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Improvement of Dimming and Transmission Efficiencies Based on Direct Sequence Spread Spectrum Scheme in Optical Wireless Communication

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Abstract: In order to simultaneously provide effective lighting and communication services, this study proposes an effective dimming coding scheme combined with a Direct Sequence Spread Spectrum (DSSS) technique in Visible Light Communication (VLC). In previous researches, Zero Reduction Code (ZRC) based on On-Off Keying (OOK) modulation were proposed for effective dimming control, and that achieved better Bit Error Rate (BER) performance and brightness than conventional dimming control scheme such as manchester and 8B/10B codes. However, there is a problem that the error probability was increased in decoding process because ZRC was also a kind of block codes. To solve this problem, the proposed ZRC coding scheme can reduce the input pattern of code sets to the encoder by using the DSSS technique. The DSSS technique uses the specific orthogonal codes, so, the spread chip sequence with a specific pattern can be inputted into the ZRC encoder. Based on this characteristic the number of decision regions can be decreased and that can be led to reduction of the error probability in decoding process. In addition, the proposed scheme can achieve the enhanced dimming level because the available ZRC sets are less restrictive than the conventional ZRC coding scheme. The experiment results indicate that the proposed scheme is able to improve the BER and dimming performance in comparison with the conventional ZRC coding scheme.

Key words: Visible light communication, dimming control, zero reduction code, direct sequence spread spectrum, bit error rate, process

INTRODUCTION

Recently, as large-capacity contents services using wireless communication networks such as multimedia streaming or cloud computing are activated, demand for high-speed data transmission is increased. However, as the number of smart devices which are connected to the network is increased, it is difficult to ensure the high-speed transmission in the conventional wireless networks such as LTE-A and Wireless Local Area Network (WLAN) (Lee *et al*., 2016). Many researchers and experts are paying attention to Visible Light Communication (VLC) technology using LED lighting to satisfy those demands. VLC is able to provide lighting and communication functions simultaneously in an indoor environment and especially, the data rates of that can be ensured of Gbps or more in a Point-to-Point (P2P) system based on LED arrays (Kim and Lee, 2016). However, since, VLC ensures the stable lighting function during communication, efficient dimming control technology should be considered.

The effective dimming control is necessary to provide simultaneously benefits such as emotional atmosphere, energy savings and enhanced communication performance. The brightness level (i.e., dimming level) can be determined according to forward current of LEDs and the control techniques of that can be classified into two ways. The first way is to apply a constant level of current to LEDs, continuously and this is simple and cost-effective system. However, there is a problem that the wavelength of emitted light is changed according to the current values and it is referred to as chromaticity shift problem (Karunatilaka *et al*., 2015). The second way is to control the brightness level using Pulse Width Modulation (PWM) after applying the maximum current to LEDs (Salehi, 2007). The second of these two ways is commonly used in VLC because it can guarantee both lighting and communication functions at the same time.

In IEEE 802.15.7 VLC standard, Variable Pulse Position Modulation (VPPM) was proposed to improve the dimming control efficiency by combining PWM with

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PPM (Stok and Sargent, 2002). The VPPM is able to represent binary data according to the pulse position and determine the dimming level according to the pulse width which is referred to as Duty Cycle Ratio (DCR). In respect of dimming control, a main advantage of the VPPM is able to provide a certain dimming level in accordance with duty cycle ratio (Prucnal, 2005). But the VPPM has a critical disadvantage that although dimming level can be enhanced when the DCR was increased, Bit Error Rate (BER) is degraded in terms of communication performance. On the other hand, On-Off Keying (OOK) is another typical modulation scheme in VLC and it can achieve the improved BER performance compared to the VPPM. However, the OOK has a drawback that the dimming level is unstable according to the input ratio of zeros and ones. In order to overcome this drawback, the VLC standard released 4B/6B and 8B/10B block codes and Manchester codes for the stable dimming control and these codes are typically called as Run Length Limited (RLL) line codes (Shah, 2003). However, their dimming level is fixed at 50% and higher dimming levels than that level cannot be supported. In order to provide more than 50% dimming level, Zero Reduction Codes (ZRCs) based on the OOK modulation were proposed by Saadi *et al.* (2013). This coding scheme can enhance the dimming levels without increasing the DCR, so, the enhanced BER performance can be achieved compared with VPPM. However, we were investigated about the possible error patterns in decoding process by Yi and Lee (2013) and these are degraded of the BER performance compared to the uncoded OOK modulation system.

To solve this drawback, this study proposes an effective dimming control system using a ZRC coding scheme which is combined with a Direct Sequence Spread Spectrum (DSSS) technique. The DSSS technique was widely used in the optical systems because it can be simply implemented based on Intensity Modulation (IM) (Shi and Ghafouri-Shiraz, 2016). The proposed system can mitigate the effects of noise by using the DSSS technique. In addition, the error probability can be reduced in the deciding process because the ZRC coding scheme is applied at the spread chip level rather than at the bit level. In other words, the DSSS technique uses the specific orthogonal codes, so, the chip data of a specific pattern are inputted into the ZRC encoder. Therefore, the number of decision regions can be decreased and it leads to reduction of error probability in the ZRC decoding process. Furthermore, the dimming levels can be enhanced compared to the conventional ZRC coding system. Those properties of the proposed system are demonstrated through simulation result.

