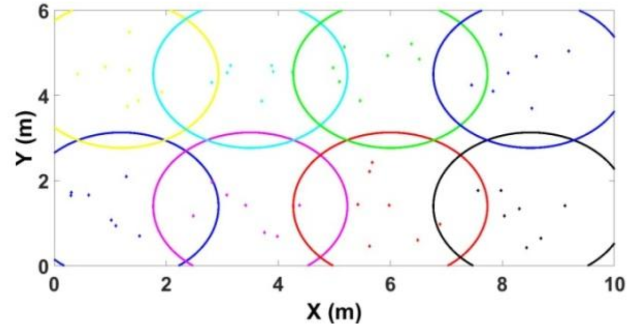
Numerical Results

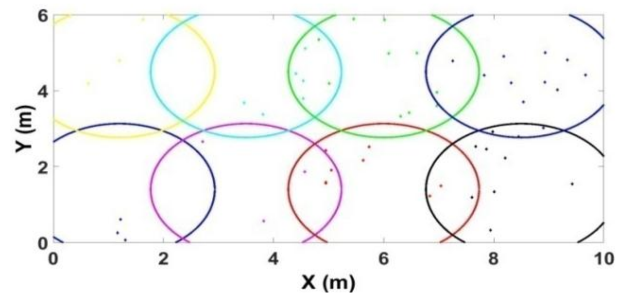
Simulation Scenario

- VPAN network with 8 OAPs within a room of size 10m x 6m x 3m
- OFDMA: 7 Resource Blocks are available
- P_{max}=1W
- W_{OAP}=20 MHz
- N_{total} = 56 users

Case 1: Uniform Distribution (7 users per OAP)

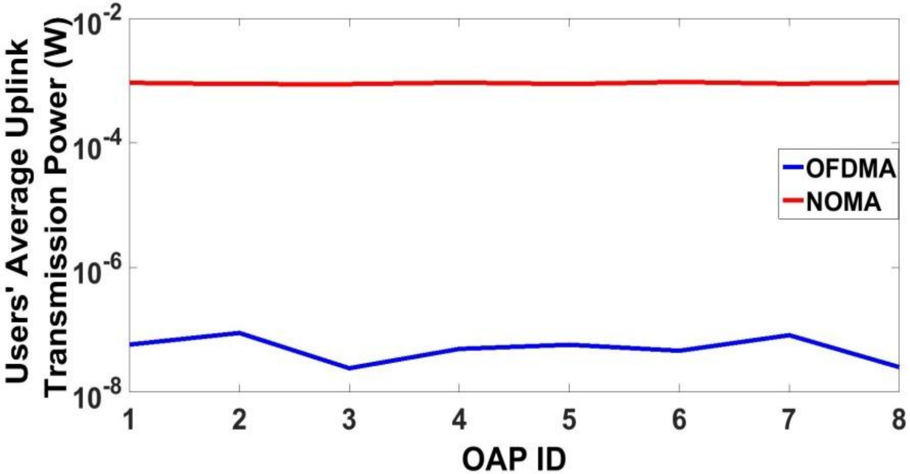


Case 2: Non-Uniform Users' Distribution



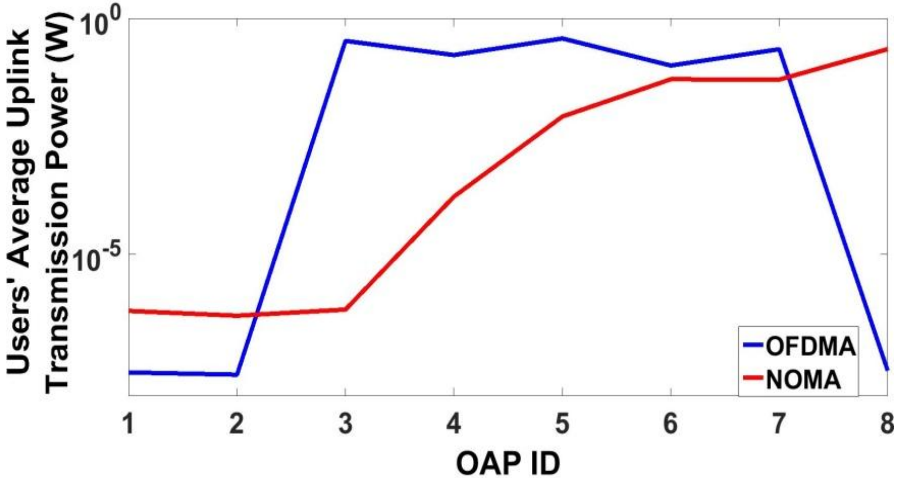
Users' Average Uplink Transmission Power per OAP

