JOURNAL PUNJAB ACADEMY OF SCIENCES (Peer Reviewed Open Access Journal)
JPAS, 23: 01-07 (January-December, 2023)
Available online at www.jpas.in
ISSN 2229-7014 (P)

MODE DIVISION MULTIPLEXING ENABLED SECURITY ENHANCED VLC SYSTEM EMPLOYING 2-D WMZCC CODES

Harleen Kaur[1] and Dr. Narwant Singh Grewal[2]
[1]Research scholar, Dept. of ECE, IKGPTU, Jalandhar, India
Email:harleen687@gmail.com
[2]Dept. of ECE, GNDEC, Ludhiana, India
Email: narwant@gndec.ac.in

ABSTRACT

Optical code division multiplexing (OCDMA), a popular multiple access technique in VLC systems, offers excellent security while supporting several users. The non-adjacent weights (W), time (t) dimension based optical coding, two-dimensional (2D) Weight Managed Zero Cross Correlation (WMZCC), and better security are all introduced in this work. In a 5 user×100 Gbps OCDMA system using 2D-WMZCC codes, Laguerre-Gaussian (LG) modes are investigated in terms of Q factor, log symbol error rate (SER), and bit error rate (BER). In proposed 2D-WMZCC codes, it has been shown that HG modes exhibit greater data eavesdropping resistance than LG modes.

Keywords: 2D-WMZCC, VLC, MDM, LG, HG

INTRODUCTION

The peer pressure on wireless communication has increased over the past few decades because to the quick development of computers, smart wearables, tablets, Internet of Things devices and smart phones (L.U.Khan,2017). Moreover, traditional Radio frequency (RF) communication with restricted bandwidth has struggled to meet the demands of data-hungry internet applications (W.Gunawan,2021). Researchers have developed the VLC, a final solution for indoor communication that can handle heavy wireless data traffic. VLC attracts the attention of business, academia, and the military with its 300 THz visible light broad spectrum for communication and super rapid data carrying capability (S.Kaur,A.Verma,2022). Due to the lack of electromagnetic (EM) interference, it may be used in a variety of settings, including healthcare, traffic control, gas stations, and ships. Also, compared to dangerous RF transmission, VLC is seen as a communication that is favourable to human health. It is more secure against unauthorised assaults since VLC signals cannot pass through the barriers. Nonetheless, data security breaches continue to occur as a result of eavesdroppers present in the same room, conference rooms, libraries, and other locations (E.Tews,2009). Hence, enhancing the security of VLC networks is essential. This may be done by incorporating several techniques into OCDMA, such as wavelength conversion, multicode keying, quantum key distribution, and optical logic gates. The aforementioned data security improvement solutions are expensive and complicated, making them unsuitable for effective data transfer (M.Bloch,2011) (G.cheng,2017) (J.Tang,2019). The two main OCDMA code types are zero cross correlation (ZCC) and non-ZCC, and each has advantages and disadvantages of its own. While the latter offers bandwidth-efficient codes, the former has the least multiple access interference (MAI) but greater code lengths (M.Rehman,2020) (B.Salah,2019).

