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A Systematic Review on Non-Orthogonal Multiple Access (NOMA) Based on Visible Light Communication for Intelligent Transportation Systems

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Keywords:
MIMO; NOMA; Power Allocation; Spectral Efficiency; Visible Light Communication (VLC); V2V Communication.

Highlights:

- *NOMA-VLC is a promising solution among multiple access technologies, offering improved spectral efficiency, system capacity, power consumption, and reliability.*
- *The interference issues can be addressed by employing Successive Interference Cancellation (SIC) technology alongside NOMA.*
- *V2V-VLC through NOMA technology was examined and outperformed OFDM with a higher SNR, while OFDM excelled in achieving a lower BER.*

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Abstract: Non-Orthogonal Multiple Access (NOMA) is a cutting-edge technology that permits several users to use the same frequency resources and transfer data at once. Visible light communication also known as VLC, is an innovative technology that offers access to an unoccupied spectrum, enables fast data transmission speeds, thereby making it a complementary addition to current radio frequency technology. Although VLC has its advantages, it also comes with some downsides. One major issue is the modulation bandwidth of LEDs, which can be quite challenging when creating high speed VLC systems. Non-orthogonal multiple access (NOMA), particularly power-domain NOMA (PD-NOMA), has become a viable multiple access approach, ensuring sufficient bandwidth allocation for VLC systems. This study delves into multiple access techniques in VLC systems, in particular NOMA, and discusses its fundamental principles, key ideas and practical implementations like vehicular communication. It also addresses the associated hurdles, such as ensuring equitable distribution of optical power among users, leveraging MIMO technology, and grappling with LED nonlinearity issues. In summary, we underscore the significance of utilizing NOMA-VLC technology to enhance wireless communication systems and optimize spectral efficiency.

مراجعة منهجية للوصول المتعدد غير المتعامد استنادًا إلى الاتصالات الضوئية المرئية لأنظمة النقل الذكية

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الخلاصة

الوصول المتعدد غير المتعامد هو تقنية واعدة لتحسين الكفاءة الطيفية وقدرة النظام لأنظمة الاتصالات اللاسلكية من خلال السماح لعدة مستخدمين بمشاركة نفس الموارد ونقل البيانات في وقت واحد. الاتصالات الضوئية المرئية هي تقنية ناشئة أخرى تستخدم الموجات الضوئية لنقل البيانات، والتي تتمتع بالعديد من المزايا مثل التداخل المنخفض والأمان العالي وسهولة التنفيذ. لذلك، اكتسب الجمع بين الوصول المتعدد غير المتعامد والاتصالات الضوئية المرئية، اهتمامًا كبيرًا كحل محتمل لأنظمة الاتصالات. تقدم هذه الورقة لمحة عامة عن التطورات الأخيرة في الوصول المتعدد غير المتعامد القائم على الاتصالات الضوئية المرئية، بما في ذلك المفاهيم الأساسية وتحليل الأداء والتطبيقات. على وجه الخصوص، نسلط الضوء على مزايا الوصول المتعدد غير المتعامد القائم على الاتصالات الضوئية المرئية لأنظمة اتصالات المركبات، مثل الكفاءة الطيفية المحسنة، وسعة النظام، والموثوقية. نناقش أيضًا تحديات وفرص الوصول المتعدد غير المتعامد القائم على الاتصالات الضوئية المرئية، بما في ذلك تخصيص الطاقة وتعدد المداخل والمخارج والخصائص غير الخطية للمصابيح الثنائية الباعثة للضوء. أخيرًا، نستنتج أن الوصول المتعدد غير المتعامد القائم على الاتصالات الضوئية المرئية هي تقنية واعدة يمكنها إحداث ثورة في أنظمة الاتصالات، وهناك حاجة إلى مزيد من البحث والتطوير لاستغلال إمكاناتها بالكامل.

الكلمات الدالة: اتصالات الضوء المرئي، الوصول المتعدد غير المتعامد، تعدد المداخل والمخارج، تخصيص الطاقة، الكفاءة الطيفية، اتصالات المركبات.

1.INTRODUCTION

The rapid growth of multimedia applications, wireless devices, mobile apps and the emergence of the Internet of Things (IoT), leads to a surge in traffic needs, that call for fast wireless connections with high data rates [1]. Visible light communication (VLC) is a cutting-edge technology in communication that utilizes visible light for both lighting and wireless transmission [2]. VLC provides advantages that make it favorable, including the wide unregulated range of visible light, resulting in faster data rates and better connectivity compared to traditional radio frequency (RF) networks. Additionally, it boasts energy efficiency and easy deployment using light emitting diodes (LEDs) and photodiodes (PDs) devices, at both the transmitter and receiver ends, respectively [3]. The transmission process is referred to as intensity modulation (IM) at the sending end while at the receiving end it involves direct detection (DD) of intensity changes using a photodetector or image sensor [4]. VLC has benefits since light frequencies have safe wavelengths for the human body compared to radio frequencies and infrared rays that may pose risks especially to eyes and skin. IM/DD-based VLC systems use cost-effective LED and photodiode devices at both transmitter and receiver sites. Visible light cannot penetrate through objects, making VLC communication inherently secure and preventing eavesdropping. However, a crucial challenge in creating high-speed systems depend on VLC is the restricted modulation bandwidth of commercially available white LEDs, which usually has a bandwidth of a few megahertz [5]. To overcome this issue, several techniques have been proposed to improve the capacity of bandlimited VLC systems. Kisacik et al. [6] proposed the pre-equalization, Anous et al. [7] applied the blue filtering, Iraqi and Al-Dweik [8] used the orthogonal frequency division multiplexing OFDM as a modulation technique due to its various advantageous characteristics, including spectral efficiency. Jabori and Ridha [9] proposed OFDM with high-order quadrature amplitude modulation (QAM) constellations, non-orthogonal multiple access (NOMA) technique has been used by Almohimmah and Alresheedi [10], Omer et al. [11] used the multiple-input multiple-output (MIMO) transmission, among others. Blue filtering and pre-equalization are two techniques that can broaden the modulation bandwidth of LEDs, but blue filtering results in decreased signal power and thus, a lower signal-to-noise ratio (SNR). Pre-equalization, on the other hand, can extend the LED bandwidth without sacrificing received signal power and is widely used in VLC systems. Another approach to capacity improvement is adaptive OFDM with bit and power loading, which has also been used in high-speed VLC systems by Mardanikorani et al. [12]. However, its implementation can be complex and the need for instant feedback information for SNR, while research has demonstrated, NOMA presents a particularly promising approach for emerging wireless communications using radiofrequency (RF) and optical technologies. Its potential to significantly enhance system throughput and support widespread connectivity make it an attractive option for future communications systems. With the purpose of assess the performance of NOMA technology that can be applied in VLC, several prerequisites have been suggested to ensure the evaluation techniques, since they are associated with the performance evaluation of visible light communication. Essentially, a main question that rose from these processes is as follow: what is the proper benchmark method that can be used to identify the suitability of NOMA for enhancing the performance in VLC? In this article, different forms of NOMA are examined and contrasted through various assessment criteria in in all of the following sections.