Case 1: Uniform Distribution



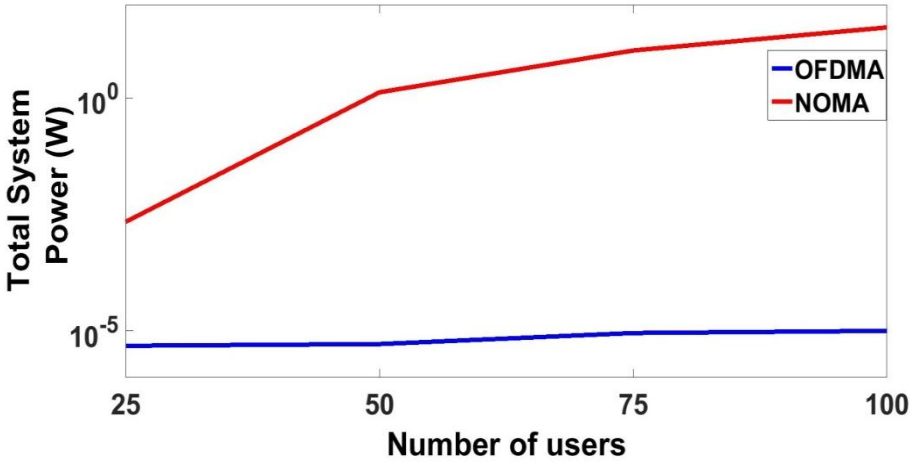
- In **OFDMA**, uplink transmission power considerably increases in non uniform user distribution since users share the same resource blocks within different OAPs, causing much higher interference

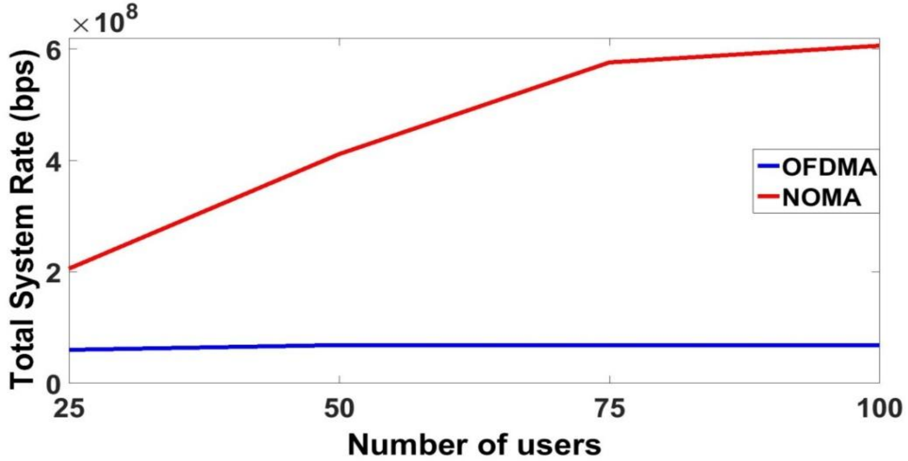
Case 2: Non-Uniform Distribution



- In **NOMA,** increase in uplink transmission power for non uniform distribution is smoother due to the interference cancellation technique