A. *OCDMA in VLC Systems*

In 2012, researchers used Ethernet OCDMA and LEDs in a multiuser VLC spanning 100 cm using a synchronisation mechanism to demonstrate a 20 kbps data rate. On the other hand, random optical codes have demonstrated weak correlation properties (M.Guerra,2012). Even at high chip speeds and with minimal noise in VLC, multi-color LEDs utilising modified prime sequence codes (MPSCs) as opposed to conventional shalaby-MPSC coding displayed MAI cancellation (S.Miyazaki,2015). A 160 Mbps data throughput in indoor VLC employing Zero Correlation Zone (ZCZ) coding is achieved in(E.Ouis,2019) using OCDMA architecture. Because to its shorter code length and flexibility, MS-OCDMA surpasses Khazani Syed code (KS-code) and Modified Quadratic Congruence code (MQC-code) at 622 Mbps over 12 m (R.Noh,2020). The introduction of DIM (S.Kaur,S.Singh,2020) and ZCCRW codes (R.Kaur,2020) resulted in the recent release of a new ZCC code family without mapping. These codes (often all ZCC codes) share the limitation of neighbouring weights in the code row matrix in addition to longer code lengths, and despite no overlap in the spectrum (ideally), significant MAI is seen. OCDMA codes with the second dimension, or Time, have drawn a lot of interest due to the removal of unnecessary logic gates and other security enhancement measures. One-dimensional (1D) OCDMA codes are believed to be less secure than two-dimensional (2D) codes (2D). Certain wavelength configurations are used in 1D codes, but in 2D codes, time is added as a second dimension, and temporal delays produce a more secure OCDMA code (K.Kitayama,2003). In (F.Akhoundi,2015), 2D-DIM codes that are generated from 1D-DIM codes are released; nevertheless, due to sequential time and neighbouring diagonal values of W in the code matrix, eavesdroppers may readily crack the code. This problem affects nearly every 2D-ZCC code. The best way to handle higher data rates is to use multilevel modulation and polarisation division multiplexing (PDM). As a result, PDM and wavelength division multiplexing (WDM) are used in VLC and successfully reached 40.665 Gbit/s utilising bit-and-power-loading OFDM (L.Wei,2019). A PDM-WDM with a capacity of 60 Gbps that covered 200 cm was proposed by (Xiang-Peng 2021).

B. MDM in VLC Systems

Space division multiplexing (SDM) has become a promising technique that has caught the attention of academics due to its capacity to address data demands and spectral efficiency of next-generation networks [24]. In SDM, several electromagnetic wave spatial distribution characteristics are multiplexed and may carry very high data rates. Data is sent using the distinct intensity profiles of laser light produced by varying the azimuthal and radial numbers in mode division multiplexing (MDM), a subtype of SDM [25]. MDM is used to improve security in wireless optical satellite networks with 100 Gbps capacity, ZCCRW codes, LG, and HG modes in [26], hybrid passive optical networks (PON), and wireless optical terrestrial networks (WOTN) with LG modes over 700 m in [27], RF over WOTN at 20 Gbps incorporating HG modes over 165 m under dense dust in [28], and HG modes enabled WOTN at 10 Gbps over 40 m in fog using decision feedback equaliser [29].

To improve the security of the VLC system, MDM and 2D-WMZCC codes have been merged in the proposed work. In our previous work [30], we built the security-enhanced VLC System using 2D-WMZCC codes while taking eavesdropper effects into consideration.

CODE CONSTRUCTION OF 2D-WMZCC CODES

Several research investigations on 2D-ZCC OCDMA codes are described in the literature, but they all show the same pattern of "1s" in the code matrix, which is a diagonal arrangement of "1s." ZCC codes theoretically have 0% MAI, however in practise, due to neighbouring "1"s, MAI enters the system and degrades performance. Additionally, an eavesdropper may easily get legal wavelengths and time delays via metadata. Since time delays also follow the same pattern as '1's (adjacent successive time delays), adjacent '1's arrangements are less secure because they are simpler for an eavesdropper to understand. Nevertheless, the suggested 2D-WMZCC codes provide strong anti-eavesdropping protection since t and W are situated at different Wavelength/time locations within the code matrix. In order to realize a 2D-WMZCC code, we have added the second dimension to the 1D-WMZCC code reported in our previous work [30]. The addition of the time dimension *(t)* to the the 1D-WMZCC code (for 5 users [30]) transforms 1D-WMZCC codes into 2D-WMZCC codes, as shown in F_T. Wavelengths are shown in rows while time is shown in columns. The chosen time *t* is

$$t_N = j_N \times t_b \qquad \text{□□□}$$

where t_b bit time slot, j is no. of time the slot j (1,2,3,4…..N) and calculated as

$$t_b = 1/\text{ bitrate} \qquad (2)$$

(8) in [30] can be rewritten as

$$[t_1 \quad t_2 \quad t_3 \quad t_4 \quad t_5 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots t_N]$$

