An In-depth Survey of Visible Light Communication Modulating and Coding schemes for Dimming/Flicker Avoidance Technologies

Christena Ghandour[1], Abdel Halim Zekry[2], Nazmi A. Mohammed[3], And S. El-rabaie[4]

[1]Giza Institute of Engineering and Technology, Giza, Egypt, (Christ.ghandour@yahoo.com).
[2]Faculty of Engineer, Ain Shams University, Cairo, Egypt, (aaazekry@hotmail.com).
[3]New Cairo Academy for Science and Arts, New Cairo, Egypt, (nazzazzz@gmail.com).
[4]Faculty of Engineer, Monof University, Monof, Egypt, (srabie1@yahoo.com).
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Abstract

Visible light communication (VLC) is considered as a promising technique for the wireless technology of the 21st century. Utilizing Light Emitting Diode (LED) technology adds a wide area of applications for VLC. Most important one is that VLC can provide illumination/communication jointly. To achieve efficient commercial VLC communication/illumination system one needs to profit from dimming schemes/flicker. Availability of suitable system designs and enhancing system's power requirements are key advantages for using dimming schemes. Effective dimming schemes/flicker are mainly achieved through several VLC based on modulation techniques. In last few years many kinds of literature discussed independently wide range of modulation schemes to address the effectively previous issue. However, few surveys for these works are presented in the field. This paper provides an in-depth survey of VLC based dimming scheme. Therefore, the kinds of modulation and coding techniques are collected and categorized of more than 60 papers extending from pioneering papers to the state of the art in the field. In addition, research and current issues are discussed especially in which trends in VLC based dimming/flicker.

Keywords: Visible Light Communication (VLC), Light-Emitting Diode (LED), photodiode (PD).

1. Introduction

The necessity for alternative technologies is a result of increased wireless data traffic from the rapidly growing wireless mobile devices, which is inspiring compression on the dwindling radio frequency (RF) spectrum. This interest about spectrum reduction led to the formularization of a new technology called visible light communication (VLC) [1- 4].

Free/large license bandwidth, availability of existing infrastructure, additional security, and the obscurity of interference with neighbor technology are the main attracting features in VLC technology today [5, 6]. It can be facilely integrated into the present lighting infrastructure with the extension of a few inexpensive front-end components. All these unparalleled characteristics make VLC a subject of rising interest and development. The IEEE 802.15 working group for wireless personal area networks (WPAN) founded the IEEE 802.15.7 VLC task Group and dedicated it to write physical layer (PHY) and medium-access control (MAC) standards for VLC [1-3, 7].

The recently diverse application uses VLC to mend their performance and existence. The application includes vehicle to vehicle communication (V2V) [7], vehicle to infrastructure communication (V2I) [7], Localization [8], [9], video streaming [10], traffic control systems [11], underwater communication systems [12], biomedical [13], and effective data broadcasting within offices [14]. efficient VLC communication/illumination system is the most desirable application.

One of the major advantages in VLC depending on applications is light emitting diode (LED) which is the primary design element. Low production cost, low power consumption, high efficiency, availability to operate at high bit rates and easy to integrate with existing lighting infrastructure are some of the traits of LED [4, 15]. In addition, LED benefits effectively from simple Intensity modulation (IM) and direct detection (DD) to establish VLC based links [3, 16].

Recalling the famous application for VLC, efficient lighting and communication VLC systems must have special dimming capabilities. Global electricity consumption for lighting is projected to rise by 60 percent through the next 25 years, which accounts for a consumption of above 4250 Tw [3]. As a result, the need for energy savings with an acceptable lighting quality in this sector is vital, and it can be effectively attained by dimming [17]. However, fulfilling efficient dimming control in a transmitting VLC communication/lighting link is rough since dimming has a reverse impact on communication. This is because it repairs the average lighting concentration according to user requirements, which reduce the data rate of a VLC communication link [3].

An extra problem, that mainly not reviewed deeply in the most previous surveys, is flicker effect. Flicker indicates to the inconstancy of the brightness of light generated in a light source. To avert Flicker, the changes in brightness must be pulsation within the maximum flickering time period (MFTP). The MFTP is defined as the utmost time period over which the light intensity can change without the human eye recognizing it [1, 18].

As a result, appropriate dimming/flicker avoid techniques and protocols must be created to coordinate between illumination and communication. Integrating efficient dimming/flicker avoid techniques into VLC systems will significantly enhance energy savings, enlarge system capacity and allow users to have full control over the lighting output [1].

The IEEE 802.15.7 task group provides dimming support as one of the key challenges in VLC [2- 4]. Flicker issue is not addressed in details yet in standards as an obstacle for efficient communication/lighting VLC system [1, 7]. To date, various dimming and flicker avoid techniques have been proposed. They can be classified into two categories: modulation-based dimming/ flicker avoid schemes and coding-based dimming schemes.

