OFDM-BASED VLC SYSTEMS: A SYSTEMATIC REVIEW

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Abstract Visible Light Communications (VLC) represents a new technology of wireless communications allowing high data rate, high-speed internet access, green and friendly communication system, especially for indoor users, where the use of Light Emitting Diodes (LEDs) is growing as a viable alternative to traditional illumination. Orthogonal frequency division multiplexing (OFDM) is a promising modulation format for optical wireless communication (OWC); however, precise channel estimation is required for synchronization and equalization. Moreover, one of the challenging issues for OFDM is its high Peak-to-Average Power Ratio (PAPR) due to the superposition of all subcarriers; therefore, the system requires a high linearity and dynamic range. This paper provides a systematic overview of OFDM-based VLC systems, highlighting the essential aspects of PAPR reduction and channel estimation techniques. Several technical challenges have been addressed to realize the full potential of OFDM-based VLC technology. Moreover, we provide new insights into the over-explored and under-explored areas, which lead us to identify open research problems of VLC based on OFDM. Concisely, this paper serves as a guide and a starting point for researchers willing to research VLC using OFDM.

1 INTRODUCTION

Wireless optical technology provides various outdoor and indoor services, such as indoor wireless infrared communication[1]. Wireless ultraviolet communications[2] and visible light communications (VLC) [3]In the latter situation, visible light is employed as the channel for transmitting data. In this scenario, there is an extra benefit in the possibility of using light for illumination and data communication, referred to as visible light communications (VLC)[4]. VLC stands for visual light communication, a short-range optical wireless communication that utilizes the visible light spectrum ranging from 380 to 780 nanometers. It offers the possibility of short-distance data transfer at multi-gigabit per second rates using essential Light Emitting Diodes (LEDs) and photodiodes (PDs) with an accessible visible light spectrum of around 300 terahertz at low power and cost[5]. Another potential alternative to WIFI for the downlink of an indoor wireless mobile communication system is VLC systems, which utilize the infrastructure of the indoor lighting system. These systems are small, safe, and environmentally friendly [6]. Researchers are evolving VLC technologies that can replace radio-frequency (RF) and microwave communications with large-band visible light to create socially oriented, highly secure, fast communication networks. Among the many appealing aspects of the VLC system are the following: the possibility to reach extremely high data speeds; a very secure communication system; the availability of unused, unlicensed bandwidth on a global scale; and the fact that it does not interact with radio frequency bands[7].

2 OFDM VLC

Orthogonal frequency division multiplexing (OFDM) is a technique that is being explored for visible light communications (VLC) to efficiently use the bandwidth of LEDs and increase the potential data transmission rates [8][9]. In[10], it has been demonstrated that by exploiting the high peak-to-average power ratio (PAPR) in OFDM, it is also possible to enhance the data rates of IM optical wireless systems significantly. The practical implementation of OFDM for optical wireless (OW) systems using non-coherent light is described in [11] by considering the LEDs and PDs. Research has shown that the length of the cyclic prefix (CP) has a negligible effect on power and bandwidth efficiency. The text discusses and demonstrates the impact of the Doppler frequency shift on intensity modulation with direct detection (IM/DD) optical transmission. That Doppler frequency results in a tiny change to the peak wavelength, corresponding to insignificant SNR variations.

