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Spectral Efficiency Improving Technique in OCDMA-VLC system for IoT Application using Catenated-OFDM Modulation Scheme

N. M. Nawawi¹, Anuar M. S.¹, Junita M. N.¹ and M. F. Talib¹

¹ Optical Group Communication, Advanced Computing Engineering (ACE) Centre, School of Computer and Communication Engineering, Universiti Malaysia Perlis (UniMAP), Pauh Putra, 02600, Perlis.

E-mail: norizan@unimap.edu.my; anuarms@unimap.edu.my; junita@unimap.edu.my; fauzan.talib@gmail.com

Abstract. Visible light communication (VLC) technology offers unregulated, unlicensed and huge bandwidth to meet the growing demand in future indoor communication system. One of the major challenge in VLC system is in improving transmission speed with optimize the bandwidth capacity. The method to improve spectral usage is using advanced modulation formats such as orthogonal frequency division multiplexing (OFDM). In this work, a new approach for modulation technique based on multiband OFDM has been developed which capable to improve the spectral efficiency and optimize the data rate. A proposed technique is then adapted in OCDMA-VLC environment to analyse the reliability of the proposed scheme in high capacity network. Different selection of parameter values such as bit rates, number of bands and effective received power will have different effect on the system performance. Numerical result shown that the catenated-OFDM outperforms conventional OFDM by five times spectral efficiency improvement and eight times spectral efficiency improvement at their five and eight number of bands respectively. It is also shown that the proposed catenated-OFDM design is working well even at very high bit rate of 15 Gbps. Moreover, there are enhancement in receiver sensitivity with 7.3 dB power penalty compared to previous work.

1. Introduction

The growing demand for internet-connected of smart devices and high speed networks shapes the internet of things (IoT) environment. The IoT interconnected different devices with ubiquitous accessibility and built-in intelligence. It has gained wide acceptance, growth popularity and predicted to reach seven billion IoT transmission devices in the forthcoming fifth generation (5G) networks by 2025 [1]. According to CISCO, there will be sevenfold increase in mobile data traffic in 2021 compared to 2016 as shown in Figure 1. The growth in the number of devices accessing the mobile networks is the main reason for the drastic increase in mobile data traffic. Along with this, the



development of online social medias (such as facebook, instagram and twitter) has further increased the mobile data traffic. The proliferation of these devices has created a huge pressure on the currently established third generation (3G) and fourth generation (4G) mobile communication networks. These technologies become unable to cope with the tremendous growth of the mobile service demands. Therefore, the research and industrial communities are targeting that the new standard of mobile technology in 5G environments will improved the security, enhanced the capacity and transmission performance by 1000 times compared to the existing technologies [2]. One of the option to overcome this issue is by using higher ranges of electromagnetic spectrum in order to replace the radio wave spectrum in 5G networks.

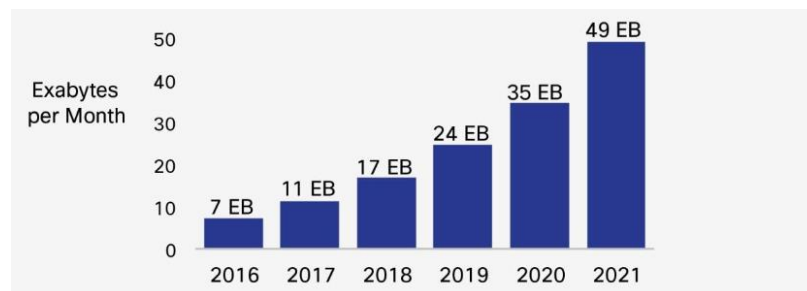


Figure 1. Global mobile data traffic [3]

Recently, optical wireless communication (OWC) came along taking the attention because of several importance characteristics such as large bandwidth, high security, low cost, and license free operation. OWC especially visible light communication (VLC) can be a potential candidate solution for 5G networks. The VLC technology utilizes a visible light spectrum in the electromagnetic spectrum which has large bandwidth, safe for eyes, more flexible and integrity than other communication systems in many regards. VLC system has been investigated for about one and half decade and received a lot of interest [4]. Since the medium for transmission in VLC system is visible light and not radio waves that can penetrate walls, the issue of security is inherently solved. It is because light cannot leave the room, containing data and information in one location. There is no way to retrieve and access the information unless a user is in a direct path of the light being used to transmit the data.