System's Total Uplink Transmission Power and Rate for Increasing Number of Users



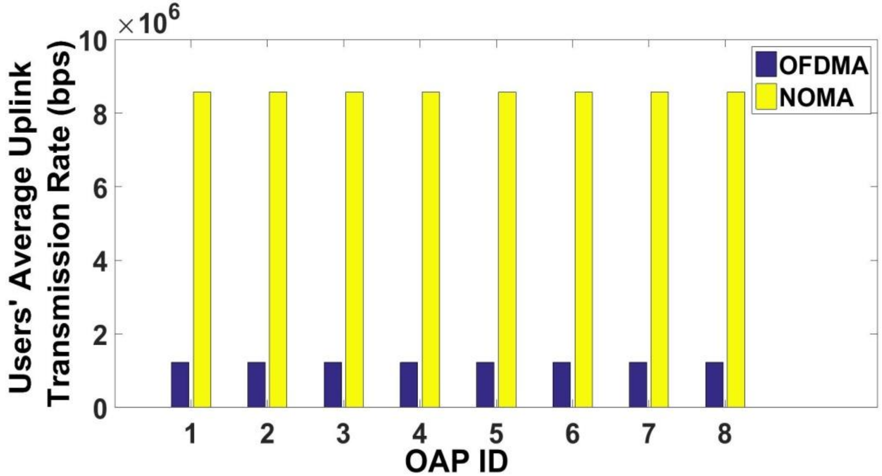


- In **OFDMA**, due to the fixed number of reusable RBs, the system cannot support more than 56 users, thus any additional users are rejected. Transmission power and rate remain constant

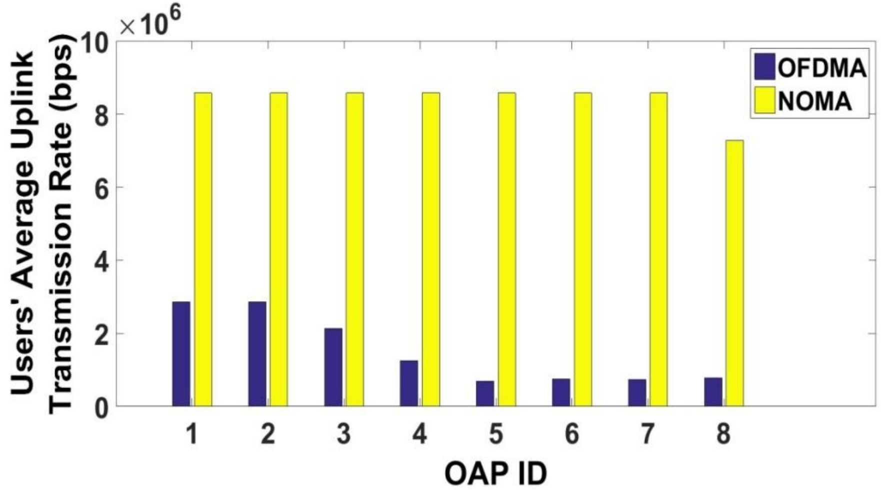
- In **NOMA**, the system can accommodate and serve a much larger number of users providing superior data rate potential

Users' Average Uplink Transmission Rate

Case 1: Uniform Distribution



Case 2: Non-Uniform Distribution



- In **NOMA**, uplink transmission rate is considerably higher than OFDMA since the users can exploit the whole bandwidth, regardless of the user distribution within the network

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Takeaways

- **Optimal Optical Access Point selection** alongside Transmission **Power Allocation** in the **Uplink of VPANs** under **various transmission techniques**

- **Visible Light Communications** a promising wireless technology:
  - Ultrahigh transmission speeds
  - Decreased users' transmission power
  - No threat to human health

- **NOMA**
  - All users can simultaneously exploit the whole bandwidth
  - Considerable interference mitigation

- **NOMA vs. OFDMA**
  - NOMA can provide users with better service quality than OFDMA due to the interference mitigation (SIC) technique, regardless of the user distribution with the network
  - Due to the absence of Resource Blocks per user, NOMA can sufficiently accommodate more users than OFDMA

Resource Allocation in Visible Light Communication Networks NOMA vs. OFDMA Transmission Techniques

Thank you for your attention!

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