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The primary time and frequency distortions in OW communication are mainly due to the sampling offsets. Another major challenge is the nonlinear behavior of the LED due to the high PAPR of the OFDM signal. The idea of transmitting sound using visible light-emitting diodes (LEDs) has existed since 1999 [11]. Academics are showing increasing interest in VLC as a new field of study. A corresponding IEEE standard regulating some of the PHY and MAC layer specifications has recently been published [12]. Two separate VLC systems with distinct physical layer properties show promise in future application scenarios. One uses VLC with indoor illumination to enable mobile users' fast internet in a house or workplace. The second option is the VLC (Visible Light Communication) technology that utilizes LED traffic lights to create intelligent transportation systems (ITSs). Komine et al. introduced interior illumination mixed with visible light communication (VLC) in 2004 [5]. By doing a comprehensive examination, we can determine the receiver's signal-to-noise ratio (SNR) in a standard indoor illumination setting. A study was carried out to investigate the problem of inconsistent arrival times for all emitting light sources. A cooperative transmission approach was proposed as a solution [12]. The practicality of optical wireless communication networks utilizing high-intensity illumination LEDs was subsequently confirmed through experimentation[13]. Simulation software was developed to facilitate the initial system design of the interior lighting mixed with visible light communication (VLC)[14]. Theoretical analysis has been conducted to study the properties of the indoor visual light communication (VLC) channel[15] and[16]. Analog pre-equalization approaches have been suggested to enhance the restricted modulation bandwidth of a white LED [17] [18] [19]. Additionally, post-equalization at the receiver to boost data rate and eliminate inter-symbol interference (ISI) has been considered [15] [20]. Orthogonal frequency division multiplexing (OFDM) has been utilized to meet the demand for high data rate communication capabilities [21][22][23] [24]. There has also been research on the impact of LED nonlinearity on OFDM systems [21][25][23] [24]. Optical multiple-input multiple-output (MIMO) technology has been suggested for use in indoor lighting-integrated visible light communication (VLC) systems to increase the transmission rate of communication data. This includes both a non-imaging MIMO system and an imaging MIMO system [26][27]. Optimization of The design parameters was discussed [28]. By integrating micro-LEDs with Orthogonal Frequency Division Multiplexing, researchers could obtain a data rate of 3Gbit/s utilizing a blue micro-LED with a diameter of 50 microns [29]. (To our understanding, this is the highest data rate ever recorded for a single-color LED). In[30], research presented a methodology for analyzing the downlink transmission at the system level in an optical atto-cell network based on DCO-OFDM. A proposal was made to analyze a line-of-sight (LOS) link based on the signal-to-interference-plus-noise ratio (SINR) and the average spectral efficiency. Demonstrations showed a 50% increase in bandwidth efficiency compared to conventional optical (OFDM), as well as a 10dB reduction in peak-to-average power ratio (PAPR) compared to typical asymmetrically clipped optical OFDM (ACO-OFDM) [31]. A lower BER or high data rate compared to DCO-OFDM, ACO-OFDM, and U-OFDM techniques by using multiple extra time slots; this method is called clipping-enhanced optical orthogonal frequency division multiplexing (CEO-OFDM) [32]. In [33], a groundbreaking transmission scheme for an OFDM-based VLC system is put forth to address the issue above. A fresh perspective on intricate signal mapping (CSM), derived from the pairing function technique, has been devised specifically for Li-Fi systems. A novel scheme called enhanced OFDM/OQAM (EO-OFDM/OQAM) is put forth for VLC, drawing inspiration from the pulse amplitude-modulation-based hybrid optical OFDM (PHO-OFDM) scheme [34].

An investigation was conducted on the EO-OFDM approach suggested for internal communication in VLC, which applies to both SISO and MIMO setups [35]. The assessment relied on parameters including bit error rate (BER), peak-to-average power ratio (PAPR), channel gain, and average received power. The effectiveness of the proposed schemes in achieving gigabit per second data rates in 2×2 SISO and MIMO-OFDM VLC systems, with a system bandwidth of approximately 100 MHz and a 3-dB cutoff frequency, was demonstrated by comparing the results with those of conventional O-OFDM, GFDM, and STBC-OFDM methods. A novel unipolar transceiver system is put forward, subjected to mathematical analysis, and contrasted with alternative techniques [36]. It is evidenced by possessing a remarkably elevated data rate ratio (43.75%) alongside a commendable system bit energy to noise ratio when juxtaposed with other prevailing methodologies. The adjacent symbol detection ASD scheme incorporates the distribution characteristic of clipping noise. It exclusively focuses on neighboring constellation symbols rather than the complete set of constellation symbols during the decoding process of DCO-OFDM symbols [37].

The two main challenges in VLC systems are the PAPR reduction and the channel estimation methods. Hence, the following sections discuss the related works on these challenges in detail.

