5G Visible Light Communication - OCDMA Setup using Catenated-OFDM Modulation Method

N. M. Nawawi\textsuperscript{1,2}, S. R. Abdullah\textsuperscript{1}, Aini Syuhada Md Zain\textsuperscript{3}, Anuar M. S.\textsuperscript{1,2} and M. N. Junita\textsuperscript{1,2}

\textsuperscript{1}Advanced Communication Engineering (ACE) Centre of Excellence, Universiti Malaysia Perlis, Universiti Malaysia Perlis, 02600 Perlis, Malaysia
\textsuperscript{2}School of Computer & Communication Engineering Department, Universiti Malaysia Perlis (UNIMAP), 02600 Perlis, Malaysia
\textsuperscript{3}Jabatan Kejuruteraan Elektrik (JKE), Politeknik Tuanku Syed Sirajuddin, 02600 Perlis, Malaysia

e-mail: norizan@unimap.edu.my

Abstract. This paper demonstrates a new high-speed architecture of visible light communication (VLC) system combining with zero cross correlation (ZCC) code of optical code division multiplexing (OCDMA) and novel catenated-OFDM modulation scheme. In order to achieve high spectral efficiency and higher bit rate system for 5G application, we embedded multiband catenated-OFDM modulation technique and OCDMA in VLC design system. Moreover, by employing visible laser diode (VLD) in designing VLC system, we achieved 10 Gbps bit rate at 2.5 dBm input power. We investigate this new combination system design to analyze the bit rate and bit error rate (BER) in 3 m indoor VLC channel propagation.

1. Introduction
Optical wireless particularly visible light communication (VLC) can be a potential applicant key for 5G networks. According to CISCO, mobile data traffic will increase sevenfold in 2021 over 2016 as shown in Figure 1.

The primary explanation for the dramatic rise in mobile data traffic is the increase of devices using the mobile systems. In addition, the growth of online media networks (such as, Instagram and Facebook) has increased the mobile data traffic even further. The explosion of these devices has generated tremendous compression on mobile communications networks which already established in 3G and 4G. These technologies fail to cope with the incredible growth in demand for mobile facility. Industrial and
research groups are therefore aiming the new mobile technology in 5G to improve safety, increase capacity and 1000 times higher transmission performance over existing technologies [2]. To address this problem, the scientific community has proposed that the 5G should not only be based on single technologies, but wider ranges of the electromagnetic spectrum will be considered by the researchers.

VLC transmission using white LED has gained interest among researchers since 2008 as it offers the potential for indoor broadcasting visible light communication [3]. Nevertheless, LED output is still restricted by low power, moderate bandwidth, and a fast-divergent beam that delivers short-range output, as well as restricted possible device applications. One of the alternatives to this problem is by replacing the LED source with VLD. VLC networks combining with visible laser diode provided high data transmission up to 6.52 Gbps [4], [5].

Recently, there is increasing interest in hybrid system by adopting optical code division multiplexing access (OCDMA) over VLC system which is promising technique for future communication network design [6-7]. The OCDMA technology itself attracts great importance due to asynchronous access capability [8] and guarantees protection in the transmission network, as each channel is identified by a different optical code. Some work on finding the most suitable type of optical CDMA coding method for coherent and incoherent multiple optical access techniques has been thoroughly investigated. Previously, on-off-key (OOK), which is referred to as OOK-OCDMA, is widely used as a modulation format for payload data in optical CDMA system. The main sources of noise in a multi-user asynchronous OOK-OCDMA device are the coherent noise and the incoherent noise MAI, which restrict the number of active users in a network. Recently, the security issue was raised that the OOK modulation in OCDMA is weak in terms of protection, which could easily be cracked by simple power detection without understanding the code. Therefore, much advanced modulation techniques are required in OCDMA in order to ensure the secure and better network.

In this paper, a new catenated-OFDM modulation technique is introduced and mixed with OCDMA/ZCC spreading code and their effects on the performance of VLC system are studied and demonstrated. Optical ZCC code is one of OCDMA generation code designed in [9] and its advantage to eradicate the phase induced intensity noise (PIIN). Thus, reduce the effect of MAI which give better BER. The goal of VLC communication system by using catenated multiband OFDM is to take advantage of the properties of enhanced multiband OFDM, to better the spectral efficiency by transmitted more data. The simulation results for catenated-OFDM OCDMA/ZCC-VLC system are carried out using Optisystem software.

2. Principle and System Design
Generally, optical wireless communication network consists of transmitter design, receiver design and channel model. For VLC system channel model depending on the frequency carrier and other physical influences such as attenuation, interference and noise [8]. In this paper, we concentrated on the Line-of-sight (LOS) distribution links for indoor VLC application as in [10]–[12].

