Integration of NOMA-Based VLC with Emerging Technologies

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Visible light communication (VLC), a high data rate communication technology, has proven its stature as a promising complementary to its radio frequency (RF) counterpart. VLC is a cost-effective, energy-efficient, and secure technology that exploits the current infrastructure, specifically within indoor and underwater environments. Non-orthogonal multiple access (NOMA) has been considered an effective technique to circumvent these shortcomings. The NOMA scheme has emerged as a revolutionary paradigm to address the shortcomings of VLC systems.

NOMA successive interference cancellation (SIC) spectral efficiency

1. Introduction

As the need for wireless data transmission continues to skyrocket, future wireless networks are going to require high spectrum efficiency, high bandwidth, and huge interconnectivity. The existing radio frequency (RF) band is getting increasingly overcrowded, making it difficult to meet these demands [1]. Because of its greater bandwidth, which does not compromise the RF spectrum, its energy efficiency, and its capacity to offer ubiquitous connection, visible light communication (VLC) has recently been suggested as a credible option for indoor wireless communication [2]. VLC can meet the above-mentioned objectives for future wireless networks by deploying an efficient multiple-access method [3]. Non-orthogonal multiple access (NOMA), which has great spectrum efficiency, is among the most transformative multiple-access techniques that have recently been suggested. Multiple users might share the same frequency/time resource block in NOMA, allowing for huge connections and great throughput. On the transmitting end, NOMA uses multi-user superposition transmission (MUST), while it uses multi-user detection (MUD) at the receiver for detection purposes, and decoding is performed through successive interference cancellation (SIC) [4].

There are several reports in scholarly articles on the use of NOMA techniques in VLC. Multiple factors make NOMA an excellent choice for downlink VLC systems, as stated in [5][6]. Firstly, a VLC cell only needs to accommodate a modest number of users for NOMA to function properly. Secondly, since the channel is relatively constant in VLC systems, channel estimation is simpler. Therefore, NOMA can execute the load distribution at the transmitting end and the interference cancellation at the receiving end by making use of the channel status information. Higher-order modulation methods, including quadrature amplitude modulation (QAM), can be used to further enhance the spectrum efficiency of NOMA-based VLC systems. QAM cannot be implemented directly to VLC due to the complex-valued and bipolar symbols it generates, which are necessary for indoor VLC, which is dependent on intensity modulation/direct detection (IM/DD).

Generally, the NOMA approaches were discussed in the literature to boost the throughput and reliability of VLC systems. Unlike OMA approaches, NOMA enables numerous users to use the same frequency/time resource blocks at the loss of certain IUI, resulting in effective resource usage [7]. Downlink PD-NOMA, in particular, depends on the SC idea at the transmission end for multiplexing distinct users' data streams in the power domain and on the SIC approach at the end users to decipher receiving data [8]. NOMA works by providing users with varying power levels that are usually related to respective channel gains. To decrypt the data, the strongest users initially utilize SIC for decoding the data of weak users, remove it from associative receivers, and then decrypt their data, but the weak users decrypt their data immediately and face IUI caused by the stronger users' data superposition. Despite the numerous advantages that VLC provides, it has a number of flaws that keep present technology from meeting the expectations of 6G networks.

The first constraint is the minimal interaction range caused by the short wavelengths of visible light signals. It leads to significant propagation losses since the VLC channel strength deteriorates substantially as the space between receiving and transmitting devices grows, besides the fact that emission spectra are easily obstructed by obstructions [9]. Furthermore, unlike its typical RF counterpart, the VLC channel is not isotropic, which means that the geometry of the receiving and transmitting instruments have a substantial impact on channel gains [10]. Consequently, the VLC channel quality varies, and the efficiency of sophisticated multiple access strategies, for instance, NOMA, suffers when integrated with VLC systems.

2. Integration of NOMA-Based VLC with Emerging Technologies

2.1. MISO/MIMO Techniques in NOMA-Based VLC Systems

By utilizing illuminating LED arrays, MIMO has been widely used in VLC systems as a natural and effective technique to widen system coverage and boost system capacity [11][12]. By installing multiple sources at the transmitter or receiver, additional spatial DoFs can be enabled. Massive MIMO (mMIMO) can also substantially boost the spectral efficiency due to the large number of spatial DoFs introduced by the multiple sources [13]. However, considering the future demand of coverage for an excessive number of users, the spatial DoFs provided by MIMO or mMIMO are not sufficient. In this case, NOMA can be incorporated to serve a higher number of users. The use of NOMA in MIMO-VLC systems has not received much research. The experimental verification of a MIMO-NOMA-aided VLC system in [14] did not take power allocation into account. In MIMO-NOMA-aided VLC systems, the PA strategies of single-LED NOMA-VLC systems cannot be immediately applied. For MIMO-NOMA radio-frequency (RF) systems, a number of PA techniques, including signal alignment [15], hybrid precoding, and post-detection [16] have been discussed in the literature thus far. These techniques, however, have a significant computational cost. For the possible widespread use of the MIMO-NOMA methodology in real-world VLC systems, effective PA techniques with low computing complexity are crucial.