1.1.Systematic Literature Review Characterization and Queries

The keywords that hold the greatest significance in the area under scrutiny are "NOMA", "visible light communication" and "performance evaluation". The pursuit of evaluating performance led to a systematic review conducted in this study, which employed the utilization of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to ensure a thorough and rigorous review process. During the search for pertinent articles, three search engines were utilized. The first one, IEEE Xplore, is a research engine specializing in academic studies, which provides access to over five million full-text documents from some of the most prestigious publications in the fields of electronics, electrical engineering, and computer science, that have been extensively cited globally. The researchers utilized MDPI as their second search engine. MDPI is known for its scientific journals. It was originally created by Shu-Kun Lin to store chemical research but over time has grown to include than 390 access peer reviewed journals. It is now a key player in open access publishing. The final search engine used in the research was ScienceDirect, which offers access to medical publications from the publisher Elsevier, a well-respected British publisher. By utilizing these three search engines the research team ensured coverage of NOMA studies and VLC performance evaluations gathering a range of articles and information to draw meaningful conclusions. After gathering articles for the literature review, the researchers went through three steps to review and filter them. Initially, they removed any extraneous papers. In the next step, they reviewed the titles and summaries to eliminate any duplicated articles during the second phase. Finally, they carefully selected full text articles from the second phase based on specific criteria set for this study as a final step. In September 2022, we searched for articles by using three search engines; IEEE Xplore, ScienceDirect and MDPI. The researchers utilized keywords to pinpoint topics related to the study field, such as: "evaluating performance with NOMA ", "analyzing performance with NOMA ", "enhancing performance through NOMA " and "improving performance with NOMA " connected by the operator 'OR'. They also explored variations of terms, like " visible light communication ", "VLC systems," "VLC networks," and "VLC channels" linked by 'AND'. Through this method, the researchers were able to efficiently collect articles for the systematic review of performance evaluation in NOMA for Visible Light Communication (VLC). All papers that satisfied the eligibility criteria outlined in Fig. 1 were included for further examination. Researcher team was able to conduct a systematic review with a focus on recent and relevant scientific papers related to the study. The initial search yielded 254 articles that were published between 2018 and 2023, consisting of 50, 40, and 164 papers retrieved from MDPI, ScienceDirect, and IEEE Xplore, respectively. After the initial search, the researcher excluded 36 duplicate articles from the gathered 254 articles, leaving 218 articles. Subsequently, the team analyzed the article titles and abstracts to filter out irrelevant papers, resulting in the removal of 172 articles. Eventually, only 46 articles were nominated for additional analysis. After straining the collected articles, the study group was left with 46 full-text articles. Next, the team further assessed these articles and tapered them down to 20 feasible articles that were thought relevant for the survey's purpose. The 20 nominated articles were read methodically, and the study's purposes were carefully summarized. This filtering process aided the researchers to confirm that only the most appropriate and high-quality articles were comprised in the survey. The research only reserved articles that content the criteria outlined in Fig. 1. The groups were found through a pre-survey of the appropriate research literature. Following the removal of duplicates, the remaining articles were subjected to two stages of screening and filtering based on the established criteria. Articles that did not meet the fixed criteria were eliminated, resulting in a final set of articles for further analysis. The criteria for exclusion were established through two steps: (1) articles that were not written in English, and (2) articles that were not related to performance evaluation for visible light communication.