$$F_T = \begin{bmatrix}\lambda_1\\ \lambda_2\\ \lambda_3\\ \lambda_4\\ \lambda_N\end{bmatrix}\left\{\begin{matrix} UR & 00 & 00\,00 & 00 & LR\,(R_1-1)^{0's}+(W-W')^{1's}\\ LR & LR & 00\,00 & 00 & 00\,(R_2-1)^{0's}+(W-W')^{1's}\\ 00 & UR & UR\;0 & 00 & 00\,(R_3-1)^{0's}+(W-W')^{1's}\\ 0 & 00 & LR & LR & 00\;(R_4-1)^{0's}+(W-W')^{1's}\\ 00 & 00 & 00 & UR & UR\;(R_5-1)^{0's}+(W-W')^{1's}\end{matrix}\right\}_{K\times(K\times W'+K)} \quad (3)$$

For *K=5* and *W=3* final matrix of 2D-WMZCC is obtained and shown in (4).

$$t_1 \quad t_3 \quad t_6 \quad t_9 \quad t_{12}..t_{15}$$

$$\mathrm{F_T} = \begin{Bmatrix} 100000000110000\\ 010100000001000\\ 001010000000100\\ 000001010000010\\ 000000101000001 \end{Bmatrix} \quad (4)$$

SYSTEM SETUP

Fig. 1 shows the suggested MDM-OCDMA-VLC system based on the 2D-WMZCC codes for security enhancement. Simulation setup is done in the Optisystem software. Table 1 shows the simulation parameters for the proposed MDM-2D-WMZCC-VLC system.

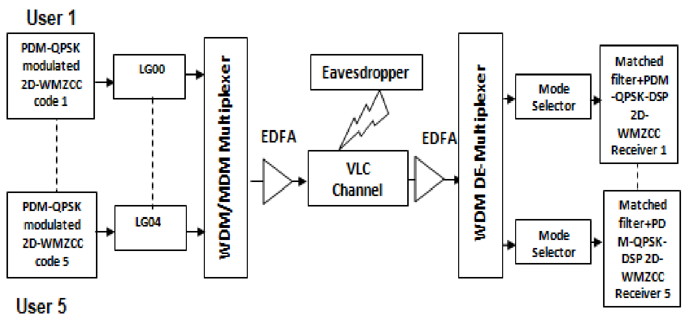


Fig. 1: Representation of 2D-OCDMA-VLC system using MDM

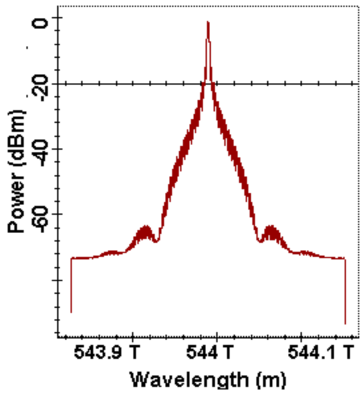
For K=5, W=3, 2D-WMZCC code matrix is illustrated in equ. (4) and frequencies/time for each user are as follows: K_1- 544 THz/t_1, 544.9/t_{10} THz and 545 THz/t_{11}, K_2- 544.1 THz/t_2, 544.3 THz/t_4 and 545.1 THz/t_{12}, K_3- 544.2 THz/t_3, 544.4 THz/t_5 and 545.2 THz/t_{13}, K_4- 544.5 THz/t_6, 544.7 THz/t_8 and 545.3/t_{14}, and K_5- 544.6 THz/t_7, 544.8 THz/t_9 545.4 THz/t_{15}. Each user in the code matrix is modulated using PDM-QPSK. Different modes, such as LG00 for User 1, LG01 for User 2, LG02 for User 3, LG03 for User 4, and LG04 for User 5, are allocated to each user. The PDM-QPSK always includes a serial bit binary data generator, serial to parallel (S/P) conversion of data, and X/Y QPSK modulators running at a 100 Gbps data rate. The polarizations of a Lambertian source are separated into X/Y components (i.e., horizontal and vertical) and sent to the appropriate QPSK modulators X/Y with the inclusion of a polarization splitter. Signals that are X/Y polarization enabled are combined and delivered to the VLC channel using a polarization combiner. VLC channel is said to be used to test system performance since it is vulnerable to eavesdroppers. The system has a mode selector to remove a certain mode profile immediately before the receiver. The 12 functions and algorithms universal DSP component performs at the receiver. The preprocessing stage, which includes DC blocking, noise addition, normalization, and signal recovery as the final step, has 8 algorithms and functions. Resampling, QI Compensation, Adaptive Equalizer, Bessel filter, PWB Compensation, time recovery, Nonlinear (NL) Compensation, CPE, and FOE are the phases of the method. To make the aforementioned improvements, DSP employs three separate methods: Viterbi Phase Estimation, Constant Modulus Algorithm, and Blind Phase Search (BPS) (VPE). In coherence detection systems, a matching filter can be used to improve the signal-to-noise ratio (SNR). Since it only allows authorised signals to get through, this filter offers excellent anti-jamming capabilities.