In a recent study [17], the authors extend NOMA to MIMO-VLC systems and provide a cutting-edge power distribution technique, called normalized gain difference power allocation (NGDPA), for effective and simple power distribution in MIMO-NOMA-VLC systems. Numerical simulations are used to assess the total rate performance of a 2 × 2 MIMO-NOMAVLC system installed inside. It is demonstrated that, as compared to NOMA with GRPA, the achievable sum rate of the 2 × 2 MIMO-VLC system may be substantially increased by using NOMA with the suggested NGDPA approach. A 2 × 2 MIMO-VLC system for k number of users is illustrated in **Figure 1**.

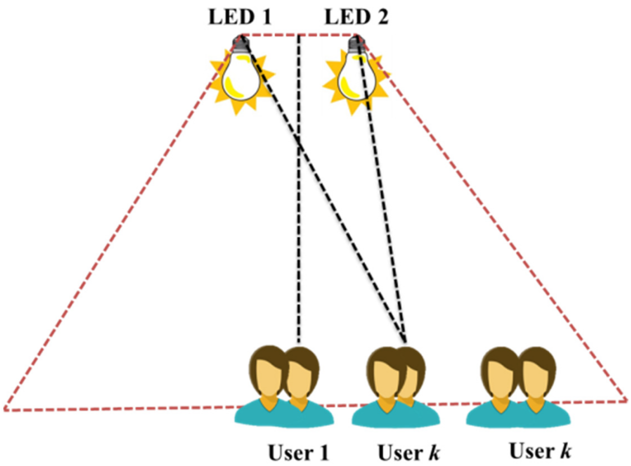

Figure 1. An overview of 2 × 2 MIMO-NOMA-based VLC system with *k*-users.

NOMA is used in a MIMO VLC system with many users in [18]. The authors of these studies demonstrate that a certain type of NOMA power allocation—normalized gain difference power allocation (NGDPA)—greatly improves the achievable sum rate. The BER performance of OQAM-OFDM-aided MIMO-NOMA over VLC has been evaluated as a function of the power allocation ratio between users [19]. Researchers point out that a MIMO-NOMA transmission has not thus far been considered in the articles on multiuser MIMO VLC systems described in the studies in order to mitigate the performance loss of multiuser precoding techniques occurred by the strong correlation between channel gain vectors of various users. VLC systems and MIMO-VLC systems [14][20] have explored PD-NOMA as well. While power domain NOMA has the potential to improve performance, it highly depends on power allocation algorithms and the user pairing/grouping techniques that are used [21], making it challenging to attain optimal performance in real-world cost-efficient MIMO-VLC systems.

2.1.1. VLC-NOMA for Underwater Applications

VLC is an emerging tool with high flexibility, huge capacity, a cheap cost, and no licensing requirements that have recently been examined for underwater applications [22]. When compared to acoustic technology, underwater visible light communication (UVLC) using blue/green light sources may efficiently enable low-latency and high-speed transmission [23]. UVLC, as opposed to underwater wireless electromagnetic communication, offers the enticing features of having no electromagnetic radiation and strong anti-interference capabilities [24]. Nevertheless, because of the significant absorption and scattering caused by water, the UVLC system still has a restricted transmission rate and communication distance. Some potential methods for improving UVLC system performance include enhanced coding techniques, updated modulation techniques, and MIMO transmission schemes. UVLC features improve optical detectors, including single photon avalanche diodes (SPAD), to increase communication distance, enabling improved detection capability [25].

The effectiveness of the NOMA-VLC system has been studied with respect to LED half-power semi-angles, photodiode fields of view (FOVs), power allocation coefficients, and channel conditions [26]. In [26], the authors offer a NOMA-UVLC system that relies on the PDM with several color LED sources introduced to increase system performance. Initially, the UVLC channel's attenuation properties were explored and discussed. On this premise, a NOMA-UVLC system with unique data on distinct carriers is created and constructed with the goal of improving total transmission rate and spectrum efficiency. When the system uses two similar or distinct light sources, the BER curve of the NOMA-UVLC system varies in accordance to the transmission rates. Furthermore, the authors carried out a comparison of the experimental findings between the underwater and the air environment.

Underwater optical wireless communication can also benefit from NOMA technology by significantly increasing transmission capacity and lowering user interference [27][28]. The practicality of the suggested system model was confirmed by an examination of NOMA's performance in a variety of underwater circumstances, as presented in [29]. A NOMA-UVLC system with a photon-counting receiver was presented in ref. [30], which demonstrated excellent sensitivity to weak signals and BER performance at extremely low signal strengths. However, the emphasis of these efforts was purely theoretical and/or simulated. There is also evidence that water strongly absorbs light, with the exception of the blue-green portion of the visible light spectrum. Therefore, various LED light sources at different wavelengths experience variable levels of power attenuation in water, providing a theoretical basis for the incorporation of PDM technology into UVLC systems in order to increase channel capacity.