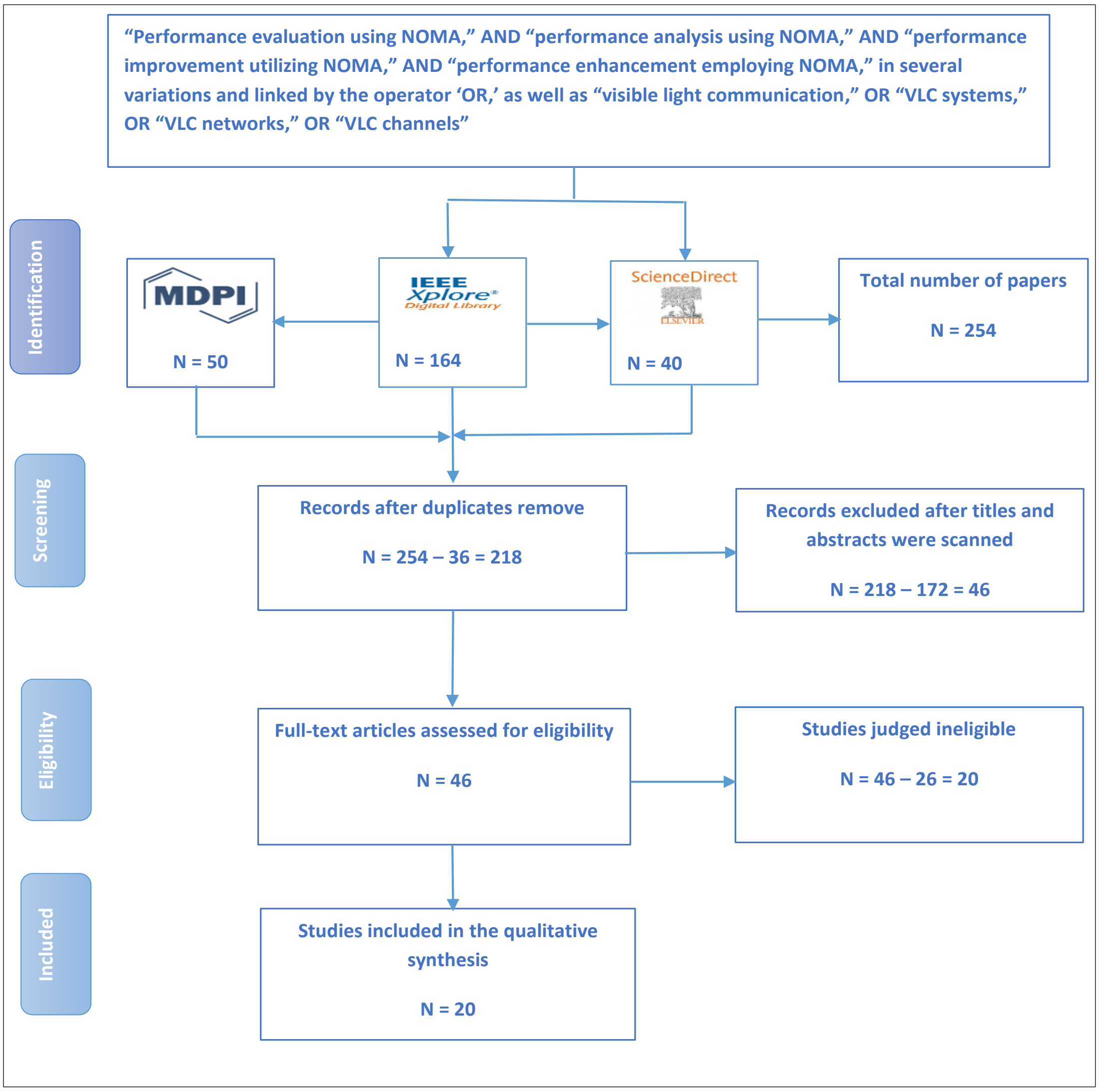

Fig. 1 PRISMA Flowchart Diagram.

1.2.Contribution of this Survey

The present article provides a comprehensive examination of NOMA in VLC, along with an overview of the prevailing difficulties and problems related to the application of NOMA. Additionally, the superiority of NOMA over other multiple access technologies for VLC is emphasized. Therefore, the key contributions of this paper include the aforementioned discussion.

- We provide a comprehensive overview of both orthogonal and non-orthogonal techniques for VLC multiple access.
- We present a thorough assessment of NOMA, investigating the diverse hurdles linked to it. The primary principle and its perks, impediments, and resolutions of NOMA are analyzed.
- We focus on VLC-based V2V communication and how NOMA can surpass orthogonal multiple access, despite the limited research in this area.
- Lastly, this paper explores different research possibilities concerning the utilization of VLC-NOMA to maximize the potential of this technology.

1.3.Organization and Reading Map

The format of this survey paper is illustrated in Fig. 2. A complete list of the acronyms employed in this article is presented in Table 1. The rest of the paper is structured as follows. Section 2 of this article provides the historical and contextual foundation of multiple access (MA) techniques used in VLC. A comprehensive overview of the different NOMA variations of VLC is presented in section 3. The topic of VLC-V2V communication is discussed in section 4. Section 5 focuses on the research opportunities for VLC-NOMA. Lastly, section 6 offers the conclusion of this paper. Fig. 3 also includes a roadmap for readers. For those who wish to gain an understanding of the basics of NOMA, we suggest focusing on sections 1, 2, and 3. Section 4 examines one of the applications of NOMA utilized in VLC. Lastly, for readers who want a comprehensive overview of NOMA, including its challenges and research opportunities, it is recommended to read sections 1, 3, 4, and 5.