Other The ZCC-VLC system with catenated OFDM architecture shows in Figure 2. Catenated-OFDM is a multiband modulation method created by the concatenation of several simple OFDM modulations so that they can be simultaneously transmitted to the receiver. The main advantage of this scheme is that the electrical bandwidth available is completely used, meaning that more data can be transmitted through the medium compared to traditional OFDM scheme. As a ZCC code encoder has been adapted to this proposed design, ZCC codes simultaneously distributed n-band of catenated-OFDM across the visible light medium centered on multiple sub-channels. That consumer has unique spreading code referring to different wavelengths which means that the produced catenated-OFDM signal band is modulated and executed in the code domain through the communication medium.

The catenated-OFDM data at the receiver is demultiplexed by application of unique code to the individual user. Photodiode is used to detect each user's optical signal and move through the splitter to isolate and retrieve each catenated-OFDM signal band by filtering it to their respective frequency band [13].
ZCC codes is adopted in our proposed design and the code structure does not have overlapping of bit ‘1’ and it will not cause the ZCC code to interfere between users and will definitely suppress PIIN [14]. The ZCC code properties is satisfied the correlation functions in (1).

\[
\sum_{i=1}^{N} z_k(i)z_l(i) = \begin{cases} 
  w & \text{if } K = l \\
  0 & \text{if } K \neq l 
\end{cases}
\]

where \(Z_k(i)\) and \(Z_l(i)\) denote the \(K_{th}\) and \(l_{th}\) ZCC code sequences as \(i_{th}\) elements, \(w\) denotes the code weight equal to '1' in the code. For \(K = 1\), autocorrelation is the process that compared the same code. If \(K\) is not equal to 1, the correlator goes through the process of cross-correlation. Autocorrelation, in other words, is the cross-correlation of a signal to itself and the cross-correlation is a function of the similarity of two waveforms [15].

3. Simulation Setup

The catenated-OFDM signals combining with ZCC optical CDMA system travelling through visible light medium is studied at four wavelengths (code weight=4) at blue region of spectrum to ensure both illumination and data transmission system. The 5-band catenated-OFDM signal is modulated by each user at their respective band frequency. Catenated-OFDM signal design can be seen in the subsystem in Figure 3(b). The simulation setup for the newly purposed system is shown in Figure 3. This simulation design is for one user. The Mach-Zehnder modulator is used to modulates the electrical catenated-OFDM data with 4 multiplexed visible wavelengths at 480nm, 480.8nm, 481.6nm and 482.4nm.

**Figure 2.** Block Diagram of catenated-OFDM ZCC VLC system (MZF: Mach-Zehnder modulator, Demux: demultiplexing PD: photodiode)
respectively. The encoded modulated data with code weight of 4 is then transmitted through VLC channel at 3m propagation distance. Figure 3(c) is the receiver part for 1 user and 1-band catenated OFDM system. PIN photodetector is used to detect an optical encoded modulated data and convert it to electrical domain. Rectangle filter for the band pass is used to filter each catenated-OFDM band back by tuning the filter at the respective band frequency.

Table 1. Catenated-OFDM center frequency band

| Band Number | Frequency (GHz) |
|-------------|-----------------|
| 1           | 3.7             |
| 2           | 7.4             |
| 3           | 11.1            |
| 4           | 14.8            |
| 5           | 18.5            |
5th International Conference on Electronic Design (ICED) 2020
Journal of Physics: Conference Series 1755 (2021) 012016 doi:10.1088/1742-6596/1755/1/012016

Figure 3. Simulation setup for catenated-OFDM ZCC VLC system using visible laser diode for 1 user; (a) Components in transmitter setup (b) OFDM modulation setup for 1-band of catenated-OFDM (c) Component in receiver setup.

4. Result and Discussion
In this work 5-band catenated-OFDM based transceiver is proposed in our simulation and analysis at 10 Gbps data rate. In simulation, we monitor the catenated-OFDM data at every point to ensure the feasibility of the system. Figure 4. represents the 4 encoded catenated-OFDM signals from four ZCC encoders for 1 user. In future, to design for more user the signals for each user will combined together by optical power combiner. The subset in Figure 4 is zoomed image of first encoder that encoded 5-band double-sided catenated-OFDM signal. The spacing between each encoder is set to 0.8nm and the input power is 5dBm. In this paper, we demonstrated catenated-OFDM data signals travelling from one user. Figure 5 shows the signals detected at PIN photodetector that consist of 5-bands catenated-OFDM signals. The intensity of power received is approximately to -53.5 dBm. Thus, the VLC channel gain and other losses at photodetector are equal to 12.5 dB without using any aid of amplifier in the system design. Each band of this signals is then filtered at their respective center band before demodulate by OFDM modulator to get back the original data. The constellation diagram in Figure 6 illustrates the first band catenated-OFDM signals encoded at 16-QAM. From these results, its clearly shown that the proposed design can be used to bring more encoded data up to 5 bands of catenated-OFDM signal simultaneously.