This article provides an in-depth survey for large modulation and code-based dimming/flicker avoid schemes. To the author's best knowledge, flicker avoid techniques is addressed deeply for the first time. More than 60 papers, ranging from the pioneering papers to the current state-of-the-art, were collected and classified based on certain criteria. A detailed comparison among existing techniques is given.

An in-depth survey about modulation schemes that are used to manage dimming issues and flicker effect are provided in section 2. Similarly, in section 3 discussion dimming based coding schemes. Section 4 concentrates on the novel trends on the topic. Finally, our conclusion presented in section 5 and the more relevant references.

2. Modulation Schemes

In this section, modulation schemes provide dimming control as shown in Fig. 1 which is utilized to balance effectively between lighting and communication quality are surveyed in section 2.1. This work classifies these schemes into six main categories.

First, simple modulation schemes (i.e. simple modulation design family or category) contain On-Off Keying (OOK), Variable OOK (VOOK), Pulse-Width Modulation (PWM), Pulse-Amplitude Modulation (PAM), and M-ary Pulse Amplitude Modulation (M-ary PAM).

Second, slope modulation family covers Pulse Slope Modulation (PSM), Pulse Dual Slope Modulation (PDSM) and Pulse Dual Slope and Amplitude Modulation (PDSAM). These schemes share the property of controlling dimming using slop.

Third, Colored modulation family covers Color Shift Keying (CSK), Color-Intensity Modulation (CIM), Generalized Color Modulation (GCM) and Color-Clustered Multi Users VLC (MU-VLC) system.

Pulse Position Modulation (PPM), Code Time Division Multiple Access -PPM (CTDMAPPM), Variable Pulse Position Modulation (VPPM), Multiple Pulse Position Modulation (MPPM), Multi-Coded VPPM (MC-VPPM), M-ary PPM (M-PPM), Sub-Carrier PPM (SC-PPM), Expurgated PPM (EPPM), a Variable Rate MPPM (VR-MPPM), Variable MPPM (VMPPM), Double Inverse PPM (DIPPM), M-ary VPPM (M-VPPM) and Overlapping PPM (OPPM) compose the fourth family.

Orthogonal Frequency Division Multiplexing (OFDM), DC-biased Optical OFDM (DCO-OFDM), Asymmetric Clipped Optical OFDM (ACO-OFDM), multi-level quadrature amplitude modulation OFDM (M-QAM OFDM), reverse polarity optical OFDM (RPO-OFDM) and Asymmetrical hybrid optical OFDM(AHO-OFDM) form fifth category.

Finally, the sixth category will be called adaptive or merged modulation techniques. It contains Complementary PPM (CPPM) jointly with CSK, M-QAM OFDM with PWM and M-QAM OFDM with MPPM.

In section 2.2, similar handling will be repeated for flicker avoid techniques. In this section, for families of modulation schemes as shown in Fig. 2 are namely simple design modulation family, slop modulation family, color modulation family and PPM modulation family which will be reviewed and their effect on flicker avoid performance will be highlighted. The reason for focusing on these four family is that they are the only families that deals with these issues in the recent years. Finally, making comparative study for different kinds of modulation schemes presented in table 1.

2.1 Modulation Based Dimming Schemes

Fig. 1 shows the tree of modulation families-based dimming schemes.