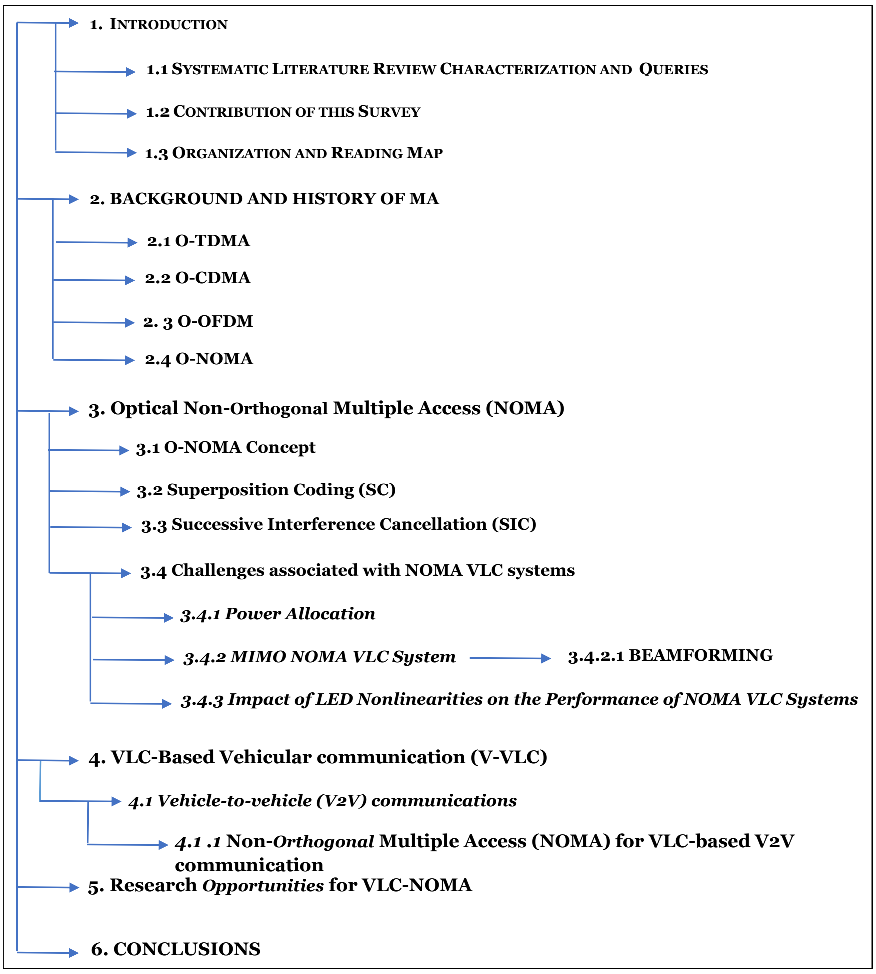

Fig. 2 The Organization of the Survey Article.

Table 1 Nomenclature and Abbreviation.

Acronym	Explanation	Acronym	Explanation
VLC	Visible Light Communication	PD-NOMA	Power Domain NOMA
LED	Light Emitting Diode	SC	Superposition Coding
IM	Intensity Modulation	MUD	Multiuser Detection
DD	Direct Detection	SIC	Successive Interference Cancellation
OFDM	Orthogonal Frequency Division Multiplexing	NGDPA	Normalized Gain-Difference Power Allocation
QAM	Quadrature Amplitude Modulation	FPA	Fixed Power Allocation
NOMA	Non-Orthogonal Multiple Access	GRPA	Gain Ratio Power Allocation
MIMO	Multiple-Input Multiple-Output	DPC	Dirty Paper Coding
SNR	Signal-To-Noise Ratio	MRT	Maximum Ratio Transmission
RF	Radio Frequency	ZF	Zero Forcing
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses	LOS	Line-of-Sight
PD	Photodiode	MUMISO	Multiuser Multi-input single output
MDPI	Multidisciplinary Digital Publishing Institute	UMTS	Universal Mobile Telecommunication System
MA	Multiple Access	AEDs	Active Eavesdroppers
V2V	Vehicle to Vehicle	PEDs	Passive Eavesdroppers
FDMA	Frequency Division Multiple Access	ISI	Inter-Symbol Interference
TDMA	Time Division Multiple Access	SER	Symbol Error Rate
3G	Third Generation	2D	Two-Dimension
CDMA	Code Division Multiple Access	V-VLC	Vehicular -VLC
OTDMA	Optical-TDMA	ITS	Intelligent Transportation Systems
O-CDMA	Optical-CDMA	V2I	Vehicle-to-Infrastructure
BER	Bit Error Rate	LTE	Long Term Evolution
MMSE	Minimum Mean Square Error	PAPR	Peak-to-Average Power Ratio
O-OFDM	Optical-OFDM	3GPP	Third-Generation Partnership Project
O-NOMA	Optical-NOMA	CD-NOMA	Code domain NOMA
DCO-OFDM	Direct Current Biased Optical OFDM	SCMA	Sparse code multiple access
ACO-OFDM	Asymmetrically Clipped Optical OFDM	LDS-CDMA	Low-density spreading-CDMA

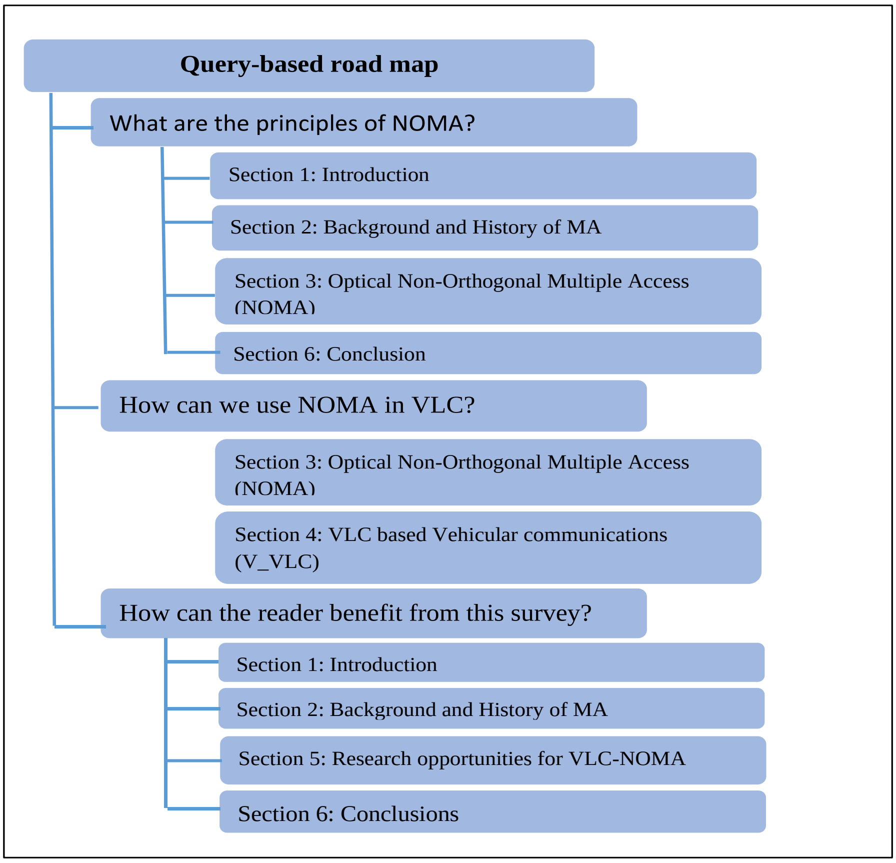

Fig. 3 The Roadmap for Readers.