3 PAPR Reduction Techniques

Many techniques have been proposed to reduce the PAPR of OFDM systems about RF baseband communication systems. Techniques such as selective mapping [38], block coding [39], and nonlinear Fourier transform (NLFT) techniques [40] have been considered. Two new methods, in-band trellis coding, and out-of-band carrier design, are suggested for lowering the average optical power in wireless optical multiple-subcarrier modulated (MSM) systems[41]. Particularly in[42], a block coding-based scheme was proposed by extending its usage from RF scenarios to optical ones. In [42] and[43], a modification of the selective mapping was presented to fit optical applications. Clipping techniques used with OFDM [24] [44] [45]reduce significant signals only, or they hard-clip prominent signal peaks. This causes distortion noise in the transmitted signal that cannot be removed. Since the VLC-OFDM signal is real-valued, the NCT can be considered to reduce high PAPR in VLC-OFDM. In NCT, the compounding function is applied to the original OFDM signal to expand the small signal amplitude and compress the large signal amplitude. A proposal and investigation have been conducted on the implementation of Single Carrier Frequency Division Multiplexing Access (SC-FDMA) in a Visible Light Communication (VLC) system[46].in[47] Explored the effectiveness of converting illumination to communication in visible light OFDM systems while considering the average optical power restriction. To decrease the Peak-to-Average Power Ratio (PAPR), propose a method that utilizes a semidefinite relaxation strategy for tone injection[48]. With the compounding function applied, the signal's average power can remain unchanged using proper constant values for the compounding function. Peak-to-average power ratio (PAPR) reduction techniques can be considered to reduce power back-off levels in optical systems [49]. A linear coding technique employing an LDPC encoder is suggested to enhance the performance of contemporary high-data-rate wireless systems. This technique contributes to the reduction of the Peak-to-Average Power Ratio (PAPR) value in Orthogonal Frequency Division Multiplexing (OFDM)[50]. Even though the three-dimensional constellation design problems have been formulated in [8] and [51], a few crucial questions still need to be addressed. They include how to compare a system with CSK employed and a conventional decoupled system, the constellation design, and the peak-to-average power ratio (PAPR) reduction[52]. Phase modulation is used in DCO-OFDM for VLC, leading to a PAPR reduction of approximately 10 dB. To decrease PAPR, one must reduce the signal's peak value while maintaining a constant average power. The authors suggest using regular envelope CE phase modulation in DCO-OFDM to address this problem. This method improved BER performance compared to conventional DCO-OFDM, considering the nonlinearity of LED emitters[53]. The work in [54]presents a novel hybrid approach to mitigate the PAPR in signal transmission by combining signal transformation and clipping. The proposed technique employs the Hadamard transform, which offers inherent benefits to decrease the peak-to-average power ratio (PAPR) without impacting the bit error rate (BER) of visible light communication (VLC) systems. Another scheme is employed in the temporal domain to alleviate the elevated PAPR encountered in ACO-OFDM. In [55] paper proposes two innovative techniques to reduce the peak-to-average power ratio (PAPR) in the asymmetrically clipped optical orthogonal frequency division multiplexing (ACO-OFDM) scheme, which is employed in visible light communications (VLC) systems. In[56], A T-transform (T-OOFDM) system utilizing optical orthogonal frequency division multiplexing is suggested to effectively counteract fiber dispersion and minimize the peak-to-average power ratio (PAPR) of the transmitted signal in comparison to the traditional optical OFDM (OOFDM) system. A multi-frequency system is formulated using the Discrete Sine Transform (DST) to convert the data signal from the frequency domain to the time part [57]. This system effectively addresses the criteria established by the HS to generate a password expressed as an absolute value. A novel approach integrates a precoding matrix and the μ-law compounding method to efficiently reduce the peak-to-average power ratio (PAPR) [58]. It is shown that this hybrid technique is an attractive solution to achieve a beneficial trade-off between PAPR and improved bit error rate (BER) of the system. In [59], a novel DP-OOFDM system was presented and assessed in terms of complexity, spectrum efficiency, PAPR, power-saving, and SER compared to standard DFT-preceded OOFDM and ACO-OFDM. One reduces the high magnitude of FBMC-modulated signals, whereas the other improves its small amplitude signals. The method reduces the effect of PAPR in three-layered filter bank multicarrier communication systems that rely on VLC technology[60]. The authors of [61] present the C-transform, a novel technique in the system architecture that combines a Walsh-Hadamard matrix and a discrete cosine transform to effectively distribute information and decrease the PAPR in the VLC system. Symbol time compression-image adjust STC-IMADJS was developed to improve throughput and reduce PAPR in OFDM-based VLC systems. Three technique variations are also designed for evaluation purposes [62]. In [63], a novel PE-ASCO OFDM scheme was introduced, using several power amplifiers (PAs) such as DHT, DST, DCT, and VLM. This technique has successfully achieved a reduced peak-to-average power ratio (PAPR) and improved spectral efficiency compared to previously investigated alternatives while satisfactorily maintaining the system's bit error rate (BER) performance.