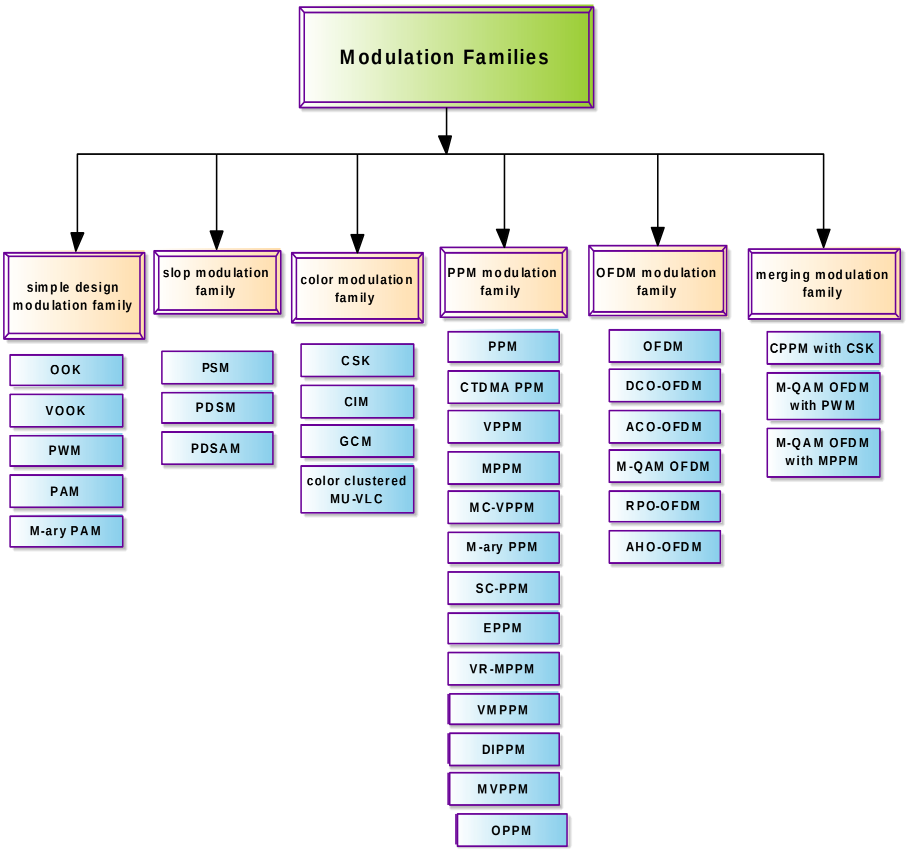

Fig. 1: The tree of modulation families-based dimming schemes.

2.1.1 Simple Design Modulation Family

One of the most prevalent modulation schemes used in VLC is OOK. Main feature of OOK is very easy to implement [15- 16, 19- 20]. On the other hand, it has a very low spectrum efficiency [15], low operating data rate [1, 3] and relatively low dimming control range (i.e. maximum 50%) [15- 16, 21]. Finally, the variable data rate can be realized by inserting compensation time [1, 3, 15]. It causes more power consumption when the duty cycle is small [22].

Improving the spectral efficiency can be realized using VOOK [23] where VOOK is nearly similar to the original OOK, but it can variate the dimming level by adding compensation symbols to an OOK frame [3, 24]. However, adding such symbols deteriorates VOOK's data-transmission rate, and also, VOOK needs to estimate the optimum threshold level for demodulating a received signal [23, 24].

PWM can also improve the dimming levels over traditional OOK [25- 26], where PWM-based dimming control provides a wide range of dimming levels [18, 27- 28]. A key advantage is enhancing power consumption [27, 29]. It also has good lighting satisfaction and little implementation cost [7, 30]. An observed limitation is vulnerable to noise which also limits the realizable data rate [27].

The need for a higher data rate leads to the utilize of multi-level modulations such as PAM [25, 31]. However, this scheme suffers from relatively high noise [26], limited power saving [29, 31] and the need for sophisticated intensity control [26]. It is required for efficient multi-level modulation adapting to the dimming requirement [25, 28- 29, 31- 33]. Finally, it has high spectral efficiency.

To enhance power saving, M-ary PAM is proposed [26, 33] which provides relatively higher operating rates (i.e. more bandwidth efficient) compared to other schemes in this family [15]. However, satisfying dimming requirements with so sophisticated intensity control and most importantly the need for system linearity are the main limits [26, 33].

2.1.2 Slop Modulation Family

This design of this family concerns most about improving signal-to-noise ratio performance for a dimmable VLC system without undue bandwidth restriction [34]. In the primary modulation scheme PSM, the modulating signal varies the slope of the leading edge of the pulse but it keeps a constant frequency carrier [35].

PDSM is an extension of PSM which enhances the slope control for rising and falling edges together to improve both dimming control [3, 7, 25, 36] over PSM.

Finally, to improve bit error rate (BER) performance over the previous two schemes in this family, PDSAM is proposed [7]. This algorithm combines the approaches of PDS and amplitude together to obtain effective dimming [7] and to enhance more BER performance.

2.1.3 Color Modulation Family

CSK is higher order modulation support to provide higher data rates at a lower optical clock frequency [1, 37- 38]. The total power of all CSK light sources is constant [7, 15] although all light sources may have a various instantaneous output power [37]. CSK dimming ensures that the average optical power from the light sources keeps the requisite intensity of the center color of the color constellation and maintains constant [15, 39]. CSK dimming utilizes amplitude dimming [7, 25- 26], but the CSK is high complexity [38] and highly cost [38, 40]. CSK does not include a systematic method of coping with varying target color conditions, so it is not suitable for communications under varying target color conditions. In addition, its performance is minor to that of the conventional intensity-based wavelength division multiplexing (WDM). Some constellation designs for CSK based on the billiards algorithm. However, the constellation design solution given for color balancing could not be verified analytically [41].