TABLE I. SIMULATION PARAMETERS OF PROPOSED WORK

Parameters	**Values**
Bit Rate	100 Gbps/User
Coding	2D-WMZCC
K and *W*	*K=5, W=3*
Modulation	DSP enabled PDM-QPSK
LG/HG modes	LG00 U1, LG01 U2, LG02 U3, LG03 U4, LG04 U5
Lambertian Source Launched Power	30 dBm
WDM spacing	100 GHz
Rate of symbols transmission	25 GSymbols/sec
States of Polarization	2
Signal Power amplification	EDFA
Length of VLC channel	5 m
Transmitter and Incidence Half Angle	20 degrees
DSP algorithms	CMA, BPS, VPE
Optical concentrator Area	1.5 cm^2

RESULTS DISCUSSION

Fig. 2. (a) and (b) show the optical carrier spectrum (OCS) for single and multiple users in a PDM-QPSK system with K=5. Degradation in



power is easily observed for K=5 OCS spectrum frequencies due to insertion losses. The implications of an unauthorised user, or eavesdropper, employing MDM-2D-WMZCC codes are examined for the proposed system.

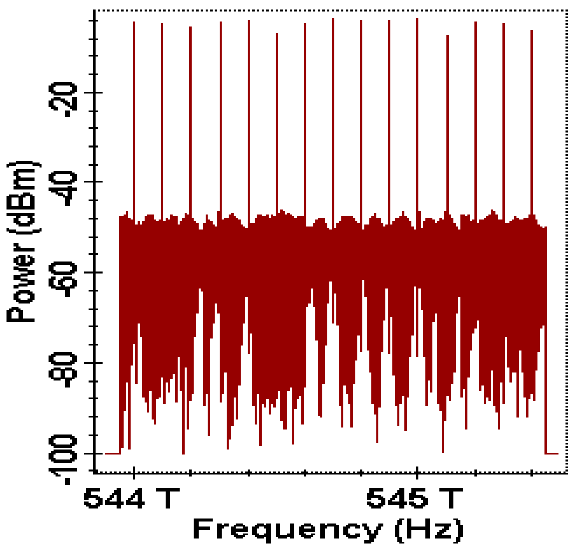
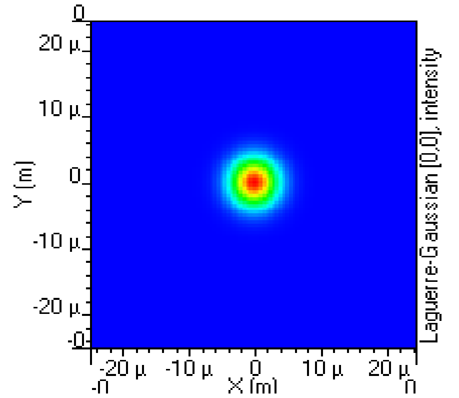


Fig. 2. Illustrations of OCS for PDM-QPSK transmitters for (a) first frequency (b) total of 15 frequencies after multiplexer