2.1.2. PD-NOMA for Underwater Applications

Because of the rising usage of underwater sensor networks (USNs) for a variety of tasks, including environmental assessment, port security, oil exploration, tactical surveillance, and collecting data, scientists have begun to examine underwater wireless networking options [31][32]. Acoustic communications have been a popular approach for USNs since they can sustain transmission lengths of several kilometers with modest data rates on the order of kbps. UVLC has been offered as a supplementary connection option, with data speeds in the tens of megabits per second (Mbps). Light is significantly attenuated when it travels through water, especially at ultraviolet and infrared wavelengths. The optimal wavelength for underwater transmission is in the blue-green region of the VL spectrum. Whereas the green spectrum attenuates less in seawater, the blue spectrum attenuates more in the wide ocean [32].

There is an expanding body of material on UVLC in which green or blue LEDs or LDs are employed as wireless transmitters [33]. Nevertheless, the majority of these evaluations are restricted to single users and point-to-point linkages. However, the actual application of USNs necessitates the creation of numerous access systems to accommodate multiple sensor nodes. As a result of this, various multiple access strategies for UVLC systems have been developed [34]. The experimental demonstration of NOMA-UVLC with a blue laser transmitter was presented in [35], with a cumulative rate of 4.686 Gbps attained for two users. Some studies investigated the numerical performance of multiuser PD-NOMA over a lognormal fading channel, which is generally applicable in low turbulence situations as experimentally validated in [36]. Ref. [37] examined the error rate performance and feasible capacity of a PD-NOMA-enabled UVLC system over the exponential-generalized gamma (EGG) distribution, which is appropriate for turbulence with air bubbles. The influence of the PA coefficient on coverage probability and attainable capacity is investigated in [28]. An overview of NOMA-UVLC is illustrated in **Figure 2**.

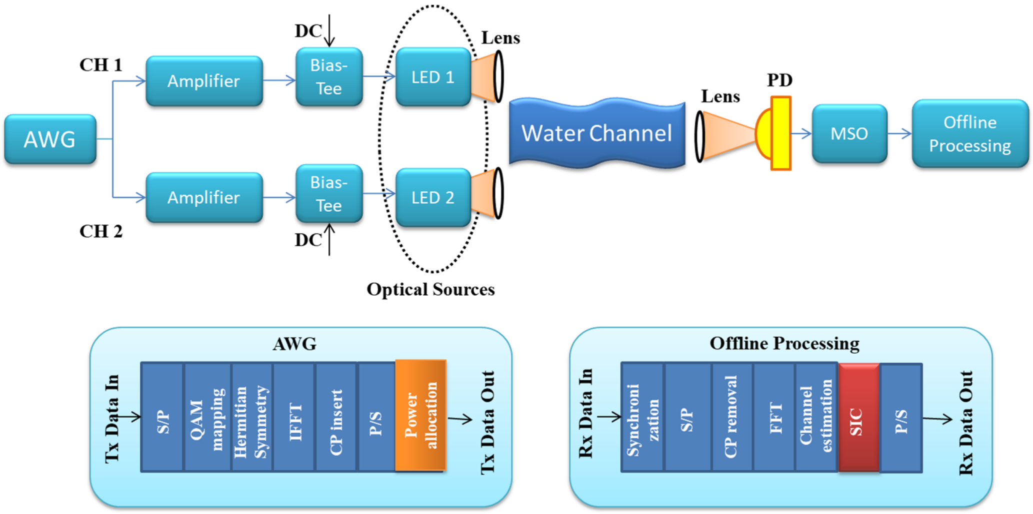

Figure 2. An overview of NOMA-UVLC system.

2.2. NOMA-Based Hybrid RF/VLC Systems

Intensity modulation and direct detection (IM/DD) is the mechanism through which VLC is achieved by adjusting the LEDs' output levels of light. Despite the many potential benefits of VLC systems, their primary downside is a severe drop in performance when a non-line-of-sight (NLOS) element is present. For NLOS wireless communication, that is not the case with traditional RF waves. However, whereas VLC systems are ideal for downlink transmission, they are not suitable for uplink transmission due to the fact that they create undesired irradiance. To address these limitations, hybrid VLC/RF designs have been developed; these systems effectively merge the advantages of RF and VLC communication. Recent years have seen a rise in interest in the cohabitation of indoor VLC and RF due to the possibility it offers of improving communication performance. The main reasons for this are the need for universal service coverage and the demand to get around the shortcomings of VLC in duplex transmission situations. Considering hybrid RF/VLC networks have been proven to significantly improve energy efficiency, range, and total system capacity [38], they have been advocated as a central option for indoor communication networks. On top of that, because the light is commonly restricted inside a relatively small region, such systems offer a solution to problems with undesirable variations of the possible throughput in VLC. Therefore, it is expected that the integration of VLC and RF would considerably enhance the whole user experience. Recent significant contributions have examined several facets of hybrid VLC/RF systems from the perspective of maximizing their combined strengths. In particular, the authors of [39] used an optimal bit-and-power allocation method to study the optimal operation properties of a hybrid VLC-OFDM system. To take advantage of both the high data throughput capabilities of the VLC component and the high connection dependability of the RF component, Wang et al. investigated a hybrid VLC/Wi-Fi system [40]. Based on their investigation of the downlink of a hybrid VLC/RF system, the researchers in [41] demonstrate that the suggested system may greatly improve the total coverage by making use of Wi-Fi in addition to the VLC connection. Likewise, in [42], the capacity performance of a hybrid VLC/RF setup based on OFDM was examined. It is emphasized that in today's communications, both local and large-scale, the energy economy is of utmost importance. Recent reports on the energy efficiency of hybrid VLC/RF networks have also been highlighted in this area. Equally, the investigators in [43] considered how to allocate energy effectively between single VLC AP and a single RF AP in an OFDMA-aided hybrid VLC/RF system. NOMA, nevertheless, has been offered as a viable alternative to OFDMA for use in future radio access networks.