2.BACKGROUND AND HISTORY OF MA

Various techniques have been developed for efficient sharing of network resources among a large number of users, such as FDMA and TDMA in first- and second-generation cellular technology, and CDMA in 3G cellular systems. Yang et al. [13] proved that the new approach of NOMA allows multiple users to transmit and receive data simultaneously on the same frequency band but with different power levels, which enhances system performance and connectivity. Traditional MA methods for RF systems may need modifications for use in VLC systems [14].

2.1.Optical Time Division Multiple Access (O-TDMA)

OTDMA, is a technique that enables multiple users to share the same LED light source in VLC systems by assigning each user a unique time slot. It provides simple implementation and high time synchronization, but has limited scalability due to the limited number of time slots and is susceptible to interference from ambient light sources.

2.2.Optical Code Division Multiple Access (O-CDMA)

O-CDMA is used in VLC to encode data by assigning each user a unique code. The encoded data is then modulated onto the LED light source and transmitted, and at the receiver, a correlator is used to detect and recover the original data. O-CDMA enables multiple users to operate within a confined space in VLC. However, it encounters issues due to interference from sources leading to the need for costly and intricate optical correlators.

2.3.Optical Orthogonal Frequency Division Multiplexing (O-OFDM)

O-OFDM represents a type of modulation used in VLC, where the frequency band is divided into orthogonal sub frequency carriers for transmission purposes [15]. This method enhances the efficiency of data transmission, optimizes the use of the frequency spectrum and also manages interference caused by signals bouncing off paths. However, it encounters challenges such as peak to average power ratio (PAPR) and frequency shifts, which may impact signal quality. According to research by Hameed et al. [16], implementing clipping and filtering techniques can address concerns related to PAPR.

2.4.Optical Non-Orthogonal Frequency Division Multiplexing (O-NOMA)

Within VLC systems, NOMA is utilized to optimize data transfer by assigning a different power level to each user. NOMA improves effectiveness, reduces sensitivity to signal degradation and channel variations. Nonetheless, NOMA faces hurdles such as susceptibility to interference and the requirement for signal processing algorithms that demand significant computational resources.

3.OPTICAL NON - ORTHOGONAL MULTIPLE ACCESS (NOMA)

3.1.O-NOMA Concept

The main concept of NOMA is that several users can use the same frequency resource at the same time in a non-orthogonal way, which enhances spectrum efficiency [17]. Nevertheless, to discrete the messages of each user, a more complicated receiver is wanted. There are two universal categories of NOMA solutions, namely code domain and power domain NOMA, based on their theoretical and implementation viewpoints [18]. Code domain NOMA(CD-NOMA) is based on the concept of multiple users sharing the same resources, similar to CDMA systems, but it differs in that it uses sparse spreading or non-orthogonal low cross-correlation sequences to achieve multiplexing. Several code domain NOMA techniques, including SCMA which applied by Zhang et al. [19]. Moreover, LDS-CDMA, LDS-OFDM, MUST, and SAMA, have been developed and gained popularity due to their effectiveness [20]. The second category of NOMA is based on power domain multiplexing (PD-NOMA), in which multiple users share the same resource (time/frequency/code) but are assigned different power levels. This enables non-orthogonal access through superposition coding (SC), which allows advanced multiuser detection (MUD) techniques like SIC or DPC which was used by Hussein and Haburi [21] at the receiver to decode the messages. The classification of NOMA schemes is presented in Fig. 4.

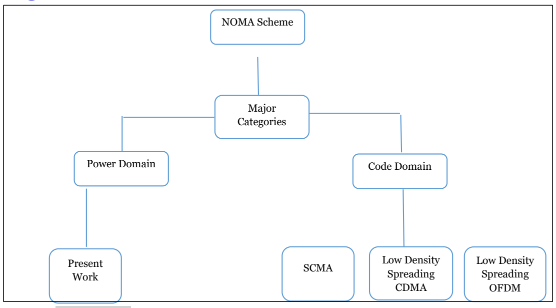

Fig. 4 NOMA Schemes Classification.

3.2 Superposition Coding (SC)

In a downlink broadcast channel, a transmitter can send multiple information signals to several receivers simultaneously. O-NOMA achieves SC by assigning higher power values to users with poorer channel conditions and lower power values to those with better conditions. Fig. 5 shows that the LED sends unipolar real signals $\varkappa_1$ and $\varkappa_2$ to U_1 and U_2, respectively. U_1, being closer to the LED and having a higher channel gain, is assigned a lower power level by the access point to $\varkappa_1$. The two signals $\varkappa_1$ and $\varkappa_2$ are combined and transmitted at the same time as S = $P_1\ \varkappa_1 + P_2\ \varkappa_2$, where $P_2 > P_1$ and the sum of the assigned power levels is equal to the total transmitting power of the LED. This principle can be extended to a larger number of users, where power values are assigned based on the channel gains of each user.