Although OFDM is an attractive modulation technique that can achieved the requirement for 5G standard performance, another issue to enable VLC system suited for future 5G networks is access control in this multiuser environment [2]. Therefore, the efficient backbone design network to support higher capacity distribution of connectivity between VLC access points are needed. Optical code division multiple access (OCDMA) is one of the promising technique that offers multiple access control based on optical encoding technique that can enable the OFDM access in the VLC network. OCDMA is a networking technique that provides multiple access and offers various advantages such as large effective bandwidth utilization, asynchronous transmission with low latency access ability to provide privacy and security [5] and soft capacity in demand. The unprecedented increasing of traffic volumes in wireless network, the data privacy and confidentiality is becoming more important. Therefore, in this paper proposed a combination design of VLC and OCDMA technologies which is useful to envision the most promising candidate for future mobile communication. This paper is divided into five sections, after introduction in Section 1; Section 2 discusses the system architecture, Section 3 gives theoretical development and simulation analysis, Section 4 discusses the analysis results followed by conclusion in Section 5.

2. System Architecture

Future telecommunication systems must be spectrally efficient to support a number of high data rate users. For all of the above reasons, OFDM has already been accepted by many of the future generation systems. Another issue to enable VLC suits for 5G requirement is an efficient backbone design of an access control in this multiuser environment. This paper discussed the catenated-OFDM as a new modulation technique for OCDMA-VLC system. A ZCC code has been used as code generation technique in optical code encoder and decoder. ZCC code is proposed to reduce the impact of system impairment and multiple access interference (MAI) in spectral amplitude coding OCDMA [6]. In cat-OFDM modulation scheme, M-QAM mapping is chosen for modulation formats taken on the data stream and shifted into parallel format. The parallel data is then mapped and transmitted by assigning one symbol for each carrier. An inverse Fourier transform is performed into the mapped spectrum to find the corresponding time waveform. To make sure any multipath interference not affected the orthogonality of the data channels, the cyclic prefix (guard period) can be added at the beginning of each symbol. Finally, the parallel data is shifted back into the serial symbols which is called OFDM signals.

Table 1. Parameter used in numerical calculation.

Parameter	Value
Number of subcarrier	$N_{sc} = 512$
Number of FFT	$N_{FFT} = 1024$
Position array	256
Subcarrier spacing	$\Delta f_c = 9.76 \text{ MHz}$
FFT sampling frequency	$f_{FFT} = 40 \text{ GHz}$
Responsivity	$R = 0.32$
Visible laser wavelength	$\lambda_o = 480\text{nm}$
Receiver noise temperature	$T = 300\text{K}$
Receiver load resistor	$R_L = 1030\Omega$
Boltzmann's constant	$K = 1.8 \times 10^{-23} \text{ W/K/Hz}$
Electron charge	$e = 1.60217646 \times 10^{-19} \text{ C}$
Ambient current	$I_{r_ambient} = 5100 \mu\text{A}$
Noise bandwidth factor	$I_2 = 0.562$

The system architecture of the proposed catenated-OFDM scheme for OCDMA-VLC system based on ZCC code is given in Figure 2. At the transmitter, an electrical adder is used to concatenate several OFDM bands before entering the optical domain. The most advantage of this scheme is it is fully utilized the available electrical bandwidth so more data can be sent through the medium compared to a traditional OFDM scheme. An electrical catenated-OFDM signal is then being modulated by Mach-Zehnder external modulator with respective unique code from ZCC encoder. As a ZCC code encoder has been adapted into this proposed design, n -band of catenated-OFDM are spread by ZCC codes simultaneously over visible light medium based on several optical channels. Each channel has specific spreading code refer to different wavelength which means the generated catenated-OFDM signal band is modulated and carried out through the communication medium in code domain. After passing through the visible spectrum medium, the signal is detected by ZCC decoder and demultiplexed to individual optical channel by applying specific code. The PIN