Downlink data throughput and spectral efficiency in cellular networks may be significantly increased by employing the NOMA approach. NOMA's defining feature is its ability to multiplex users in the power domain simultaneously, allowing each user to make full use of the available frequency bandwidth. This would be accomplished by the transmitter employing superposition coding and the receiver using SIC to first remove the interference caused by the ensuing information signals and then decode them. In light of these observations, a recent article [44] proposes and analyzes a NOMA-enabled VLC/RF system that, to the researchers' knowledge, does not exist in the existing literature. Here, the authors measure how much energy it saves during downlink transmission on the network under consideration. To achieve this goal, they first compare the advantages of the studied method to those of its OFDMA counterpart scheme and then derive an analytic expression for the energy efficiency of VLC/RF NOMA. **Figure 3** presents an overview of hybrid RF/VLC wireless network.

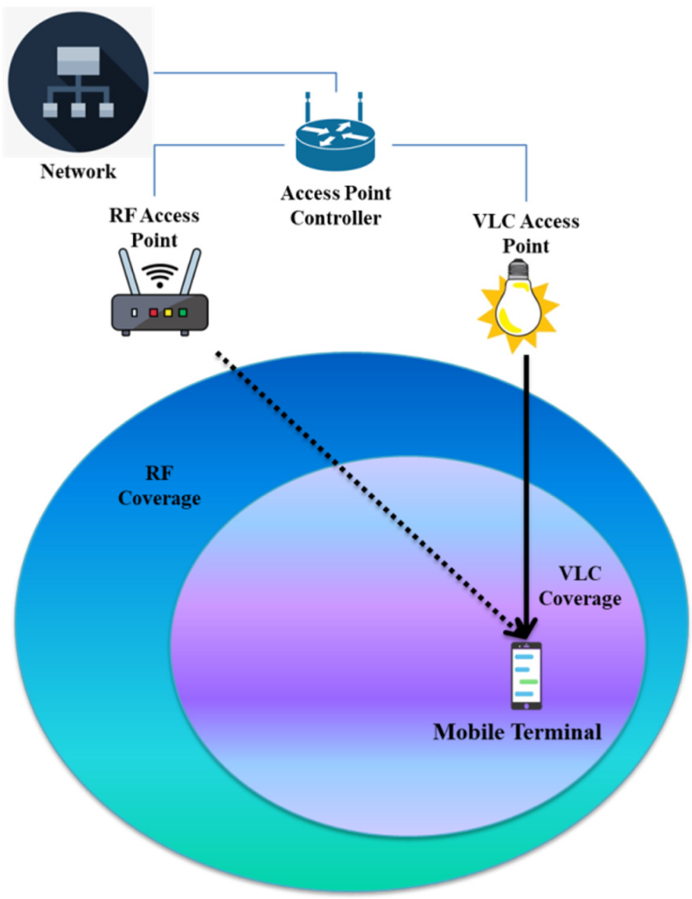

Figure 3. An overview of Hybrid RF/VLC wireless network.

An online method was developed by the authors of [45] to reduce the energy used by a hybrid VLC-RF network in a low-light environment while still meeting the need for the available light. Similarly, in [46], the paper analyzed optimum categorization for a NOMA hybrid VLC-RF network in the presence of perfect CSI. To the same end, [47] tackled the issue of efficient resource allocation in NOMA-aided hybrid VLC-RF with shared backhaul to optimize the possible data rate. In order to ensure that vehicular communications are both ultra-reliable and low-latency, the researchers in [48] presented a powerful hybrid VLC/RF paradigm for resource management. In addition, a heterogeneous RF/VLC model for optimizing RF/VLC link selection has been presented [49]. Last but not least, the NOMA-aided hybrid VLC-RF system's performance was examined in the context of reconfigurable intelligent surface (RIS) by scientists [50].

2.3. NOMA-Based VLC System with IRS

The idea of "intelligent reflecting surfaces" (IRSs) has recently become a hot topic in the wireless communication industry. This is because IRS offers a spectrum-, power-, and cost-efficient way for wireless networks to evolve over the long term. An IRS is made up of a number of reflecting elements (REs) that may be intentionally created to alter the way they react to incident light rays. Based on this, it is feasible to efficiently manage light signal propagation to obtain desired performance benefits. The researchers [51] give a full analysis of the pros and cons of using IRS technology in VLC and LiFi systems. Ongoing studies have concentrated on evaluating and improving VLC performance in IRS-enabled systems. For instance, [52] explored IRS-enabled indoor VLC systems, whereas [53] addressed the optimization of the IRS reflection coefficients with the goal of sum-rate maximization. The authors of [54] describe a framework for an IRS-assisted NOMA-VLC system with the goal of improving connection dependability. The authors look into how adding IRSs to NOMA-based VLC systems could improve their performance. In traditional NOMA-aided VLC, the decoding order of users and, by extension, power allocation may be determined by the LoS channel gain. However, in IRS-aided systems, this is not always the case. As a result, tweaking the IRS allows you to gain control over the apparent overall channel at the receiver. With the goal of improving the BER, the authors present a structure for the coordinated design of the IRS reflection coefficients, NOMA decoding order, and power allocation. In addition, they prove that this multi-dimensional optimization issue is NP-hard and present an adaptive-restart genetic algorithm (GA) to solve it efficiently. The compelling integration of IRS and NOMA has drawn significant research attention in an effort to exploit the new DoFs empowered to NOMA through IRSs [55].