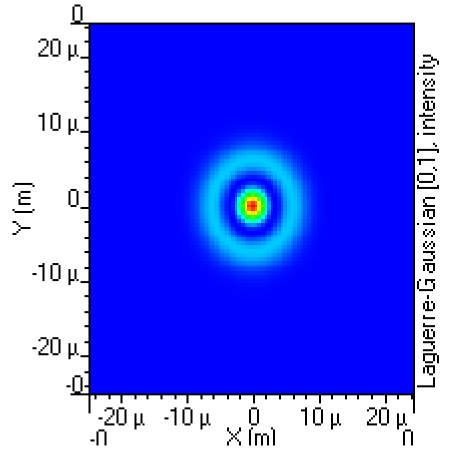
The intensity profile of light changes during light propagation across a homogeneous optical medium or through unoccupied space. This is not the true for all electric field amplitude distributions, or modes; in some cases, the received power, phase, and profile may change, but the shape of the amplitude profile does not. LG modes have doughnut-like helical phase front intensity profile and expressed as [31]

$$\Psi_{lm}(r,\emptyset) = \left(\frac{2r^2}{w_0{}^2}\right)^{|l|} L_m^l\left(\frac{2r^2}{w_0{}^2}\right)\exp\left(\frac{r^2}{w_0{}^2}\right)\exp\left(j\frac{\pi r^2}{\lambda R_0{}^2}\right)\begin{cases}\cos(|l|\phi), l \geq 0\\ \sin(|l|\phi), l < 0\end{cases} \quad (5)$$

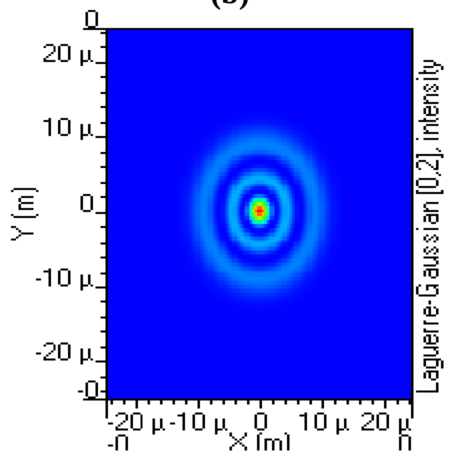
Where, Laguerre polynomial is L_{lm}, azimuthal and radial indexes are represented by l, m in X, Y indices. Fig. 3.(a) to 3(e) show laser profiles for various LG modes, such as LG00 to LG04, and it can be seen that as the radial numbers vary, more circular structures develop around the azimuthal peak.



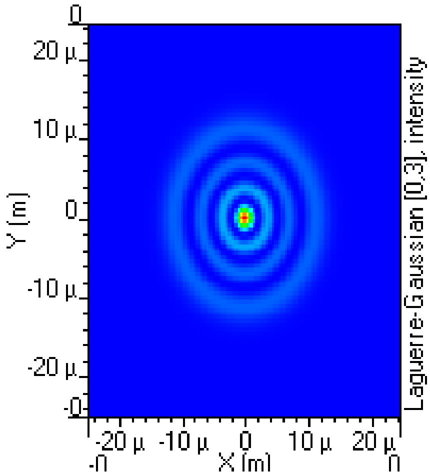
(a)



(b)



(c)



(d)

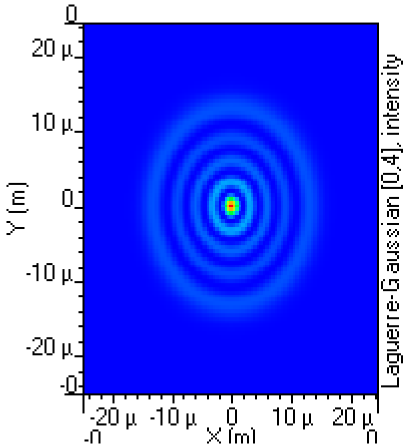


Fig.3.(e)

Fig. 3. LG mode profiles for (a) LG00 (b) LG01 (c) LG02 (d) LG03 and (e) LG04

Eavesdroppers assault the VLC system via a LoS or NLoS link in an effort to collect legitimate data information. As a result, we looked at a scenario in which a VLC eavesdropper targets the LoS link. The performance of MDM-based 2D-WMZCC codes is evaluated by considering the log BER. In VLC, the detecting region and the emitting source are separated by 4 m, and the launching power of K=5 is varied between 0 and 40 dBm. The log BER for the LG-2D-WMZCC legitimate user and LG-2D-WMZCC eavesdropper are shown in Figure 4. According to the findings, the log BER measured in LG-2D-WMZCC for a legitimate user is -4.21 and for an eavesdropper at 0 dB, it is -1.37.