photodetector at receiver part is used to detect the optical signal of each optical channel and pass through to the splitter to separate and extract back each catenated-OFDM signal band by filtering at their respective frequency band. At a very high data rate, the required electrical bandwidth also would be wider and is not cost-effective to implement even with the best commercial digital-to-analog converters (DACs) and analog-to-digital converters (ADCs) in silicon integrated circuit (IC) [7]. Instead of having high spectral efficiency, this technique also has a great capacity to accommodate exponential growth in communications mainly for internet users [8]. This process may eventually lead to the realization of commercial transmission products based on optical OFDM in the future, with the potential benefits of high spectral efficiency and flexible network design. An Optisystem Version 11.0 was used as a simulation tool to simulate the proposed catenated-OFDM modulation technique in OCDMA-VLC system shown in Figure 2 based on parameter on Table 1. The optical channel is set to two using four number of weight for each encoder.

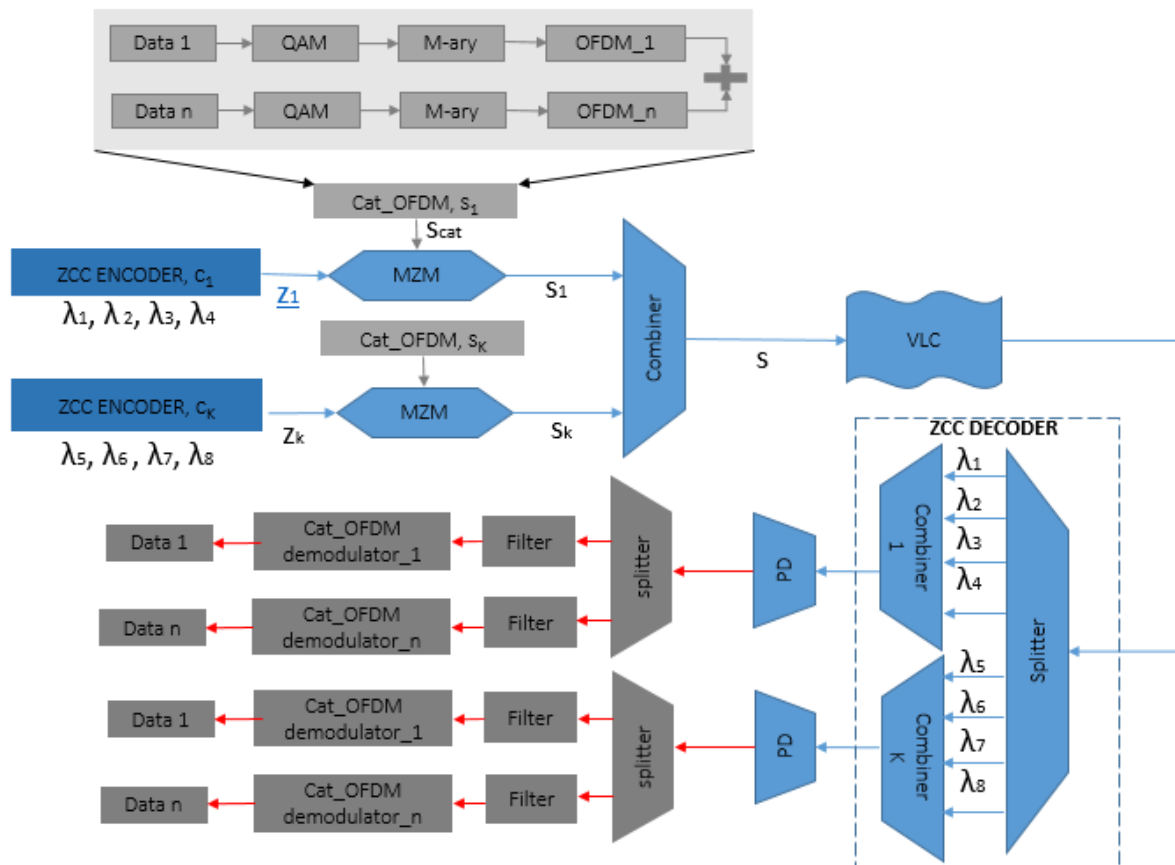


Figure 2. System architecture of Catenated-OFDM modulation technique in OCDMA-VLC system based on ZCC code.