In another recent work [56], the authors provide a PLS method for NOMA-VLC systems with IRS support. PLS is shorthand for "physical layer security," which describes methods that use the inherently unbreakable nature of the optical channel to protect data transmission from snoopers. They propose a challenge to maximize the secrecy capacity of a trusted user by preserving minimal rate limitations for the untrusted user, under the premise that users in the network are given a trust score, i.e., based on their recent behavior. To accomplish this, the optimal PA of NOMA and IRS setup are collectively optimized according to the available system characteristics, user locations, and desired rates. To achieve computational efficiency, the authors offer a novel PLS approach and an alternating optimization technique that employs the adaptive-restart genetic algorithm (GA). IRS-aided NOMA-VLC system for two users is shown in **Figure 4**. The system is based on a trusted user and an untrusted user. The users can get data from LoS and reflected path from IRS.

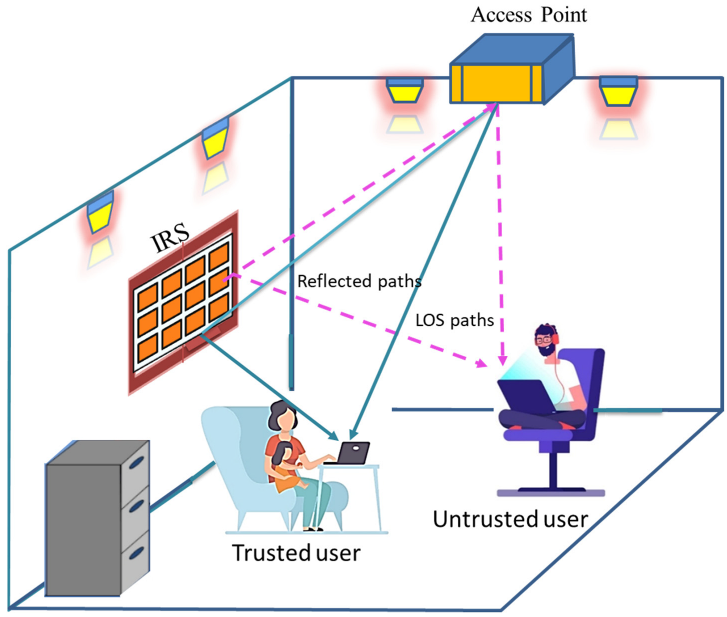

Figure 4. System model with two users: trusted and untrusted.

2.4. NOMA-VLC with UAV

New research has been done on how combining NOMA and UAV could be a game-changer for 5G and beyond in terms of making connections and coverage available everywhere. In [57], a path-following algorithm was used to tackle a joint optimization issue for NOMA-empowered UAV downlink networks, including bandwidth allocation, antenna beamwidth, UAV altitude, and power allocation. When used to uplink cellular networks, NOMA has been proven to reduce UAV runtime while fulfilling the QoS needs of ground users [58]. In [59], the authors analyze a non-orthogonal multiple access (NOMA) method for uplink UAV-aided wireless communications and compare it to the currently used slotted ALOHA. Both [60][61] took into account the network energy efficiency and sum rate as motivations for jointly optimizing UAV deployment and power distribution. Ref. [62] optimizes user association and UAV placement to reduce total power consumption. Some methods, including machine learning (ML), game theory [63][64], and network optimization [57][65] have been developed to improve UAV/NOMA/VLC systems. In particular, ML has found various uses in 5G wireless networks as a result of the advent of new applications and technology. For instance, [64] considered deep learning as an expanded version of the previous work [62], used federated learning to address a number of issues at the wireless edge, and [66] provided a thorough overview of deep reinforcement learning and its many applications in fields as diverse as wireless caching, edge computing, and network security. Swarm intelligence is seen as a crucial method for improving 5G and beyond networks because of its competitive performance, high dependability, and quick convergence. Since its proposal [67], the Harris hawk optimizer (HHO) has quickly risen to prominence as a cutting edge swarm intelligence approach.

In order to reduce overall power consumption, [68] developed a scenario in which a UAV's position and user were linked. The latest research in [69] is the first instance in which the researchers have discussed the topic of employing UAVs to improve NOMA-VLC systems explored in the literature. The authors highlighted in [69] as to why the research community thinks UAV and NOMA integration with VLC is highly promising. To begin with, a NOMA-VLC system with the help of UAVs may supply not only light but also communication services for several users at once, allowing for a vast and pervasive connection for IoT applications in B5G. Furthermore, while sustainable energy and wireless power transfer do help with UAVs' energy conservation, using UAVs with very low power (VLC) capabilities for communications rather than UAVs with radio frequency (RF) resources is an even better solution. Finally, UAVs' great mobility and adaptability make it possible to ensure and improve users' LoS connections and QoS in VLC. The next step is testbed testing, which has been conducted to validate the use of UAVs in VLCs [70]. Simulation findings further show that the suggested method for UAV-assisted NOMA-VLC outperforms OMA and fixed-position (i.e., non-adjustable LED location) schemes.