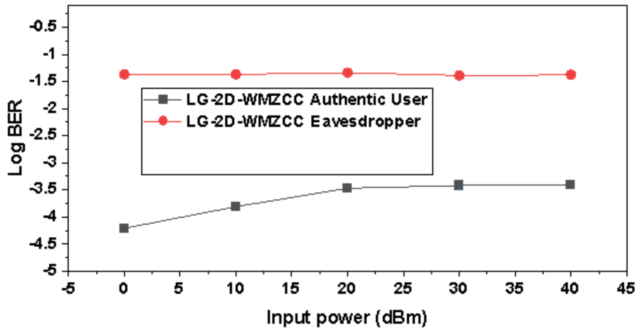


Fig. 4. Performance of LG modes for authentic user and eavesdropper in terms of log BER

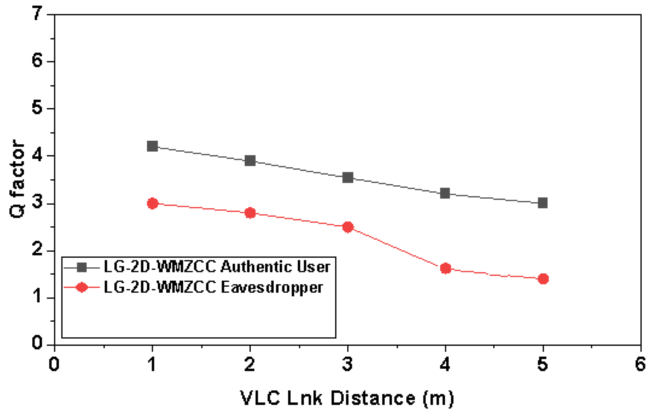


Fig.5. Performance of LG modes for authentic user and eavesdropper in terms of Q factor

The effect of the VLC connection length on the Q factors of authentic and eavesdropper signals are depicted in Figure 5. When the distance between the irradiating source and the detecting zone in VLC is increased from 1 m to 5 m, it is evident that an increase in length results in higher Q factor degradation. The legitimate LG-2D-WMZCC user provides a Q factor of 3, while the eavesdropper was able to get a Q factor of 1.4.

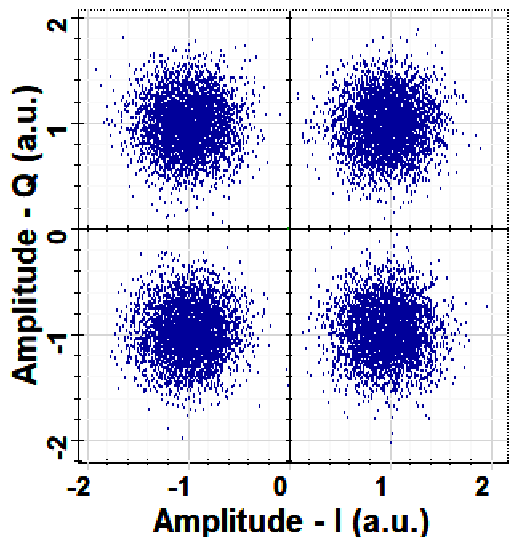


Fig.6.(a)