MATERIALS AND METHODS

Analysis of the dimming properties and the conventional ZRC coding scheme: In VLC, the optical signal based on IM should be expressed as positive signals (Liu and Adachi, 2006). Therefore, the transmitted optical signal should satisfy the following conditions (Tseng and Chao, 2002):

$$s(t) \geq 0 \text{ and } \lim_{T\to\infty}\int_0^T s(t)dt \leq \gamma P \quad (1)$$

Where:

- s (t) = The transmitted signal
- T = Means a bit duration of the OOK modulation
- P = Denotes the average power of the transmitted signal
- γ = Means dimming factor which is certainly satisfied

With $0\leq\gamma\geq 1$. If the dimming factor conditions were 0.9, 0.6 and 0.3, the b rightness levels can be determined as 90, 60 and 30%, respectively. In the pulse modulation schemes such as OOK and VPPM, the dimming factor can be determined according to DCR and the input data ratio of ones and zeros and that is represented by Tseng and Chao (2002):

$$\gamma = \Pr[b=1]\times\delta_{b=1} + \Pr[b=0]\times\delta_{b=0} \quad (2)$$

where, Pr {b = 1} and Pr {b = 0} denote the input probability of ones and zeros and the summation of thme should be one. Also, $\delta_{b=1}$ and $\delta_{b=0}$ means the DCR of ones and zeros, respectively.

In the case of the VPPM, the dimming level can be controlled by changing the DCR conditions and at this point the DCR conditions of ones and zeros should be equal to each other. Therefore, the dimming levels of the VPPM are not determined by the input ratio of the binary data. However, the BER performance of VPPM is rapidly degraded when $\delta_{b=1}$ and $\delta_{b=0}$ were 0.5 or more. This is because decision interference of the binary data is growth owing to the decision region overlapped (Hasegawa *et al.*, 2007). In OOK, $\delta_{b=1}$ and $\delta_{b=0}$ are fixed at one and zero, respectively. Therefore, the dimming levels of that can be affected by the input ratio of the binary data.

The basic concept of the ZRC coding scheme proposed by Saadi *et al.* (2013) and Yi and Lee (2013) is to make the ratio of ones in the binary input data larger than zeros. In the conventional system to which the ZRC code is adopted, the input data of the ZRC encoder are composed of blocks with sequences of k digits. Those data blocks can form 2^k distinct bit sequences which are referred to as k-Tuples. Then, those k-Tuples are converted into the code blocks with sequence of n digits by adding redundant bits. Those code blocks can be formed up to 2^n distinct sequences which are referred to as n-Tuples. These encoding process can be denoted by (n, k) and it is similar to the conventional block codes (Pakravan and Kavehrad, 2001). The following Table 1 shows an example of look-up charts for ZRC codes at (5, 4).

Also, Fig. 1 denotes a block diagram of the conventional system with the ZRC coding scheme. In the conventional syste, the ZRC encoding process is performed at the bit-level as shown in Fig. 1. In the case of that, if there is an error in a received code block owintg to channel noise, the error probability can be increased in the decoding process. This is because it can be decoded into data of completely different blocks. To overcome that problem we proposed the ZRC coding scheme at the chip level based the DSSS technique and the details of the proposed system will be described in next section.

Proposed dimming control scheme based on DSSS: Figure 2 shows a block diagram about transmitter and receiver architectures of the proposed system where a white LED device is assumed. The white LED lighting is consisted of three color LED sub-chips which are Red (R), Green (G) and Blue (B) colors and the white color can be achieved according to the mixture ratios of them (Barry *et al*., 1993). Also, the number of users in this study assumes one (i.e., single user system).

At the transmitter, the input data of each sub-LED chip modulated by Binary Phase Shift Keying (BPSK), because the modulated symbols must be represented by the real-values in the optical systems. Therefore, the BPSK modulation of several M-PSK modulation schemes are generally used in our proposed system. In order to accommodate the DSSS technique, a set of specific orthogonal spreading codes is adopted to the BPSK symbols. Therefore, the BPSK symbols can be spread to time-domain chips. In this study, Walsh codes are applied to the proposed system as an example of optical Orthogonal Codes (OOC) and the sequence of orthogonal codes can be expressed a $\vec{C} = [c_1, c_2, \ldots, c_{SF}]$ where SF means the length of orthogonal spreading codes. In the k-th chip, C_k, of the n-th BPSK symbol, x_n, the spread chip data can be expressed as $S_{n,k} = x_n c_k$. At this point, the spread chips can be fixed to the sequence of two patterns according to the BPSK symbol values because the BPSK

Table 1: An example of look-up chart for ZRC encoder (5, 4)