CIM has been submitted to enable the modulation of both color and intensity for dimming support [2, 25- 26]. Since CIM utilizes the entire three-dimensional district to optimize symbol mapping in the signal extent and regulate color demands in the color space jointly [2], it outperforms CSK [2, 25- 26, 33].

In order to overcome these limitations, a color space-based modulation scheme termed GCM for color-independent VLC [41]. The most important merit of GCM over the other modulation schemes is color independency, while CSK is currently applicable for only white visible light [42]. GCM is able to produce any color within a gamut area by adding some of the wavelengths or colors. Therefore, through GCM, a VLC scheme can keep the original color and brightness while implementing seamless communication. GCM can have any number of wavelengths which can be randomly selected from a visible band. In addition, separate color channels increase data throughput and communication under dimming control [41- 42].

To achieve a high-speed data transmission by using the color-clustered MU-VLC system, MU-VLC specifies various users into these three essential colors realized as color clusters: cluster r, cluster g, and cluster b. Using OOK, the data of the users in each cluster is intensity-modulated with RGB beams of the RGB LED individually and transmitted jointly. It supplies considerable performances. Additionally, the RGB LEDs are utilized to control the color of the indoor illumination [6].

2.1.4 PPM Modulation Family

PPM is an attractive modulation scheme for optical communications since it requires simple transmitter/receiver structures [43], it is power efficient and is easy to implement [3, 44]. However, in high-rate free-space optical systems requiring higher-order modulation, it introduces several impairments such as a high peak to average power ratios (PAPR) and low spectral efficiency. A dimming level and a lower communication system performance are a result of a high PAPR; a low spectral efficiency causes high interference between symbols in bandlimited systems [43], it preserves the dimming contribution from its fixed average power [44- 45].

CTDMA-PPM is multiple access schemes. It is a form of PPM which is keyed with regard to a spreading sequence. This scheme considers illumination constraints and communication requirements jointly, it has not been addressed by other optical modulation methods. Based on the proposed modulation method and multiple access schemes, the promoting of a system structure includes illumination sources and a control system. Illumination sources send information and illuminate the environment, jointly. This system structure could support the dimming range [46].

To support illumination with dimming control and communication simultaneously, VPPM is proposed [25, 32, 43]. VPPM is the modulation scheme suggested by the IEEE 802.15 standard group [47]. It uses PWM for dimming control and binary PPM for communication [36, 48]. However, the main obstacle of the VPPM scheme is that the data rate is limited to the bandwidth of an LED since it uses only binary PPM modulation. It is easy to implement [15, 24, 49].

MPPM proposed to offer to control the brightness and modulating data simultaneously. The bandwidth efficiency of MPPM can be decreased to about half of PPM at the same transmission efficiency [29, 50- 51]. It analyzed communication performance in terms of the normalized less power requirement, the best achievable rate and relative high spectral efficiency [20, 23, 48].

To implement better realizable data rate than the conventional VPPM scheme, MC-VPPM is investigated. MC-VPPM for VLC systems is contained from Two kinds of signals PPM and PWM which these are multi-coded by orthogonal codes for transmitting data at the same time. Then, all multi-level value of the MC signal improved data rate. In addition, dimming control for light illumination can be supported without any degradation in communication performance [52].

M-ary PPM (M-PPM) is a candidate for VLC in early stages to implement dimming matching, and easy synchronization is enabled by strict run-length limitation. Each M-PPM yields various BER and throughput [33].

The submitted scheme which achieves improvement in power savings is SC-PPM [53]. There are two methods using SC-PPM for data transmission. One method is using PWM for brightness control. Brightness and communication can be controlled independently, however, changing the brightness affects the communication signal power. And the other brightness control is realized by changing the modulation depth, which This scheme achieves constant data transmission rates even if the brightness is varied [53- 54].

To excess the spectral-efficiency of PPM [55] and to improve its performance in bandwidth limited channels, EPPM is suggested [56]. EPPM can extend a wide range of PAPR needed for dimming of the indoor illumination. Interleaving applied on EPPM in order to reduce the inter-symbol interference (ISI) impact in dispersive VLC channels can significantly decrease the error probability. The suggested interleaving technique makes EPPM a preferable modulation option compared to PPM for VLC systems. An overlapped EPPM pulse technique is suggested to raise the transmission rate when bandwidth-limited white LEDs are provided as sources [43, 57].

To improve the data-transmission rate of VPPM, VR-MPPM has been explored in [58]. VR-MPPM system is the developed version of MPPM for supporting dimming control [51]. The VR-MPPM will estimate the received optical power per frame by the threshold detection, and it increased the complexity of the receiver [24].