Figure 7 shows BER performance comparison for three different bit rate at different input power. The purpose of this graph is to analyze the minimum required input power when varies the speed of the system. As expected, BER is depicted to be deteriorating by increasing the value of bit rate at similar input power level. For BER=$10^{-9}$ error floor, a system at 10 Gbps required approximately 2.5 dBm input.
power level, while the system at lower speed performs better with less input power. It proves that this combining catenated-OFDM modulation technique with ZCC spreading code can be used for very high bit rate VLC system.

Figure 4. Encoded double-sided catenated-OFDM signals
Figure 5. Received signal at PIN photodetector

Figure 6. Constellation diagram of first band catenated-OFDM signals
8

5. Conclusion
We had proposed and elucidated the hybrid design of catenated-OFDM ZCC code in VLC system. We compared and analyzed the OCDMA-VLC system at different bit rate. The simulation results show successful data transmission of 5 catenated-OFDM bands with acceptable bit error rate. The demonstration is done for one user and the number of users can be added in the design for future work to examine the performance of overall system in term of number of users. Using a new catenated-OFDM modulation technique, OCDMA-VLC system is proved can be used to transmit up to 5 band of OFDM signals, which means more data can be transferred at same time.

References
[1] Cisco. (2017). Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021. Cisco, 2016–2021.
[2] Abdallah, W., & Boudriga, N. (2016, July). Enabling 5G wireless access using Li-Fi technology: An OFDM based approach. In 2016 18th International Conference on Transparent Optical Networks (ICTON) (pp. 1-6). IEEE.
[3] H. Le Minh, D. O. Brien, G. Faulkner, L. Zeng, K. Lee, D. Jung, and Y. Oh, “80 Mbit / s Visible Light Communications Using Pre-Equalized White LED,” 34th Eur. Conf. Opt. Commun. 2008. ECOC 2008., vol. 5, no. September, pp. 1–2, 2008.
[4] H. Le Minh, D. O. Brien, G. Faulkner, L. Zeng, K. Lee, D. Jung, and Y. Oh, “High-Speed Visible Light Communications Using,” vol. 20, no. 14, pp. 1243–1245, 2008.
[5] H. Chun, S. Rajbhandari, D. Tsonev, G. Faulkner, H. Haas, and D. O. Brien, “Visible Light Communication using Laser Diode based Remote Phosphor Technique,” pp. 1392–1397, 2015.
[6] Anilkumar, Oppicharla, and R. K. Jeyachitra. "Performance enhancement of indoor VLC system by employing SAC OCDMA technique." 2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET). IEEE, 2017.
[7] Y. Idriss, R. K. Sahbudin, S. Hitam and S. B. Ahmad Anas, "Performance comparison of indoor VLC system employing SAC-OCDMA technique," 2016 IEEE 6th International Conference on Photonics (ICP), Kuching, 2016.
[8] X. Wang, “Keys towards practical OCDMA networks,” 7th IEEE Int. Conf. Optoelectron. Fiber Opt. Photonic, 2004, pp. 1–6, 2004.
[9] M. S. Anuar, S. A. Aljunid, N. M. Saad, and S. M. Hamzah, “New design of spectral amplitude coding in OCDMA with zero cross-correlation,” Opt. Commun., vol. 282, no. 14, pp. 2659–2664, 2009.
[10] A. R. Ndjomoung, “Visible Light Communications (VLC) Technology,” no. September 2016, 2015.
[11] X. Bao, G. Yu, J. Dai, and X. Zhu, “Li-Fi: Light fidelity—a survey,” Wirel. Networks, vol. 21, no. 6, pp. 1879–1889, 2015.
[12] D. Deqiang, K. Xizheng, and X. Linpeng, “An Optimal Lights Layout Scheme for Visible-Light Communication System,” 2007.
[13] N. M. Nawawi, M. N. Junita, A. K. Rahman, S. A. Aljunid, and C. Engineering, “CATENATED OFDM MODULATION SCHEME,” vol. 91, no. 1, 2016.
[14] Nordin, Junita Mohd, Syed Alwee Aljunid, Anuar Mat Safar, A. R. Abdullah, and R. Abd. "Performance of hybrid subcarrier multiplexing over optical CDMA network based on zero cross correlation code." J Commun Inf Sci 2, no. 1, 2012.
[15] M. S. Anuar, S. A. Aljunid, N. M. Saad, and S. M. Hamzah, “New design of spectral amplitude coding in OCDMA with zero cross-correlation,” Opt. Commun., vol. 282, no. 14, pp. 2659–2664, 2009.