4 Strategies for Channel Estimation

Several technical obstacles must be overcome before VLC technology can reach its full potential. First, research on channel models and platforms for VLC is ongoing, and channel models for VLC are not well known [64]. In[65], a study of the channel estimation methods for several OFDM systems is examined to find an effective candidate for the real-world deployment of dependable and affordable short-range wireless communication devices. In the work in [66], channel information on the data subcarriers is extracted using one-dimensional models, and the estimate is performed in a slow fading channel using the least square (LS) or the minimum mean-square error (MMSE). More analysis on channel estimation techniques used in VLC has been carried out in [67]. An Investigation of the basic issues and channel estimation in practical indoor visible light communication was presented. We suggested a post-processing discrete Fourier transform (DFT) channel estimation approach to enhance the system's performance to remove noise beyond the maximum channel delay. in the work conducted by [68], a novel approach for assessing the quality of a channel is introduced. This approach aims to represent the link bit error rate (BER) accurately. The proposed method is comprised of two distinct steps. Firstly, a channel amplitude gain and phase tracker are implemented as part of the estimator. Secondly, the estimator incorporates a channel quality indicator based on the distance between the received signal and the maximum likelihood path along the decoder trellis. In [69], authors discovered that the channel response of the white-light LED-based OWC was smooth and stable. Hence, they proposed and demonstrated using a specific and adaptive arrangement of a grid-type pilot scheme to estimate the LED OWC channel response. Using a particular and adaptable arrangement of the grid-type pilot in a white-light LED-based VLC system, they have tested and characterized the technology comparable to what is used in RF. In [70], the authors offer a theoretical evaluation of the merits of nonlinear VLC systems that use discrete multi-tone (DMT) modulation. Since DMT modulation is more resistant to nonlinearity, they prove it is superior to PAM modulation for the VLC system. Furthermore, empirical evidence has demonstrated that the post-distortion nonlinear elimination technique at the receiver may be a dependable remedy for addressing nonlinearity in the visible light communication (VLC) system. The research investigation [71] reveals that the iterative channel estimation (CE) algorithm, which is suggested for employment in spatial modulation MIMO (SM-MIMO) systems, exhibits enhanced performance in terms of BER and MSE when facing a rapidly fluctuating Rician fading channel compared to conventional recursive least square (RLS) based approaches. Explored the process of estimating channel properties and determining the maximum data transmission rates for massive MIMO systems using one-bit quantization [72][73] employing estimating the experimental channel using (OFDM). Additionally, an examination of the smaller square method for Least Squares (LS) channels. Their findings indicate that the performance of the Minimum Mean Square Error (MMSE) technique surpasses that of the suggested separate LS method. In [74], a novel blind channel estimator with a sole transmitting antenna has been proposed using a hybrid OFDM code architecture for OFDM systems with a sole transmitting antenna. Conventional OFDM systems have been modified by substituting experimental subcarriers with M-array phase shift keying (MPSK) codes. In contrast, contiguous subcarriers are generated by employing M-array amplitude shift keying MASK. The study proposes in [75] to use the null subcarriers, namely the cyclic prefix interval, to increase the utilization of the pilot subcarriers. In [76], this study uses the ACO-OFDM modulation scheme to analyze the channel estimation problem in a VLC system. Two different realistic channels are considered to provide a comprehensive evaluation; channel coefficients are estimated using the linear minimum mean square error (LMMSE) estimation method. The performance of the estimated channel coefficients is then compared to that of the original coefficients by evaluating the mean squared error (MSE). Additionally, the Cramer Rao bound of the system is presented to further enhance the understanding of its overall performance. In [77], a comparative examination was undertaken to investigate the BER, the magnitude of the error vector attained, the least squares LS, the minimum mean square error MSE, and the Kalman filter (KF) channel estimators when employed in the context of MRC and zero effect receivers RZF. A novel iterative channel estimation algorithm has been put forward to leverage channel scatter in the time domain of multiplex systems employing optical DCO-OFDM in indoor VLC, taking into consideration a channel description with a restricted count of tracks, each being distinguished by channel delay and gain called estimated by orthogonal matching pursuit (OPM) algorithm [78]. A particular system proposed by [79] is called the interference approximation method (IAM), in which the bipolar signal is transformed into a unipolar signal by isolating the positive and negative components and subsequently converting them into a positive form before ultimately delivering the signal. Additionally, a novel channel estimation approach has been introduced for the multi-wave system associated with facial filter banks, thereby enhancing the effectiveness of channel estimation when contrasted with the efficacy of conventional methods. To address the issue of sparse recovery and attain enhanced accuracy in the estimation of UVLC channels, the present study puts forth a scheme known as compressed sensing [80].