3. Theoretical Development

For the noise variances, there are two types of noises considered dominant in this analysis which are quantum shot noise and thermal noise. The quantum shot noise is essentially represented by the variance of the photocurrent that contains a distortion to the desired signal. The signal and ambient

light induced quantum shot noise for catenated-OFDM VLC system and catenated-OFDM OCDMA-VLC system can be written as below

Catenated-OFDM VLC system	Catenated-OFDM OCDMA-VLC system
$\sigma_{shot}^2 = 2eRP_r c_k m_n B + 2eI_{r_ambient} I_2 B$ (1)	$\sigma_{shot}^2 = 2eR \frac{P_r w}{L} c_k m_n B + 2eI_{r_ambient} I_2 B$ (2)

where e is the electron charge, R is the responsivity of the photodetector, P_r is an effective received power, w and L are the ZCC code weight and code length respectively, c_k is an OFDM information symbol, m_n is the modulation index for respective sub-band, $I_{r_ambient}$ is an ambient currents in the photodetector, and I_2 is the noise bandwidth factor which is set to 0.562 [9]. When the generated signal current is much smaller than the ambient noise current, the induced shot noise in the photodetector can be usually treated as additive white Gaussian noise (AWGN), to which category the electrical pre-amplifier noise also belongs [10].

The mean square of the random current is given by

$$\sigma_{thermal}^2 = \frac{4kTB}{R_L} \quad (3)$$

where T is an absolute temperature, k is the Boltzmann's constant, B is the receiver bandwidth and R_L is load resistance. Note that, the thermal noise can be reduced by using large value or load resistor but still consistence with the receiver bandwidth requirement.

The signal to noise ratio (SNR) is given by

$$SNR = \frac{\text{Total signal power}}{\text{Total noise}} = \frac{I_r^2}{\sigma_{Total}^2} \quad (4)$$

The SNR in Equation (5) for catenated-OFDM VLC system by substituting Equation (1) and Equation (3) in Equation (4) and the SNR in Equation (6) for catenated-OFDM OCDMA-VLC system by substituting Equation (2) and Equation (3) in Equation (4).

Catenated-OFDM VLC system	Catenated-OFDM OCDMA-VLC system
$SNR = \frac{R^2 P_r^2 c_k^2 m_n^2}{2eRP_r c_k m_n B + 2eI_{r_ambient} I_2 B + \frac{4kTB}{R_L}}$ (5)	$SNR = \frac{R^2 \frac{P_r^2 w^2}{L^2} c_k^2 m_n^2}{2eR \frac{P_r w}{L} c_k m_n B + 2eI_{r_ambient} I_2 B + \frac{4kTB}{R_L}}$ (6)

As the proposed system consists of catenated-OFDM OCDMA-ZCC model with M-ary QAM in each sub-channel, thus, the bit error rate (BER) can be obtained from SNR as below:

$$BER = \frac{\sqrt{M} - 1}{\sqrt{M} \log_2 \sqrt{M}} \operatorname{erfc} \sqrt{\frac{3 \log_2 M}{2(M-1)} SNR} \quad (7)$$

4. Results and Discussion

The effect of spectral efficiency due to the changes in catenated-OFDM modulation technique is compared to the conventional OFDM. Figure 3 shows the comparison of signal spectrum as a function of frequency for conventional OFDM, 5-bands catenated-OFDM and 8-bands catenated-OFDM. The link parameters used for numerical calculation is in Table 1. Bandwidth of each OFDM band can be calculated as $BW_{SC} = \Delta f \times N_{sc_used} = \Delta f \times N_{position_array} = 2.5$ GHz. The maximum OFDM bands can be carried are eight with no guard band. For a system with 1024 of FFT size at FFT sampling frequency of 40 GHz, the available electrical bandwidth is 20 GHz (half of the sampling rate) as shown in Figure 3. Catenated-OFDM modulation technique aims to fully utilized the available electrical bandwidth by concatenating several OFDM bands into the whole spectrum.