To achieve a higher data-transmission rate than the conventional VPPM, the VMPPM modulation scheme is submitted. VMPPM system proposed with a dimming control that joins the employ of pseudo-orthogonal codes and MPPM. VMPPM is superior to VPPM in the spectral efficiency. Symbol error rate (SER) performance of VMPPM is superior to that of both VR-MPPM and VPPM [24].

To satisfy higher dimming levels for illumination sources in VLC system, DIPPM scheme that allows for dimming control is proposed. DIPPM is a progress form of the IPPM scheme. Inserting a compressed IPPM symbol in the off slot of IPPM symbol produces DIPPM symbol. The data is encoded by changing the position of the off slot, and by allowing for data transmission of more than one bit per symbol [36].

To achieve the increasing demands of multimedia services in VLC, this proposes an M-VPPM scheme that provides a higher data rate than that of VPPM. The transmit-receive modem structure and optical wireless channel were modeled which provide a guideline for M-VPPM operation satisfying both lighting and communication abilities for a given environmental condition [18].

To relieve the weaknesses of simple PPM, generalized forms of PPM have been submitted to improve its performance in optical systems. Two methods for supporting dimming on the method; changing the amplitude of OPPM symbol pulses is proposed [44, 59, 60], other method is suggested by changing OPPM codeword [61] weight. OPPM is employed to excess the data rate of PPM in communication systems [61] with bandwidth limited sources [62]. The application of OPPM to VLC systems is also utilized in combination with PWM to accept the average power constraint [7, 43, 63].

2.1.5 OFDM Modulation Family

Multiple-subcarrier modulation (MSM) is OFDM in OWC [26]. OFDM signals are bipolar with classification to the medium which is generally zero. The medium should be moving to a positive value because VLC displays the only nonnegativity. This medium value becomes the desired dimming level of the lighting [26, 64]. OFDM is presupposed to be the most advantageous for VLC systems [42, 65]. It is also supplied equal data transmission by orthogonal subcarriers submits above all high data rates [3, 42, 65] which can fulfill with high SNR [3], high bandwidth efficiency [15- 16, 42, 64- 65] and decrease complexity in equalizers [39, 42]. Due to its long symbol period, OFDM is inherently very powerful against multipath create ISI which is a central attention in indoor OWC [42]. OFDM has a comparatively huge PAPR which brings poorer power efficiency than single-carrier approaches [26, 42- 43, 64]. The produce of the OFDM modulator is bipolar and complex. However, in IM optical systems, the baseband signal must be real and unipolar. The DCO-OFDM and the ACO-OFDM are well known IM forms of optical OFDM [66- 67].

DCO-OFDM is utilized to yield a non-negative signal [2, 26]. This technique discards the DC-bias at the receiver which causes a major loss of power. The DC informative modulation schemes were then submitted such that hundred percent optical power is utilized for data transmission [26, 68]. This technique can provide all dimming methods [2].

ACO-OFDM is well suitable for dimming systems because it has better performance than DCO-OFDM at low SNR regime [67]. ACO-OFDM is converted bipolar signal to unipolar signal by clipping all nonpositive levels to zero by electrical signal processing. That technique can provide all dimming methods except for distribution adaptation because an instantaneous signal level within a single OFDM symbol is hard to control by adjusting the signal level of individual subcarriers [2, 64, 68].

The advantage from realizing an advanced modulation format is that M-QAM OFDM in the VLC system is to solve the power-consuming problem, where M is firstly altered according to the changed duty cycle followed by the variation of symbol rate. The effect of modulation index to dimming control scheme is also discussed. Note that the modification of modulation format and symbol rate are widely utilized in wireless communications. The required symbol rates of M-QAM OFDM are always less than the original symbol rate, but not less than the half of the original symbol rate which fulfills the dimming control scheme easy to be attained [7, 27, 50].

RPO-OFDM is submitted to combine the PWM dimming signal with the O-OFDM communication signal where both signals affect the LED brightness [3, 5, 28]. The merits of utilizing RPO-OFDM include that the data rate is not limited by the frequency of the PWM signal, and to maintain a high link capacity for a wide dimming range. Therefore, the signal-to-noise ratio (SNR) is independent on the dimming level within that wide range [3, 28, 69].

A wide dimming range with a small throughput fluctuation is fulfilled by using AHO-OFDM. AHO-OFDM is submitted for VLC systems which totally utilizes the subcarriers and the dynamic range of LEDs for supporting diverse dimming objectives to improve the realizable system performance [64].