TABLE I. Some methods related to PAPR reduction and channel estimation techniques in OFDM OWVLC

Referen ce	Approach	Purpose	Advantages	Drawbacks
[8]	asymmetrically clipped O-OFDM	PAPR Reduction.	Over the subcarrier bandwidth, the dispersive optical wireless channel fades to a flat track. Combat ISI effectively	In the temporal domain, the coherent addition of the individual subcarrier OFDM signals cannot produce high peaks.
[24]	The use of the SC-FDMA technique —Single-carrier frequency domain equalization (SCFDE) modulation	PAPR Reduction.	One significant benefit that can be used to offset LED nonlinearity distortions is the low PAPR of SCFDE.	Due to the flat optical channel, the intrinsic frequency variety of the SCFDE system renders it worthless for use with the OW system, which is very susceptible to inter-carrier interference.
[33]	Complex signal mapping CSM-OFDM based on LIFI.	PAPR Reduction & BER enhanced.	Saves about 50% of the required bandwidth simple equalization.	This system is more sensitive to channel changes than other systems, mainly when (SNR) is low.
[40]	nonlinear Fourier transform (NLFT) algorithm.	PAPR Reduction.	Additionally, it offers respectable signal-to-noise ratio (SNR) performance at tolerable BER levels.	There is a severe decrease in BER performance and an increase in out-of-band subcarrier power.
[41]	trellis coding.	PAPR Reduction.	Low complexity requirement.	Increasing the required transmission bandwidth.
[44]	A pilot-assisted technique	PAPR Reduction and channel estimation.	This approximation is derived using a formula that aids in precisely identifying the sent data symbol.	The approach applies only to particular signal processing as the received signal is available only in the frequency domain.
[45]	Iterative Clipping	PAPR Reduction.	Reduction is done without introducing in-band distortions.	Noises that clip high-order constellations are a threat.
[46]	Single-carrier frequency domain equalization.	PAPR Reduction.	Additionally, the suggested solution shields human eyes and LED devices from overexposure to peak signal power. Additionally, the LED-based VLC system can prevent nonlinear distortion due to the low PAPR attribute of the SC-FDMA technology.	Their primary mode of operation is complex-valued quadrature modulation, which poses a unique challenge in optical IM/DD channels.
[47]	linear scaling and biasing model.	PAPR Reduction.	It was shown that upper PAPR and lower PAPR directly impact OFDM performance. Working with the dynamic range-constrained VLC system has been the OFDM signal.	To convert the bipolar OFDM signal into the unipolar version, high PAPR needs significant biassing.
[48]	Semidefinite relaxation approach.	PAPR Reduction.	It relieves the linear requirement of the electrical transmitter.	The complexity of the proposed scheme is related to the maximum number of iterations and the desired PAPR.
[53]	(PM-DCO-OFDM) modulation system.	PAPR reduction.	Achieves PAPR reduction in VLC by using phase modulation in DCO-OFDM. Improves BER performance	The paper and its sources do not explicitly refer to any disadvantages or restrictions of the suggested approach.