2.5. NOMA-VLC with OFDM

When it comes to 5G networks, OQAM/OFDM is seen as potential modulation scheme. The use of a filter with a high side-lobe suppression ratio and well-defined time-frequency localization provides OQAM/OFDM with their primary benefits [6]. For this reason, OQAM/OFDM has been shown to be more resilient against ICI in both VLC systems and fiber transmission systems due to its reduced out-of-band power leakage. The spectral efficiency is further enhanced by employing OQAM modulation and a filter bank, both of which eliminate the need for CP. As of now, OQAM and OFDM have been shown to be appropriate for asynchronous carrier amass in the 5G HetNets. However, true orthogonality among subcarriers is still necessary, which in turn restricts the possible number of users.

OFDM-NOMA in a single-cell VLC system is suggested in [71]. In an earlier work [19], the authors presented OQAM/OFDM-NOMA for a 2 × 2 MIMO-VLC system to increase system capacity. To reduce interference between two neighboring channels, the MIMO equalization approach with unique training sequences (TSs) is utilized. A single-cell VLC system requires spatial combination with two receivers to get the sent signal, and the system performance at a given place is examined. OQAM/OFDM-NOMA modulation is suggested and experimentally proven in a recent study [6] for a multi-user asynchronous multi-cell VLC system. It can increase user fairness among cell-edge and cell-center users inside the same cell and overall system performance as well. PD multiplexing is enabled by NOMA and used by altering the power weight of each user correspondingly. Furthermore, in a multi-cell VLC system, the combination of OQAM/OFDM and NOMA may efficiently decrease intercell interference. The outcomes of the experiments reveal that since the power ratio is 8 dB, OQAM/OFDMNOMA might attain the highly similar BER performance across cell-edge and cell-center users, thereby supporting user fairness.

Recently, experimental and computational studies on the OFDM-NOMA-VLC have been undertaken [72][73]. Ref. [71] studied the OFDM-NOMA-VLC uplink and downlink systems, as well as the effects of channel estimation and power allocation. The performance benefit of non-Hermitian symmetric (NHS) inverse fast Fourier transform

(IFFT)/FFT-based OFDM-NOMA-VLC has been demonstrated through an experiment in [73]. The authors of [72] explored an enhanced power allocation (EPA) method for OFDM-NOMA-VLC and showed that it might improve throughput over traditional techniques. Nevertheless, it only addressed power distribution for various users inside each subcarrier, not power allocation across subcarriers. Subcarrier transmission, along with power allocation, is a critical challenge in the actual deployment of the OFDM-NOMA-VLC system. There is currently no requirement for subcarrier allocation in the present OFDM-NOMA-VLC system since it is expected that any subcarrier would multiplex all users. Unfortunately, given the SIC complexity at the receiver, the number of multiplexed users on every subcarrier in a realistic OFDM-NOMA system should be restricted. The proportion of multiplexed users for each subcarrier in OFDM-NOMA could be smaller than the overall number of users, but subcarrier allocation can still maintain the user fairness. Ref. [74] designed a software-based NOMA-VLC system featuring dynamic power and carrier allocation, but somehow it did not investigate the particular subcarrier allocation technique. To facilitate large-scale device connections and reduce energy, [34] suggested a power allocation and subcarrier technique for asymmetric clipped optical (ACO) OFDM-NOMA for an uplink underwater VLC system. This approach, unfortunately, cannot be used for DC-biased OFDM-NOMA in indoor VLC systems because the electrical signal's peak amplitude must be controlled to assure human eye safety and optical signal non-negativity. A generic overview of two-user NOMA-based VLC system with QAM and O-OFDM is presented in **Figure 5**.