2.1.6 Merging Modulation Family

To improve data rate and reliability of the link, so that a CPPM is jointly with CSK. CPPM signaling is a PPM format with the variation of carrying information only where power is not present. By fact, CPPM utilized in combination of CSK can be interpreted as a sort of Not-Return-to-Zero (NRZ) signaling since there is lower rate request for implementing such a CPPM. The submitted scheme is robust with respect to optical interference. It presents high rate and low BER at the cost of a bit complexity raising with respect to other approaches [37- 38].

Reduce symbol rate and required LED power are the result of proposing the combination between variable M-QAM OFDM with PWM, which is much easier for system implementation and more power-saving compared to OOK signal transmission. However, in this scheme, OFDM signal is only transmitted during the "on" period of PWM pulses. Thus, the data rate is still inversely proportional to the duty cycle for maintaining constant rate transmission. When reducing duty cycle, the required symbol rate will be greatly increased which pushes up receiver sensitivity requirement [28, 50].
There is a new dimming control scheme in indoor VLC systems. This scheme joins OFDM signal and MPPM light pulse with each other by dividing conventional PWM pulses into MPPM pulses with the same duty cycle. Thus, the pattern effect of MPPM pulses is utilized which fulfills excess signal transmission possible. The brightness of LED and the achievable symbol rate using dimming control pattern are not higher than the traditional PWM scheme and the launched LED power is also reduced, which satisfies both system reliability and energy effectiveness under constant high data rate and BER is less than 10^{-3} [28- 29, 50].

2.2 Flicker Scheme

Fig. 2 shows the tree of modulation families-based flicker schemes.

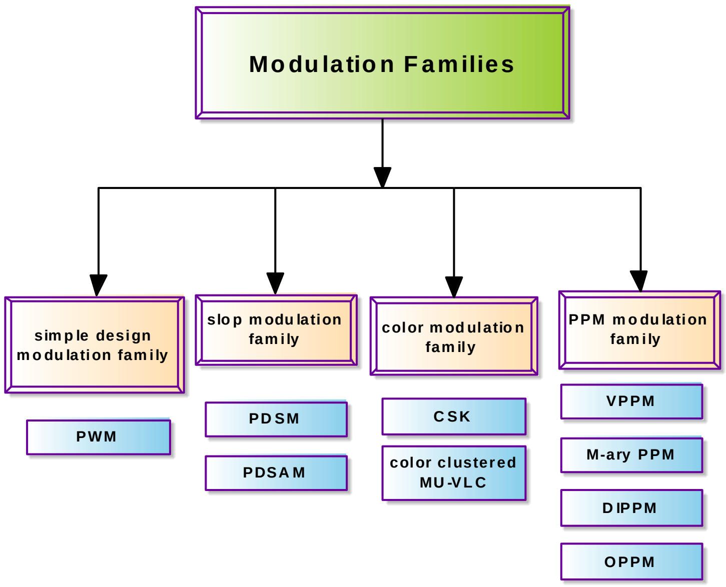

Fig. 2: The tree of modulation families-based flicker schemes.

2.2.1 Simple Modulation Family

PWM is a simple method for non-flickering [48].

2.2.2 Slop Modulation Family

PDSM offers improved flicker [7, 26] by changing the slope of the rising and falling edges of the pulse to represent 1 and 0 bits, respectively [36]. PDSAM utilized for addressing flickering [7].

2.2.3 Color Modulation Family

As the average optical power from the light sources is maintained constant and preserves the requisite intensity of the center color of the color constellation, so that there is no flicker issue associated with CSK [39- 40]. The color cluster MU-VLC system flicker-free effect is ensured [6]. CCMA, a new modulation scheme for bidirectional multiuser VLC, is presented for smart home applications and provided flicker-free illumination [70].

2.2.4 PPM Modulation Family

VPPM offers with improved flicker mitigation [25, 48], M-ary PPM implements flicker-immunity [33], DIPPM scheme is used to minimize flickering [36], and the OPPM method for communication minimizes the flickering effects [7].

Table1: Comparative study for the different kinds of modulation schemes.

Modulation Schemes	Design		Efficiency		Dimming Control		Operating Data Rate		Power Consumption		Implementation Cost		Relative noise		Flicker	Communication system performance		order modulation	
	S	C	H	L	H	L	H	L	H	L	H	L	H	L		H	L	H	L
OOK	√			√		√		√	√										
VOOK	√		√		√														
PWM					√			√		√		√			√				
PAM			√				√		√				√						
M-ary PAM							√			√									
PSM						√								√					
PDSM					√										√				
CSK		√					√				√				√	√		√	
CIM		√			√		√				√					√		√	
GCM		√			√		√√									√		√	
PPM	√			√						√							√	√	
VPPM	√				√					√					√			√	
MPPM					√		√			√						√			
MC-VPPM					√		√									√			
SC-PPM					√					√√						√		√	
EPPM			√				√									√		√	
VR-MPPM		√			√		√												
VMPPM			√		√		√							√					
DIPPM					√					√					√				
M-VPPM					√		√									√			
OPPM					√		√								√	√			
DCO-OFDM					√		√		√					√			√		
ACO-OFDM					√				√							√			
M-QAM OFDM					√					√									
RPO-OFDM					√									√				√	
CPPM		√					√				√								
M-QAM OFDM with PWM	√				√					√								√	
M-QAM OFDM with MPPM	√				√		√			√						√		√	

S: refers to "Simple", **C**: refers to "Complex", **H**: refers to "High", and **L**: refers to "Low".