Referen ce	Approach	Purpose	Advantages	Drawbacks
			compared to conventional DCO-OFDM.	
[54]	HTCC technique: Hadamard transform mixed with clipping	PAPR reduction.	This technique reduces PAPR without increasing the system BER	It needs a high power to broadcast since it uses DCO-OFDM. Thus, it needs a strong DC bias
[55]	Gaussian blur (GB) and hybrid (OFDM-PWM) modulation are two methods.	PAPR reduction.	Simple implementation. Enhanced bit error rate (BER) performance and increased resistance to source non-linearity.	Introduces signal distortion and out-of-band emissions.
[56]	T-transform (T-OOFDM) system.	To reduce the scattering of long-distance optical fiber channels in wide area networks (WANs).	The amplitude of the transmitted signal will be significantly decreased while maintaining the average power of the transmissions, enhancing the (BER).	Sensitive to noise.
[57]	Spreading from DST to DST-DCO-OFDM system.	PAPR reduction.	It enhances the throughput and reliability of the communication system, increases data transmission capacity, and reduces the complexity of receiver design.	- The DST-DCO-OFDM system is less power-efficient than the DST-ACO-OFDM system. - Because it transmits data using all available subcarriers, it might add some spectrum efficiency.
[58]	a scheme that combines a precoding matrix with the Mu-law compounding method.	PAPR reduction	Compared to pre-coding alone, the hybrid approach provides a higher peak-to-average power ratio (PAPR) reduction; the suggested amalgamated approach that employs a fusion of precoding and mu-law surpasses both coding and precoding individually in the measurement of bit error rate (BER).	No explicit reference is made to any deficiencies or constraints regarding the suggested approach from the sources provided.
[59]	DP-OOFDM scheme compared with DFT-pre-coded OOFDM scheme.	PAPR reduction.	The collective preceding schemes offered superior power conservation compared to all other plans examined in this study, reducing the computation complexity.	The scheme is more complex because of the combination of DFT pre-coding and GMSK pulse modulation. Although collective pre-encryption was introduced to address this complexity, it still increases computational load compared to traditional DFT pre-encryption.
[60]	Two new non-redundant signals overlap the FBMC-based VLC data signal.	PAPR reduction.	The measurement factor's high value dramatically decreases the rate; elimination interference from usable data on subcarriers is analogous to the signals of the second and last layers; the recommended method provides an excellent compromise between lowering PAPR and raising PER efficiency.	Introduces signal distortion and out-of-band emissions; this specific technology demands the creation and implementation of the second and final-tier indicators, which increases the system's complexity.
[61]	The approach known as symbol time compression-image adjust (STC-IMADJS)	PAPR reduction.	Simultaneous transmission of two subcarrier waves is possible through Walsh deployment codes without	Introduces signal distortion and out-of-band emissions.

Referen ce	Approach	Purpose	Advantages	Drawbacks
			interference, reducing code time by 50%; this system's computational complexity is significantly lower than other OFDM systems based on VLC.	
[62]	C-OFDM & F-OFDM	PAPR reduction.	Applying this specific technological development results in significant benefits within the domain of (VLC), such as reducing the distance between subcarriers and replacing complex modulation formats with more useful ones, such as PAM).	Cyclic OFDM (C-OFDM) technology may necessitate supplementary computational intricacy in contrast to conventional (OFDM) formulations due to the incorporation of the WALSH-HADAMARD transformation and the inverse discrete cosine conversion (IDCT) in the system architecture. This heightened intricacy may impact the system's overall processing efficiency.
[63]	Proposed PE-ASCO OFDM	Various precoding strategies have been suggested for the PE-ASCO OFDM VLC system to decrease the peak-to-average power ratio (PAPR) and achieve a power-efficient VLC system.	This system has a superior data rate and BER performance compared to other systems documented in the article.	Using pre-encryption techniques within the suggested methodology amplifies intricacy and necessitates a more incredible amount of bandwidth.
[64]	Fast multi-receiver for channel estimation.	Propagation modeling for OWC.	Enhances channel estimation by improving the accuracy of both channel gain and delay spread estimations.	BER, PAPR, or SNR are not evaluated in the article.
[66]	block-type and comb-type pilot-based channel estimation.	Channel estimation. To show the benefits of the pilot arrangement.	However, low-pass interpolation comb-type channel estimation is more resilient for increases in Doppler frequency. Therefore, increased data bit rates can still cause some performance deterioration for low-Doppler spread channels.	No mention of (BER), (PAPR), or (SNR) was made in the article.
[69]	Using a variety of luminaries that are commercially accessible.	Channel estimation Using an adaptive arrangement of the pilot sequences.	Enhanced the bit error rate (BER)	The research should have investigated the topics of (PAPR) and spectral efficiency.
[71]	Recursive least square (RLS) algorithm.	Channel estimation to evaluate the performance of spatially modulated systems.	Compared to previous channel estimating algorithms suggested in the literature, this approach substantially improves BER/MSE performance and is suitable for time-varying channels.	The research should have investigated the topics of (PAPR) and spectral efficiency, Limited by channel coherence time.
[72]	Linear minimum mean square error (LMMSE) channel estimation.	Estimating channel characteristics and calculating feasible data transmission rates for the uplink of a large-scale multiple-input multiple-output (MIMO) system.	Improved performance in noisy conditions.	Increased complexity.