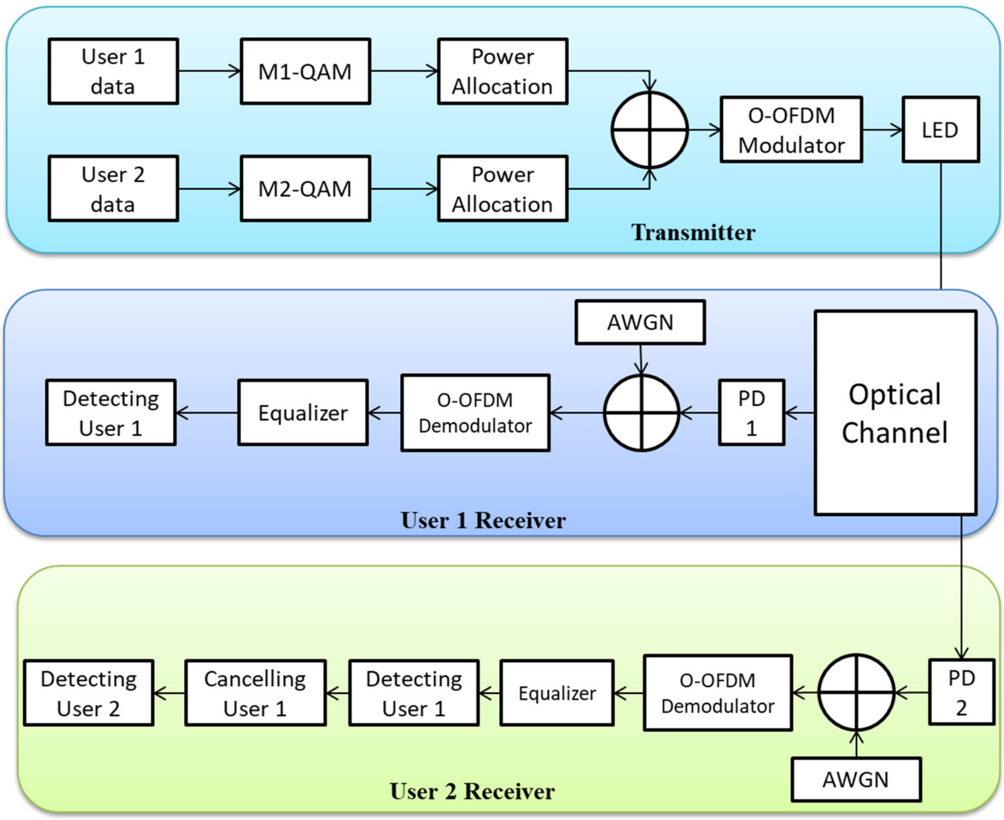

Figure 5. Block diagram of two-user NOMA-based VLC system with QAM and O-OFDM.

2.6. Machine Learning Techniques for NOMA-VLC

With the introduction of machine learning (ML) algorithms, particularly deep learning (DL) and neural networks (NNs), VLC has the potential to become more efficient and solve numerous issues at the physical layer [75]. Multi-CAP and Nyquist pulse amplitude modulation (PAM) VLC systems were addressed in [76][77], respectively, with a clustering algorithm-aided perceptual choice approach and a nonlinear compensation mechanism. In order to compensate for PAM-transmission VLC's flaws, a post-equalizer based on deep long-short-term memory (LSTM) was developed. The use of red, greenish, and blue LEDs in deep learning (DL)-aided multi-colored VLC connection was described in [78]. With the use of machine learning, the authors of [79] explored the possibility of using this technique to build and implement a VLC connection for demodulating signals.

To address the linear and nonlinear deformities that plague NOMA-VLC transmissions, the authors in [75] present a convolutional NN (CNN)-based signal demodulator as presented in **Figure 6**. Recorded NOMA signals are utilized for: (i) offline CNN training and (ii) online signal compensation and recovery using a CNN-based demodulator. Remember that the NOMA signal can be detected without the free-space channel response. They demonstrate, via modeling and experimental data, that the recommended CNN-based demodulator would successfully attenuate nonlinear and linear distortions, therefore enhancing the system's functionality.

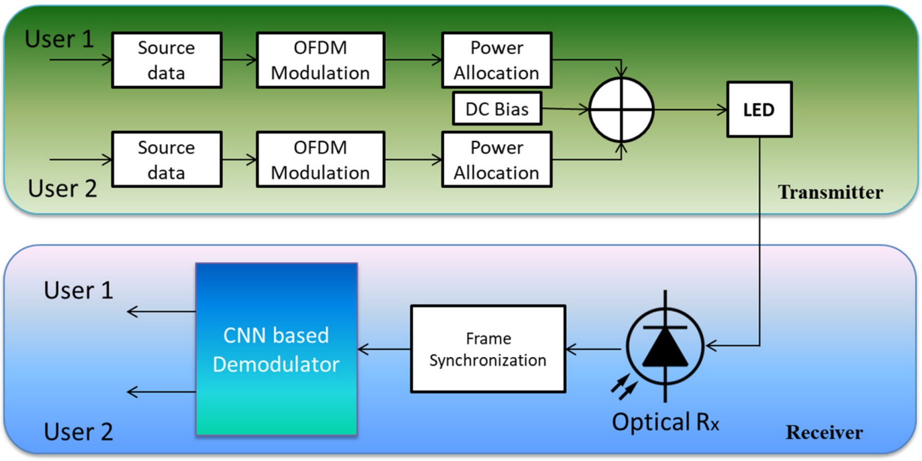

Figure 6. An overview of NOMA-VLC system using a CNN-based demodulator.