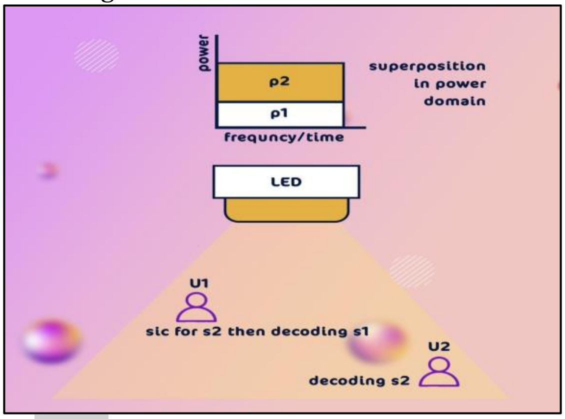

Fig. 5 Unipolar Real Signals in Downlink NOMA VLC System.

3.3. Successive Interference Cancellation (SIC)

As a result of the predominance of $\boldsymbol{P_2\varkappa_2}$ in the received signal portrayed in Fig. 5, $\boldsymbol{U_2}$ can interpret its signal directly by treating interference from the other user's signal as noise. In contrast, $\boldsymbol{U_1}$ must initially decode $\boldsymbol{x_2}$ and then subtract it from the combined signal to separate $\boldsymbol{x_1}$ from the residue. This is identified as successive interference cancellation (SIC), where the users are arranged in order of their respective signal strengths, enabling each receiving terminal to decode the strongest signal first, remove it, and iterate until it decodes the desired signal.

3.4.Challenges associated with NOMA VLC systems

3.4.1.Power Allocation

In NOMA-VLC, the power allocation involves assigning varying power levels to users using the same frequency band. The goal is to boost power for users with bad channel conditions aiming to improve their connection. Successive Interference Cancellation (SIC) can be used for balance throughput and fairness [22]. The challenge of the power allocation in NOMA-VLC can be addressed using optimization techniques, including fixed power allocation (FPA), gain ratio power allocation (GRPA) and normalized gain difference power allocation (NGDPA). Fixed Power Allocation (FPA) is a method for determining power allocation in VLC where power levels are assigned based on increasing channel gain values to the user's proximity to the transmitting LED which has been studied by Mounir et al. [23]. Though, to promote equitable power allocation, a new process called Gain Ratio-based Power Allocation (GRPA) was developed by Elewah et al. [24], take into consideration the channel gain ratio of a user relative to that of the first sorted user. Additionally, a method called Normalized Gain Difference Power Allocation (NGDPA) allocates power based on user channel conditions was applied by Shahab et al. [25].

3.4.2.MIMO NOMA VLC System

MIMO channels offer a compelling advantage as their capacity shows remarkable improvements compared to the basic single-input-single-output (SISO) channels that has been approved by Liu et al. [26]. The combination of MIMO and NOMA techniques in VLC systems, known as MIMO NOMA VLC, shows great potential in increasing system capacity and spectral efficiency. With multiple antennas on both ends and each user assigned to a unique beam, power allocation is adjusted based on individual channel conditions for maximum capacity and efficiency. Precoding schemes and SIC can be employed in multi-user MIMO-VLC systems to separate signals and cancel interference [27]. So, Utilizing MIMO-VLC has the potential to enhance system capacity by allowing for the simultaneous servicing of multiple users, that has been proved by Nawaf [28]. But the employment of MIMO-PD-NOMA-based VLC systems can result in heightened design complexity.

3.4.2.1.Beamforming Based MIMO-NOMA

Beamforming, in simple terms, refers to the technique of gathering signals from multiple sensors with the primary objective of enhancing the Signal-to-Noise Ratio (SNR) [29].So, Beamforming-based MIMO-NOMA is a technique that combines beamforming, MIMO, and NOMA to improve the performance of visible light communication (VLC) systems. This technique uses multiple antennas at both the transmitter and receiver ends to improve the system capacity and spectral efficiency. Beamforming is used to direct the signal to a specific user, while NOMA is used to enable multiple users to share the same resources. In beamforming-based MIMO-NOMA, the transmitter usages many antennas to generate many beams that are focused towards different users. Each beam is optimized to transmit a signal to a specific user, and the signal is amplified to maximize the received signal strength at the intended user. At the receiver end, multiple antennas are used to capture the signal from the different beams [30]. Beamforming techniques are used to direct the signal to a specific user. Various methods of beamforming can be applied, including Maximum Ratio Transmission (MRT), Zero Forcing (ZF) and Minimum Mean Square Error (MMSE). Ma et al. [31] Suggested employing beamforming to minimize the interference in downlink multi-cell MUMISO in VLC systems. Shaleesh et al. [32] Introduced ZF beamforming methods to enhance VLC systems. ZF beamforming and relaxed ZF beamforming can cater to both AEDs and PEDs devices simultaneously. The ZF beamforming method places a beamforming vector in the free space of the AEDs channel matrix to reduce their SNRs while boosting the UEs SNR. Conversely, the relaxed ZF beamforming strategy considers the presence of PEDs thereby relaxing the constraints on the SNRs of AEDs.

3.4.3.Impact of LED Nonlinearities on the Performance of NOMA VLC Systems

LEDs are widely utilized as transmitters in VLC systems due to their data transmission capacity, cost effectiveness and energy efficiency. Nonetheless, the nonlinear behavior of LEDs can result in challenges like, inter-symbol interference (ISI), signal distortion, decreased SNR and reduced system efficacy. Various strategies can be implemented to mitigate the effects of LED nonlinearity on NOMA-VLC system performance, such as adaptive modulation, channel equalization and pre-distortion. Adaptive modulation adjusts the modulation technique according to channel conditions to improve system performance. Channel equalization compensates for distortion induced by the characteristics of LEDs. Pre-distortion involves using a compensation filter to offset the nonlinear attributes of LEDs.