The spectrum of catenated-OFDM consist of several bands that contain of OFDM data at their representative center or carrier frequencies. Each band brings 10 Gbps data rate. Figure 3(a) shows the OFDM band at carrier frequency of 3.75 GHz. The carrier frequency for second, third, fourth and fifth band are then set accordingly as 7.5 GHz, 11.25 GHz, 15.0 GHz and 18.75 GHz, respectively as shown in Figure 3(b). Each band occupied 2.5 GHz bandwidth thus accommodated five different bands of data. When we set the band spacing equal to subcarrier spacing (9.76 MHz), catenated-OFDM can accommodate eight number of bands and fully utilized the available electrical bandwidth as shown in Figure 3(c).

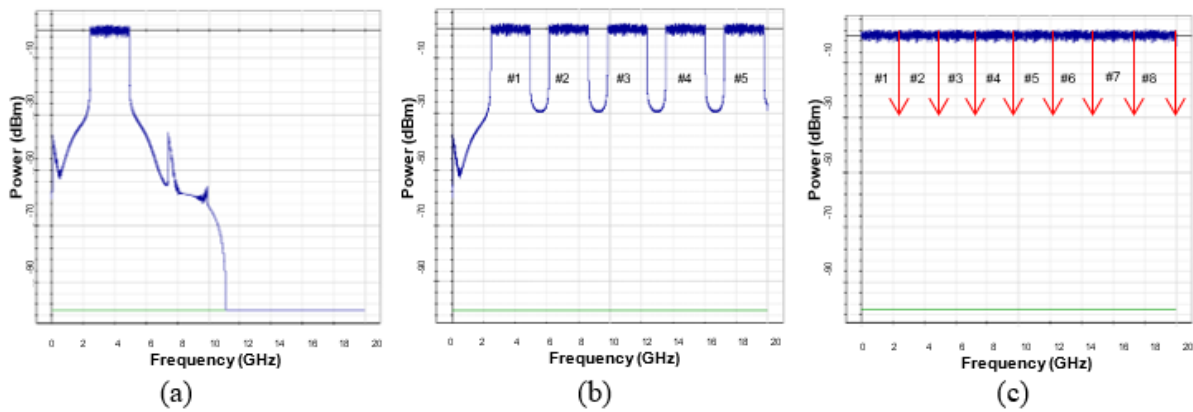


Figure 3. Spectrum of (a) conventional OFDM signal and (b) five bands of catenated-OFDM signal and (c) eight bands of catenated-OFDM signal. IFFT size is 1024 is applied.

The catenated-OFDM outperformed conventional OFDM by five times spectral efficiency improvement and eight times spectral efficiency improvement at their five and eight bands catenated-OFDM respectively. Higher number of bands in a spectrum means that more data can be transferred with benefits of high bandwidth efficiency to the system.

Table 2. Conventional OFDM and catenated-OFDM spectral efficiency improvement

	Spectral Efficiency (SE) (b/s/Hz)	Improvement
Conventional OFDM	0.5	-
2 bands catenated-OFDM	1	2 times
5 bands catenated-OFDM	2.5	5 times
8 bands catenated-OFDM	4	8 times