To increase the spectral efficiency of a MIMO-NOMA system when facing interference from a smart jammer, the researchers in [80] suggested a swift RL-based power allocation technique. For mobile edge computing with NOMA, the research in [81] employed Q-learning to create a framework. DRL solves a problem with Q-learning related to Q-table storage and lookup by combining deep learning into RL. Power allocation in cache-assisted NOMA systems was created by [82] authors using dynamic resource balancing. A DRL was employed in [83] to find sub-optimal power allocation strategies for an uplink multicarrier NOMA system. In conclusion, a combined channel assignment and power allocation problem in a two-user NOMA system was addressed by He et al. [84] utilizing a DRL framework. The key goal [85] is to find the configuration between optimal power distribution and optimal LED transmission angle adjustment for a virtual local area network (VLAN) with users spread out evenly around the space. The issue is NP-hard, meaning it cannot be solved by traditional optimization techniques in this context. DQL's greatest strength is in its ability to address difficult joint optimization issues in wireless communication, issues that are typically intractable with the use of more traditional mathematical analysis [86]. Several recent publications have shown that DQL is effective. For example, the researchers in [87] used DQL to forecast and modify the IRS phase shift matrices optimally, allowing for the optimization of an IRS-NOMA system. Although it is impossible to get complete information about the channel state, the DQL method enables the agent to acquire new knowledge about the nature of communication, which can then be used to find the best possible solution. In [69], the authors proposed an energy efficient HO algorithm for UAV-aided VLC-NOMA. As a swarm intelligence tool, the Harris hawks optimizer (HHO) is among the most contemporary algorithms that have gained popularity since its inception. It formulated a joint problem by considering UAV's placement and PA to maximize the sum rate of all users.

2.7. Physical Layer Security (PLS) in NOMA-VLC

Recent research on PLS in NOMA networks released after the 2016 study by Zhang et al. [88] has been on NOMA users who are either snooped on or apprehended by exterior hostile snoopers [89]. Researchers have also looked into how certain users behave as fake nodes in comparison to other, more reputable NOMA users [90]. In order to create a foolproof method of transmission, the researchers behind [91] took into account the possibility of both internal and external eavesdropping. Analysis of NOMA system secrecy performance is possible thanks to the accepted mathematical tools of game theory [92], stochastic geometry theory [89], and optimization theory [88]. With the right signal processing, PLS for NOMA systems may use the same transmit antenna selection [93] that is used in PLS for VLC networks. Although PLS in VLC systems is only relevant to downlink wireless communication, in NOMA systems it may also be used for uplink transmission [94]. Nevertheless, due to the unique qualities of the optical wireless transmission channel and optical transceiver, these studies on PLS in NOMA systems are limited to the RF domain and it is difficult to directly extend to the VLC domain. Research on PLS in NOMA-aided VLC networks has been done on many occasions. Secrecy outage probability (SOP) for a multiuser, multi-external-eavesdropper downlink NOMA-VLC network was inferred in [95], which showed that SOP performance was linked to the variables of the snooping density and optical transceiver, according to the spatial distribution of eavesdroppers and trusted users. Numerous recognized relays with the optical transceiver have been developed, and secure beamforming vectors have been tailored [96] to guarantee safe transmission in a two-user, single-external-eavesdropper downlink NOMA-VLC network, demonstrating that the ideal relaying technique changes depending on the number of relays and the geometric configuration. Until now, however, only genuine users in a static state have been included in PLS studies in NOMA-enabled VLC networks. In [97], the authors transform a resource allocation problem into the problem of dynamically allocating power to address PLS for mobile users in NOMA-VLC systems. To the experts' knowledge, however, research into AN-assisted secure beamforming for a VLC-NOMA system has not yet been published. To help bridge that gap, a recent work [98] investigates the secure resource allocation issue for VLC-NOMA systems. In the case of NOMA in particular, it is important to keep in mind that the performance increases are heavily dependent on the precision of the CSI. Therefore, a realistic, inaccurate CSI of both the targeted users and eavesdroppers is assumed in order to properly examine the performance increase realized by an AN-assisted stable beamforming structure in a multiple-input, single-output (MISO) NOMA-VLC system. Particularly, the inter-user interference issue in NOMA-VLC systems can be efficiently mitigated through exploiting the spatial DoFs to design appropriate transmitter and receiver beamformers. **Figure 7** presents an overview of a NOMA-VLC system with two trusted users and an eavesdropper who can steal data.

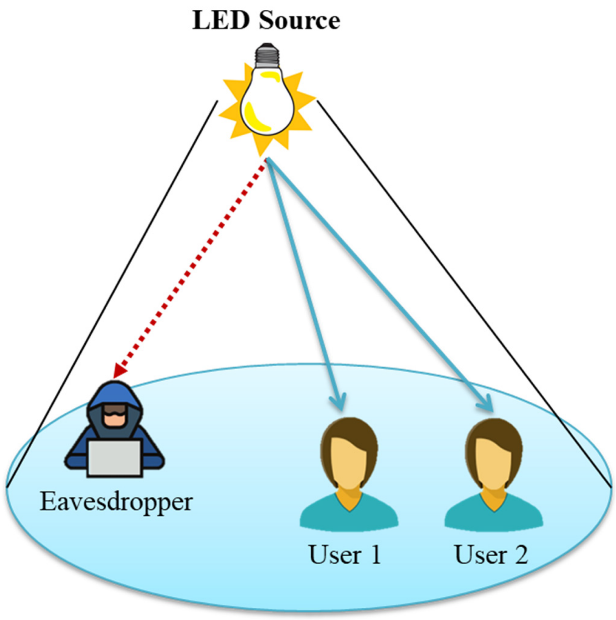

Figure 7. NOMA-VLC system with two users and an eavesdropper.

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