4.VLC-BASED VEHICULAR COMMUNICATION (V-VLC)

Vehicular Communication involves sharing information with their surroundings using wireless communication technologies. It is a vital aspect of Intelligent Transportation Systems (ITS) that goals to enhance transportation safety, efficiency, and sustainability [33] . Vehicular communication can be categorized into two types: Vehicle-to-Vehicle (V2V) communication and Vehicle-to-Infrastructure (V2I) communication. V2V communication contains exchanging information between two or more vehicles to deliver real-time information about possible road hazards and support advanced safety applications. V2I communication contains exchanging information between a vehicle and roadside infrastructure to offer drivers with real-time information about road traffic situations and provision progressive traffic management systems. The progress in vehicular communication has been importantly contributed by the use of suitable communication protocols such as IEEE 802.11p [34] and LTE-V2V standards [35].The IEEE 802.11p standard is intended to support V2V and V2I communications [36], offering data rates ranging from 6 Mbps to 27 Mbps at a transmission distance of around 300 meters [37]. Whereas cellular technologies have been assessed as an alternative, the 3GPP standardization has permitted effective message spreading over a large zone. UMTS and LTE are recognized as the third and fourth generation of mobile cellular systems, respectively. Due to the growing request for bandwidth, the current radio frequency (RF) spectrum is becoming strained, and new communication technologies need to be discovered. Visible light communication (VLC) has appeared as a viable choice for vehicular communication. VLC utilizes LED lights and photodiodes or cameras as receivers, resulting in minimal channel congestion and making it less susceptible to interferences. VLC allows for the transfer of data between points, maintaining low delays and using lightweight protocols even in areas with a high concentration of vehicles. VLC has been getting noticed as a replacement for radio-based communication [38]. Researchers are actively looking into VLC based transportation communication systems because they can integrate lighting traffic signals and data transmission effectively [39, 40]. The VLC system can be enhanced for V2V scenarios and similar applications due to its features. This system offers spectrum resources (ranging from 380 THz to 780 THz) which's approximately 10,000 times more than the RF spectrum (ranging from 300 kHz to 30 GHz). In 2020, Wang et al., [41] from the laboratory of electromagnetic wave information science at Fudan University presented a vehicle networking system that makes use of a VLC system with one input and multiple outputs. This cutting-edge system utilizes the headlights of vehicles as the transmitter integrating a a neural network deep learning equalizer to achieve transmission speeds of over 1 Gbps within a communication range of 4 meters.

4.1.Vehicle -to- Vehicle (V2V) Communications

V2V communication is a technology that allows cars to interact with each other for enhancing safety and traffic flow. A particular V2V communication approach employs VLC where LED lights are utilized to transmit data between vehicles. In this form of V2V communication each vehicle is fitted with modified LED lights that transmit data, which nearby vehicles can receive and interpret using VLC receivers. This communication is bidirectional, enabling data exchange between vehicles in a manner. VLC based V2V communication offers advantages, such as low latency, high data rates and minimal interference since it relies on visible light without being impacted from other wireless systems like cellular or Wi Fi networks. This technology holds the potential to enhance road safety by enabling vehicles to share real time information about road conditions, traffic flow and potential hazards. However, one of the challenges faced by VLC based V2V communication is its line-of-sight nature requiring transmitting and receiving vehicles to have visibility of each other for effective communication. It might pose a challenge in cities with high buildings or when the transmitting vehicle is blocked by another vehicle. Fig. 6 explain the principle of V2V based VLC. Meucci et al. [42] have devised a method that allows vehicles to exchange data using VLC with the Time Division Multiplexing (TDM) technique in outdoor settings even under direct sunlight. They tested the system at realistic distances of around 30 meters with vehicles positioned at angles. The results of the experiment showed that their system successfully enabled VLC communication between two motorcycles up to 21 meters apart when facing each other with error free transmission maintained within a range of 12 meters. Farahneh et al. [43] investigate how O-OFDM and adaptive modulation methods are used for V2V-VLC. The study explores a MIMO channel involving bidirectional polarimetric reflections and Interference from sunlight. Two O-OFDM schemes are investigated, namely Direct Current Biased Optical OFDM (DCO-OFDM) and Asymmetrically Clipped Optical OFDM (ACO-OFDM). Simulation results indicate a significant improvement in data rates, up to 50 Mbps, and a reduction in bit error rates (BER) in both line-of-sight (LOS) and non-LOS conditions, even with high noise levels. Sharda et al. [44] present a model for V2V-VLC in two realistic situations. In the first scenario, the study examines how vehicles randomly shift sideways while maintaining a fixed distance lengthwise between two communicating vehicles. In the second scenario, the distance between two vehicles can vary lengthwise, but their sideways movement remains constant. The research indicates that the effectiveness of the V2V-VLC system is significantly influenced by both shifts and variable longitudinal distances between vehicles.

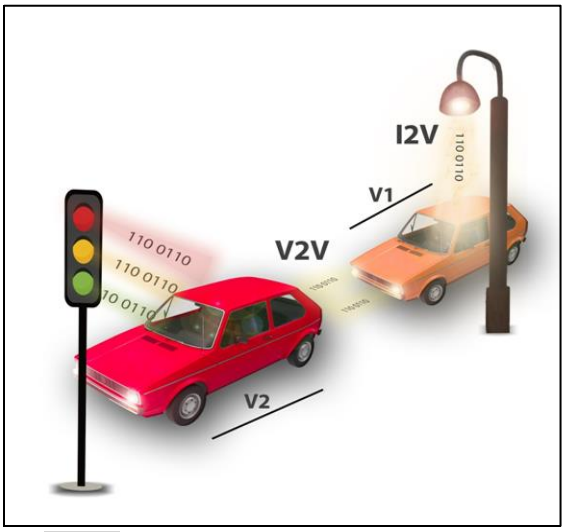

Fig. 6 The Principle of V2V Based VLC.