3. Coding Schemes

In this section, coding schemes that provide dimming control which is used to balance effectively between lighting and communication quality are surveyed. In IEEE VLC standard [1, 20- 21], the dimming function is provided via run length limited (RLL) codes and compensation symbols (CS) for OOK modulation; however, either a Reed Solomon (RS) [16] or a concatenated code composed of RS and convolutional codes are used for forward error correction (FEC) codes. This system does not consider modification of FEC codes according to dimming support [1, 20- 21].

Inverse Source Coding (ISC) changes uniform symbol probabilities of the binary information source to certain values of symbol probabilities, which is the best possible upper bound [25]. The ISC concept is presented to show the information theoretic approach and one of its practical implementation based on inverse Huffman coding is to maximize the realizable data rate under the support of dimming control [16, 20, 26] and asymptotically achieves the theoretic performance bound [2, 33].

Reed-Muller (RM) code is one form of linear error-correcting code used in communication systems [3]. Modified RM code was submitted to guarantee the same number of zeros and ones in a codeword [48]. While this scheme provides a stable brightness of lights, it can support dimming levels due to the structural constraint [20, 25- 26, 48].
FEC codes in OOK based VLC system utilized RM codes for realizing dimming control [3, 16]. The code was submitted to ensure that the number of zeroes and ones in a codeword are the same, and dimming was fulfilled by inserting a CS [16, 21, 50]. CS takes the value of either one or zero depending on the dimming target. Although this technique can expand stable brightness, it can only support dimming levels due to structural constraints [3, 16, 20]. FEC codes extend more improved BER performance [16, 50].
The proposed turbo coded system employs puncturing and scrambling techniques to match the Hamming weight of codewords with targeted dimming rates [19, 21, 48]. The iterative decoding algorithm developed for turbo codes allow better decoding performance over existing coding schemes devised for VLC systems [19, 48].

Rate-Compatible Punctured Convolutional (RCPC) codes are a subclass of punctured convolution codes utilized in telecommunications. Puncturing involves deletion of some bits in the encoder based on a puncturing pattern [3]. The simple design method for dimming control is introduced using RCPC code which can generate codes of various rates using the same encoder [48].

Low-Density Parity Check (LDPC) coded VLC systems is currently studied to mitigate the influence of interference in LED arrays, but its spectral efficiency must be further improved. While VLC could be applied to various lighting [3]. VLC systems to support data rate over 1Gbps were also proposed by using LDPC codes [21]. Quasi-cyclic (QC) LDPC codes are adopted for efficient encoding in implementations and code design to adjust dimming control [21].

Automatic Repeat Request (ARQ) is normally adopted. In LED-based VLC system, ARQ has little complexity which requires a reliable feedback channel, thus large memory size and large delay are needed [5]. The information is difficult to be recovered if packet loss occurs. Also, some hybrid schemes of FEC and ARQ are submitted to make the error control decisions according to media and channel characteristics. The suggested scheme needs a simple per packet acknowledgment scheme [5].

Fountain codes are embedded for error control scheme for VLC system. Various dimming target values can be supported simply and the least complemented symbols are needed. According to the properties of the fountain codes, the new scheme is rate less. That fits well for the channels in which interruptions occur frequently due to the encoded bits of the same original message are produced continuously till the successful transmission is completed. Protocol complexity and packet delay can be reduced because of the fact that only the correct receiving information is necessarily to be feedback [5].

A MU-VLC transmission scheme using optical code division multiple access (CDMA) has also been submitted by Guerra-Medina et al. [6, 46, 57]. Random optical codes have been utilized as the basis for OCDMA to transmit data from multiple sources [6, 46]. OCDMA transmits data bits that are multiplied by the code sequence. The OCDMA system only achieves a bit rate of 20 kbps, although the LEDs could transmit data at a much higher speed [6, 57].

Optical Orthogonal Codes (OOC) are binary sequences with special cross-correlation constraints which are utilized to encode the data of users in the time-domain. The application of OOCs to VLC networks requires codes with a wide range of parameters for various dimming levels [57].