The results in Figure 4 and Figure 5 are based on SNR in Equation (5). Figure 4 shows the effect of effective received power on the system performance at data rate of 10 Gbps. According to typical acceptable BER of 10^{-9} error floor [11], the effective power for conventional OFDM is approximately -16.8dBm. The effective power of catenated-OFDM technique for two, five and eight bands are approximately to -17 dBm, -15 dBm and -13.4 dBm respectively. Compared to conventional OFDM performance, two bands catenated-OFDM outperformed the conventional OFDM by 0.2 dB with double improvement in spectral efficiency. While the power penalty is only ~1.8 dB with five times improvement in spectral efficiency for five bands catenated-OFDM performance and eight times spectral efficiency improvement in eight bands catenated-OFDM performance with only ~3.4 dB power penalty (the spectral efficiency improvement is shown in Table 2). This indicates that the catenated-OFDM technique is not only able to achieve high spectral efficiency but still capable to detect weak power (less than -10 dBm) at the same time. Thus, it proves that the proposed catenated-OFDM modulation technique can be used in visible light communication system with low power penalty.

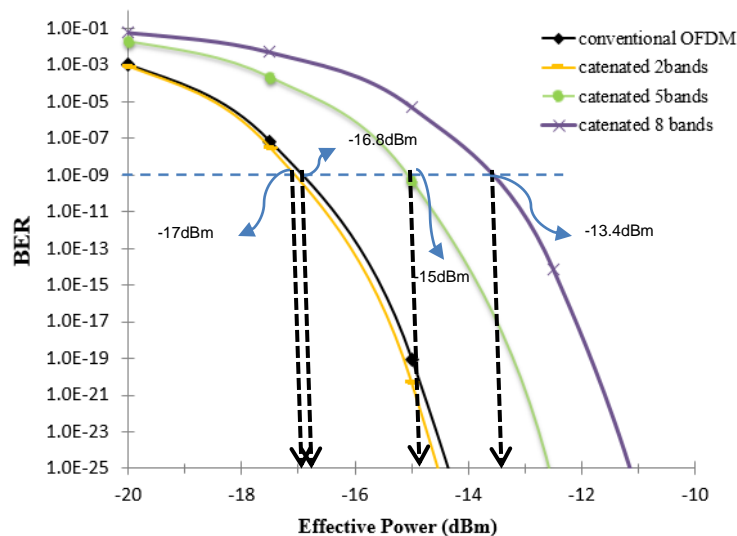


Figure 4. Performance of BER against the effective power for catenated OFDM and conventional OFDM

Figure 5 depicts the corresponding BER with respect to the effective power level as the bit rate varies from 5 Gbps to 15 Gbps. In this analysis, the number of band is fixed to five. At BER of 10^{-9} , the photodetector sensitivity for 5 Gbps, 10 Gbps and 15 Gbps are at -16.5 dBm, -15 dBm and -14 dBm respectively. As can be seen the lower the bit rate, less bit errors have occurred. The power penalty loss is about 1 dB when the bit rate increases from 10 Gbps to 15 Gbps in the same environments. Between 5 Gbps to 10 Gbps the penalty loss is approximately 1.5 dB. This graph proved that the proposed catenated-OFDM design is working well even at a very high bit rate of 15 Gbps.