4.1.1.Non-Orthogonal Multiple Access (NOMA) for VLC-based V2V Communication

NOMA offers advantages compared to multiple access techniques, like OFDMA and TDMA. NOMA can serve a number of users with transmission needs at the same time which is leading to increased spectral efficiency, lower latency and reduced energy consumption. Moreover, NOMA promotes resource distribution among users by allocating more resources to those facing challenging channel conditions. In V2V communication NOMA enables communication between vehicles using the same VLC channel. This can be principally suitable in urban environments, where several vehicles may be in close proximity to each other, and diverse lighting sources may cause interference. NOMA can mitigate the effects of interference and enable more efficient use of the available channel resources. However, studies on NOMA in the field of vehicle communications are still few, Ghazijahani [45], focuses on utilizing NOMA technique in VLC for Vehicle-to-Vehicle (V2V) communication. The researchers simulated the proposed system under various realistic conditions to evaluate its performance in different scenarios. In addition to our work that deals with Beamforming based MIMO-NOMA in V2V communications. Fig. 7 illustrate the block diagram of 2*2 MIMO-NOMA-based VLC with applying beamforming technique. We have developed and implemented a VLC system for vehicular communication. Our system is designed to facilitate multi-vehicle communication (V2MVs) by incorporating random mobility of vehicles. Fig. 8 illustrate our work of V2MVs-based VLC system. Our hardware and software have been tested in various scenarios, including direct sunlight exposure, night light, fog, dust, and variable angle of FOV. To optimize bandwidth usage, we have used NOMA to distribute sub-bands among users, and beamforming has been utilized to improve the quality of service (QoS) by identifying desired users and treating other users as interferers. We have evaluated the system's performance based on received signal amplitude, packet error rate (PER), and SINR. We are currently investigating how vehicles can effectively and promptly share data. To accomplish this, we have evaluated two methods; NOMA and OFDM. By comparing these two technologies we aimed to determine which one is most suitable for our system based on their strengths and weaknesses. In this section, we present a representation that shows the results of implementing NOMA and OFDM. The graphical representation allows us to evaluate the performance of each method. Upon analyzing the representation, NOMA excels in achieving a SNR whereas OFDM performs better in reducing BER. Fig. 9 illustrate the SNR Vs BER for NOMA and OFDM.

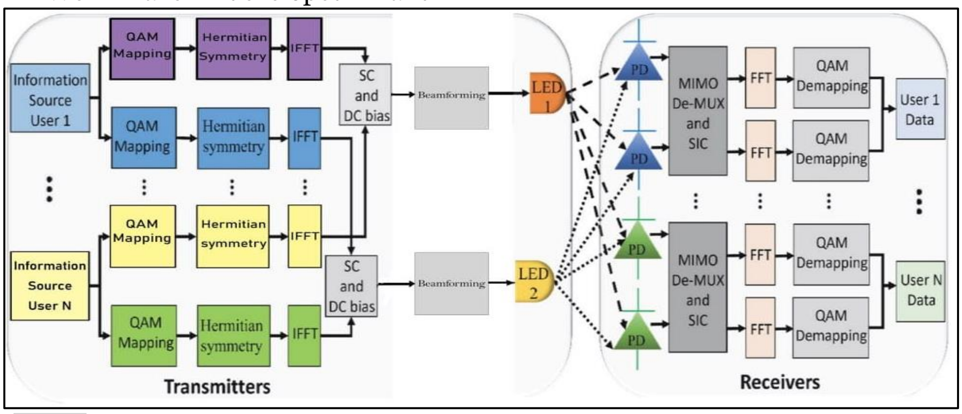

Fig. 7 The Block Diagram of 2*2 MIMO-NOMA-Based VLC with Beamforming.

Fig. 8 The present proposed Work of V2MV-Based VLC System.

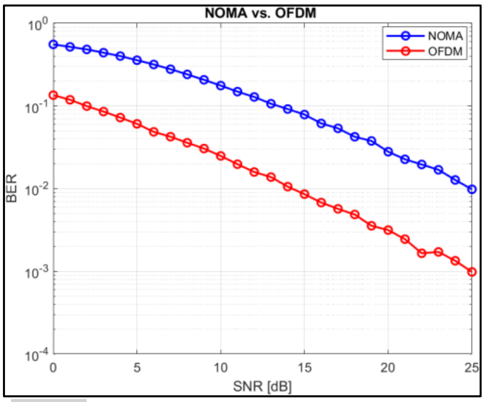

Fig. 9 The SNR Vs BER for NOMA and OFDM.

5.RESEARCH OPPORTUNITIES FOR VLC-NOMA

The new advancements, in Visible Light Communication (VLC) and Non-Orthogonal Multiple Access (NOMA) present research prospects across a range of fields. This encompasses examining the effectiveness of VLC-NOMA in situations, developing strategies, for allocating resources modeling channels, establishing security and privacy protocols integrating with wireless technologies and conducting real world trials and evaluations.

6.CONCLUSIONS

In our study we've examined the pros and cons of multiple access technologies, in Visual Light Communication (VLC) including NOMA. O-TDMA shows improved efficiency in VLC, but struggles with synchronization issues. On the hand, O-CDMA enhances security. but facing multiple access interference problems. O-OFDM is resilient against multipath fading. It may face challenges with high peak-to-average power ratio. Among these technologies, NOMA-VLC emerges as a solution that offers spectral efficiency, system capacity, lower power consumption and enhanced reliability. By allowing multiple users to share resources and transmit data simultaneously, NOMA-VLC opens up communication possibilities. While interference remains a concern, but solutions like Successive Interference Cancellation (SIC) can help address these issues. Additionally, we explored V2V communications using technology through NOMA which showed better performance compared to OFDM in terms of Signal-to Noise-Ratio (SNR) while OFDM excelled in achieving a lower BER. Overall, NOMA-VLC is seen as a groundbreaking technology that has the potential to transform communication standards. However, further research and development are crucial to realize its capabilities and unlock its future.

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