Referen ce	Approach	Purpose	Advantages	Drawbacks
[74]	using ASK and PSK, which allows for realizing an (OSBCE), a decision-directed (DD) one-shot blind channel estimator.	Channel estimation: I discovered the blind channel estimation for OFDM.	We can confirm that the proposed OSBCE is efficient because its MSE is comparable to pilot-based estimators.	The research should have investigated the topics of (PAPR) and spectral efficiency.
[76]	using the linear minimum mean square error (LMMSE) estimation method.	Channel estimation Investigating the realistic indoor optical system.	Enhanced the bit error rate (BER) and improved performance in noisy conditions.	The research should have investigated the topics of (PAPR), spectral efficiency, and increased complexity.
[78]	estimated by the orthogonal matching pursuit (OPM) algorithm.	Channel estimation to show the effects of clipping noise on channel estimation.	The technique achieves convergence in little more than two iterations, producing superior performance in terms of mean square error (MSE) and bit error rate (BER). It even surpasses channel estimation algorithms that cannot mitigate clipping noise.	The research should have investigated the topics of (PAPR) and spectral efficiency.
[79]	New interference approximation method (IAM) preamble configuration for F-FBM in a VLC channel Approach	channel estimation Assessing the channel estimation for flip (FBMC)based indoor VLC systems.	The suggested approach outperforms standard IAM structures in terms of NMSE and BER. The simulation findings confirm the enhanced performance using the indoor Visible Light Communication (VLC) channel model.	The research should have investigated the topics of (PAPR) and spectral efficiency.
[80]	(SL-UVCE) schemes are proposed based on the CS.	Channel estimation Investigating the channel estimation for underwater VLC.	The suggested technique can achieve a high level of accuracy in channel estimation. Efficient for sparse channels.	The research did not investigate the topics of PAPR and spectral efficiency. Complexity increases with channel density.

5 Conclusions

VLC technology based on the OFDM scheme has emerged as a promising future broadband technology to support conventional RF communications. Several factors are crucial in designing and performing OFDM-based VLC systems, such as the PAPR and channel estimation, which are vital challenges. OFDM signals often exhibit a high PAPR, leading to power inefficiency in the transmitter and requiring power amplifiers with large dynamic ranges. At the same time, channel estimation is vital for VLC-based OFDM systems as it enables the adaptation of communication parameters to the emotional and unique characteristics of the optical wireless channel, leading to improved performance and reliability. Addressing the broader challenges is essential to successfully deploy OFDM-based VLC systems in practical applications. This paper has investigated and systematically reviewed an up-to-date comprehensive survey on several schemes for PAPR reductions and channel estimation techniques for OFDM-based VLC systems. The survey reveals diverse methods to address critical challenges in optical wireless communication. Both PAPR reduction and accurate channel estimation are pivotal for ensuring the robustness and efficiency of OFDM-based VLC systems. The choice of PAPR reduction and channel estimation methods depends on the specific requirements of the VLC system, considering factors such as computational complexity, bandwidth utilization, and resilience to channel variations. Further research and development in these areas will contribute to optimising OFDM-based VLC systems for enhanced performance and reliability in optical wireless communication scenarios.

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