Table2: Comparative study for the different kinds of Coding schemes.

Coding Schemes	Dimming Control	Data rate		Performance	Brightness		Design	
		High	Low		stable	unstable	simple	Complex
ISC	√	√		√				
RM	√				√			
FEC	√			√	√			
turbo coded	√			√				
RCPC	√						√	
LDPC	√	√					√	
ARQ	√							√
Fountain codes	√						√	
CDMA	√		√					
OOC	√			√				

4. Some Novel Trends for Dimming Schemes

Dimmable VLC systems are still at an extremely neoteric stage, and there are considerable areas that desire attention such as:

- The simulation-based analysis should be explored experimentally, taking the communication, and energy-based performance into account under one structure.
- Study factors such as ambient light, non-linearity of LEDs, shadowing, junction temperature, and surrounding reflections of the wireless channel have a considerable impact on VLC link performance which cannot be well modeled by simulations.
- An efficient dimming scheme for VLC systems must extend high data rates and power savings while accurately abiding by the required illumination level, which can only be justified by such experimental explorations.
- Efficient dimming control mechanisms integrated into VLC system can give a rise to considerable useful applications. One of the favorable applications of dimmable VLC is a transmission of information concerning artifacts inside a museum.
- VLC can be utilized in hospitals and airplanes where the use of radio frequency communication devices is prohibited. These

indoor environments in particular desire dimming control is used to comfort and appropriateness of surrounding occupants.

- Automated dimmable VLC systems can be utilized in offices where illumination level would be preserved based on ambient light, and various cubicles will have different light levels based on the tasks carried out.

5. Conclusion

This paper reviews major kinds of modulation and coding schemes considerations for VLC systems. High-rate transmission over dimming support and flicker are identified as the two main driving forces that motivate the creation of newly enhanced specifications in VLC. Modifications in coding and modulation are necessary to support adaptive dimming and solving flickering. From this perspective, the kinds of modulation and coding schemes considerations highlighted in this article are intended to serve as guidelines to realize these requirements and to motivate further research in dimming support and flickering.

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الملخص باللغة العربية

لقد شاع استخدام تكنولوجيا الاتصالات باستخدام الضوء المرئي **(Visible Light Communications “VLC”)** مؤخرًا كمُساعِد لتكنولوجيا الاتصالات التي تستخدم موجات الراديو، وذلك نظراً للعديد من المُميزات والتي من بينها: عدم الحاجة للحصول على رخصة الترددات، وتوافر البنية التحتية، وعدم التداخل مع موجات الراديو، والخصوصية وارتفاع عامل الأمان. وبالإضافة إلى عملها كمصدر للإضاءة، فإن تكنولوجيا الاتصالات باستخدام الضوء المرئي تهدف أيضًا للعمل كمصدر للاتصالات، حيث أن من أهم الخصائص التي يجب توافرها هي عدم ظهور إحدي الوظيفتين على حساب الأخرى. ولذا فقد تم الاعتماد على الصمام الثنائي الباعث للضوء **(LED)** كمصدر ضوئي بغرض الإضاءة وبغرض العمل كمصدر للاتصالات ونقل البيانات. وقد وُجِد أنه يُحقق هذا التوازن ويلعب كلا الدورين بكفاءة عالية، فالصمام الثنائي الباعث للضوء يتصف بطول العُمر الافتراضي، والاستهلاك الضعيف للطاقة، والكفاءة العالية، كما يُمكن استخدامه أيضًا في نقل البيانات بمُعدّل عالٍ مُقارنة بباقي مصادر الضوء التقليدية. تُستخدم تكنولوجيا الاتصالات بالضوء المرئي في العديد من التطبيقات، من بينها: بث البيانات بمُعدلٍ عالٍ داخل المنازل والحُجرات، وفى الأماكن ذات الحساسية العالية لموجات الراديو مثل الطائرات والمُستشفيات، كما تُستخدَم هذه التكنولوجيا أيضًا في تنظيم المرور لنقل البيانات بين المَرْكبات وبعضها وأيضًا لنقل البيانات بين إشارات المرور لزيادة كفاءة المرور وعامل الأمان، كما أن هذه التكنولوجيا تُستخدَم في نقل البيانات تحت الماء لمسافات قصيرة وبكفاءة عالية. وقد تم التركيز في هذا البحث علي عمل دراسة مرجعية كاملة لكل من عمليات التعديل **(Modulation Techniques)** والترميز **(Codding Techniques)** المختلفة المستخدمة في دعم عملية التعتيم **(Dimming schemes)** والحد من الوميض **(Flicker schemes)** بغرض اجراء دراسة مقارنات بينها وكذلك تقديم اهم الاتجاهات البحثية الحديثة في الموضوع.