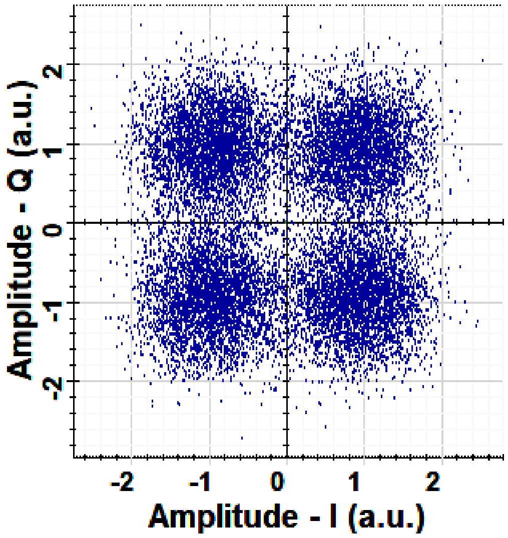


Fig.6. (b)

Fig.6. Constellation diagrams of (a) LG-2D-WMZCC authentic user (b) LG-2D-WMZCC eavesdropper

Fig.6 (a) and (b) illustrates the LG-2D-WMZCC authentic user, eavesdropper, respectively and it is observed that constellation diagram for authentic used is having better placed symbols and eavesdropper has distorted constellations.

I. CONCLUSION

A security-enhanced non-adjacent weight-managed and time-dimension-based 2D-OCDMA code for K=5 at 100 Gbps per user in VLC over 5 m has been provided in this study. Authentic user and eavesdropper performance of LG-2D-WMZCC has been compared. According to the findings, the log BER in LG-2D-WMZCC for a genuine user is -4.21, whereas it is -1.37 for an eavesdropper at 0 dB. For an authentic user, symbols in the LG-2D-WMZCC constellation are equally scattered at a distance of 5 metres. For an eavesdropper, however, a corrupted constellation is visible at the same distance. Hybrid LG and HG modes can be added to the suggested system to increase security and performance in WMZCC codes.

REFERENCES

A. Almogahed, et al., "Performance improvement of mode division multiplexing free space optical communication system through various atmospheric conditions with a decision feedback equalizer", Cogent Engineering, 9, (2022) pp. 1-25.

A. E. Siegman, Lasers, University Science Books (Sausalito, CA, 1986) pp. 1-1283.

A. Mostafa, L. Lampe, Physical-layer security for indoor visible light communications. In Proceedings of the 2014 IEEE International Conference on Communications (ICC), Sydney, Australia, (2014) pp. 3342–3347.

B. Salah, L. KASSA-BAGHDOUCHE, A. Verma, "SAC-OCDMA System with EDW codes over FSO under different conditions of Weather", IJRAR, 6, (2019) pp. 749-755.

C. Xiang-Peng, "A Cost-Efficient RGB Laser-Based Visible Light Communication System by Incorporating Hybrid Wavelength and Polarization Division Multiplexing Schemes", Front. Phys., 9, (2021) pp. 731405 (1-6).

E. Ouis, B. Fassi, and S. Driz, Performance Analysis of Indoor VLC-ZCZ-OCDMA System using High Performance Photodetector, In The International Conference On Materials Science And Engineering and Their Impact On the Environment, Algeria, (2019) pp. 1-7.

E. Tews, M. Beck, Practical Attacks Against WEP and WPA. In Proceedings of the WiSec '09—Second ACM Conference on Wireless Network Security, Zurich, Switzerland, (2009) pp. 79–86.

F. Akhoundi, J. A. Salehi, A. Tashakori, "Cellular Underwater Wireless Optical CDMA Network: Performance Analysis and Implementation Concepts", IEEE Trans. Commun., 63, (2015) pp. 882–891.

G. Chen, J. P. Coon, M. Renzo, "Secrecy Outage Analysis for Downlink Transmissions in the Presence of Randomly Located Eavesdroppers", IEEE Trans. Inf. Forensics Secur., 12, (2017) pp. 1195–1206.

G. Xie, et al., "Performance metrics and design considerations for a free-space optical orbital-angular momentum–multiplexed communication link", Optica, 2, (2015) pp. 357-365.

H. Kaur, N. S. Grewal, Security Enhancement of Visible Light Communication System Using Proposed 2D-WMZCC Codes Under the Effects of Eavesdropper, Journal of optical communications. (2022) https://doi.org/10.1515/joc-2022-0070.