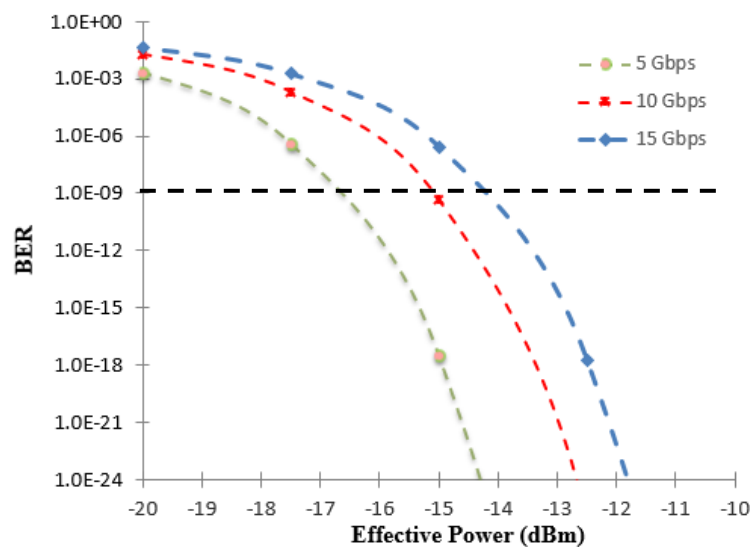


Figure 5. Performance of BER against the effective power with different bit rate

Figure 6 gives the BER performance from the SNR Equation (6). This result compared the performance of catenated-ZCC-VLC (Band = 8), OZCZ-VLC [12] and ZCC-VLC systems with respect to the effective power received for the same number of optical channels. In order to quantify the performance in VLC system, the BER is evaluated using similar parameters setup to give an indication of minimum effective power for three different systems. For this result, the bit rate is fixed to 622 Mbps with number of weight is 3 and the number of channels is 4. It can be observed that, the proposed catenated-OFDM in ZCC-VLC system performs better than OZCZ-VLC and conventional ZCC-VLC systems. At BER = 10^{-9} , the received effective power is approximately -10.2 dBm for conventional ZCC-VLC system, -13.2 dBm for OZCZ-VLC system and -20.5 dBm for catenated-ZCC-VLC system. This result reveals improvement in term of receiver sensitivity of catenated-ZCC-VLC, which the power penalty of 7.3 dB compared to OZCZ-VLC and 10.3 dB compared to ZCC-VLC system. It shows that the catenated-ZCC can advanced the performance of conventional ZCC-VLC and OCZC-VLC. This condition is due to the proposed catenated-ZCC-VLC system has a large number of subcarriers in which increase the signal power and the SNR.

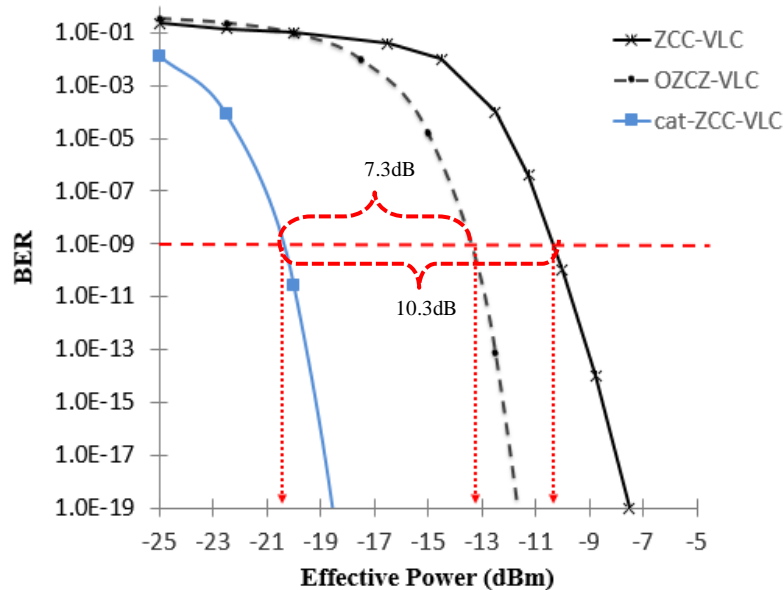


Figure 6. BER performance comparison versus effective power for $W = 3$ and

5. Conclusion

In summary, the performance of catenated-OFDM has been analyzed and presented for VLC system and also its integration with OCDMA system based on ZCC code. The proposed catenated-OFDM modulation technique indicates performance improvement in term of spectral efficiency, bit rate and effective power. Different selection of parameter values such as bit rates, number of bands, effective power, weights and number of user will have different effect on the system performance. The combination of OCDMA and VLC can be regarded as a new attractive research area as OCDMA is an effective multiple access network to support higher capacity distribution of connectivity between VLC access points. This result reveals improvement in term of receiver sensitivity of catenated-OFDM OCDMA-VLC, which approximately -20.5 dBm for 8 bands. Using catenated-OFDM modulation and zero cross correlation between users, the proposed system totally eliminated the PIIN noise thus significantly improved the overall system performance.

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