H. Singh, et al., Mode Division Multiplexing (MDM) Based Hybrid PON-FSO System for Last-Mile Connectivity, In third South American Colloquium on Visible Light Communications (SACVLC), (2021) pp. 01-06.

H. Y. Lan, et al., "High-speed integrated micro-LED array for visible light communication", Opt. Lett., 45, (2020) pp. 2203–2206.

J. Tang, G. Chen, J. P. Coon, J.P., "Secrecy Performance Analysis of Wireless Communications in the Presence of UAV Jammer and Randomly Located UAV Eavesdroppers", IEEE Trans. Inf. Forensics Secur., 14, (2019) pp. 3026–3041.

K. Kitayama, Optical Code Division Multiple Access: A Practical Perspective, 1st ed., (Cambridge University Press: Cambridge, UK, 2003) pp. 1-357.

L. U. Khan, "Visible light communication: Applications, architecture, standardization and research challenges", Digital Communications and Networks, 3, 78-88 (2017).

L. Wei, et al., 40-Gbit/s Visible Light Communication using Polarization-Multiplexed R/G/B Laser Diodes with 2-m Free-Space Transmission, In: Optical Fiber Communications Conference and Exhibition (OFC), (IEEE, San Diego, CA, USA, (2019) pp. M3I.3.

M. Bloch, J. Barros, Physical-Layer Security: From Information Theory to Security Engineering (Cambridge University Press, UK, 2011), pp. 1-329.

M. F. Guerra-Medina, et al., "Ethernet-OCDMA system for multi-user visible light communications", ELECTRONICS LETTERS, 48, (2012) pp. 1-2.

M. Krenn, et al., "Twisted light transmission over 143 km", In proc. Natl. Acad. Sci. U. S. A., 113, (2016) pp. 13648-13653.

M. Singh, et al., "Millimeter-wave hybrid OFDM-MDM radio over free space optical transceiver for 5G services in desert environment", Alexandria Engineering Journal, 60, (2021) pp. 4275-4285.

M. T. Rahman, et al., "Review of advanced techniques for multi-gigabit visible light communication", IET optoelectronics, 14, (2020) pp. 359-373.

R. Kaur, R. S. Kaler, "Performance and security analysis of novel ZCCRW codes in lower earth orbit based MDM-OWC incorporating hybrid modulations", Journal of Electrical Engineering, 72, (2021) pp. 46 – 52.

R. Kaur, R. S. Kaler, "Performance of zero cross correlation resultant weight spectral amplitude codes in lower Earth orbit-based optical wireless channel system", Int. J. Commun. Syst., 33, (2020) pp. 1-10.

R. M. Noh, et al., Performance of MS-code of OCDMA over VLC System, In IEEE 8th International Conference on Photonics (ICP), (2020) pp. 58-59.

S. Kaur, A. Verma, From Communication to Illumination: Visible Light Communication, Pros and Cons, Applications, Current and Future Trends, State-of-the-art Discussion. In SSRN, Available at SSRN: https://ssrn.com/abstract=3868998 or http://dx.doi.org/10.2139/ssrn.3868998, (2022) pp. 1-5.

S. Kaur, M. Kumar, A. Verma, "An Integrated High-Speed Full Duplex Coherent OFDM-PON and Visible-Light Communication System", Journal of Optical Communications, 43, 379-383 (2022).

S. Kaur, M. Kumar, A. Verma, "Visible light communication employing multiplexing of different colours", IJRAR, 6, 300-304 (2019).

S. Miyazaki, et al., A visible-light communication system using optical CDMA with RGB multi-chip LEDs, In 15th International Symposium on Communications and Information Technologies (ISCIT), (2015) pp. 101-104.

S. Kaur, and S. Singh, Highly Secured all Optical DIM Codes using AND Gate, In Indo – Taiwan 2nd International Conference on Computing, Analytics and Networks (Indo-Taiwan ICAN), (2020) pp. 64-68.

W. Gunawan, Y. Liu, et al., "High Speed Visible Light Communication Using Digital Power Domain Multiplexing of Orthogonal Frequency Division Multiplexed (OFDM) Signals", Photonics, 8, 1-10 (2021).