Order	Input	Output
1	0000	01001
2	0001	01010
3	0010	01011
4	0011	01101
5	0100	01110
6	0101	01111
7	0110	10011
8	0111	10101
9	1000	10110
10	1001	10111
11	1010	11001
12	1011	11010
13	1100	11011
14	1101	11101
15	1110	11110
16	1111	11111

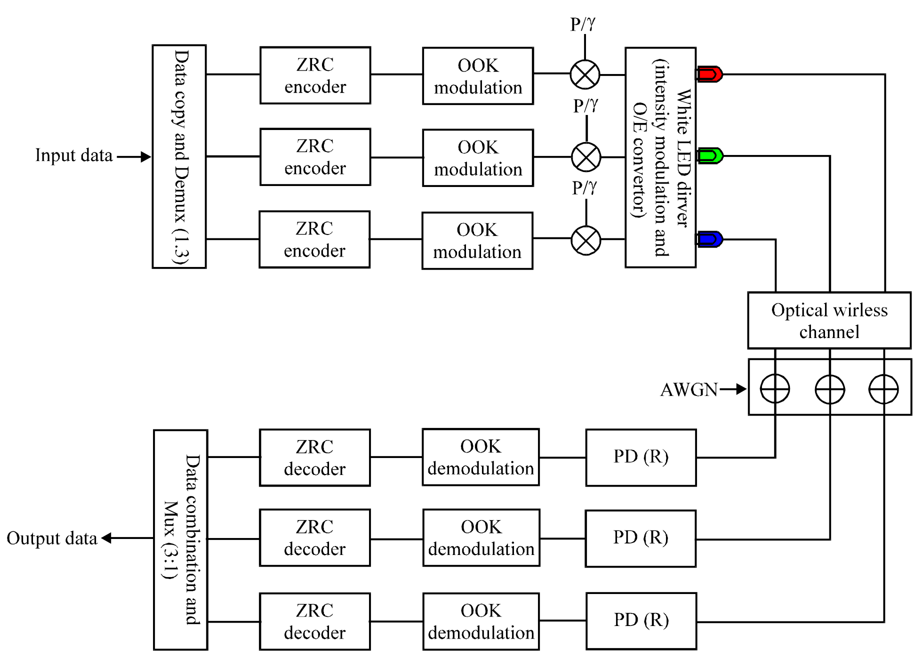

Fig. 1: Transmitter and receiver structures of the conventional system with ZRC

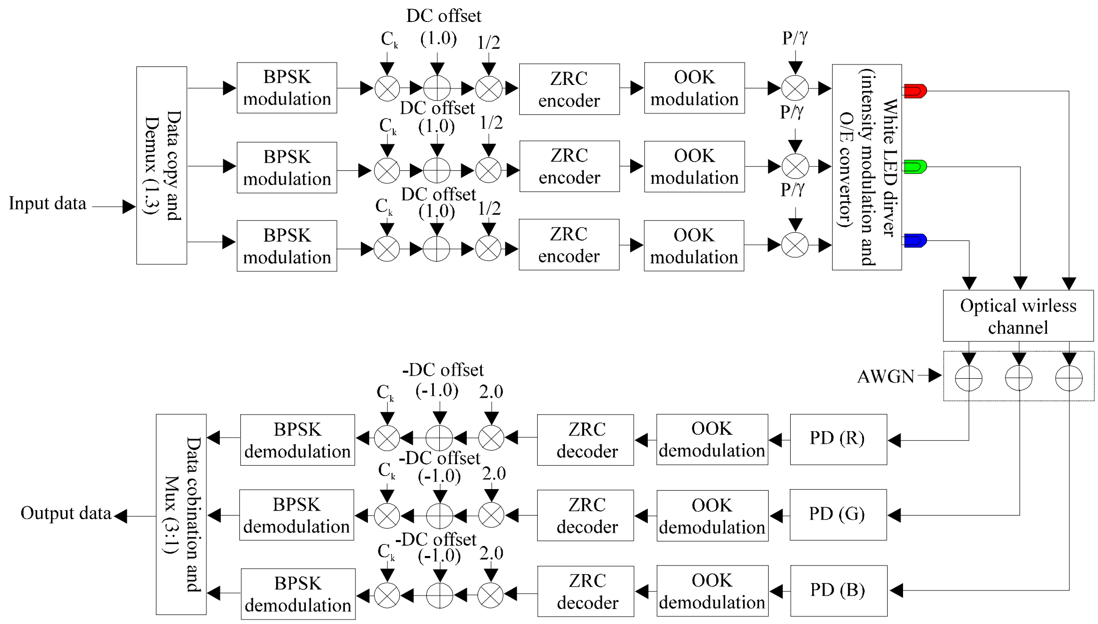

Fig. 2: Transmitter and receiver structures of the proposed system

symbols should be represented only by the values of 1 and -1 on the real axis. Then, in order to remove the negative values, DC off set with a certain level is added to the spread chip data where this study assumed the DC level with 1.0. This is because the proposed system is a single user system. Those positive spread chip data are divided by 1/2 in order to transform the binary data with ones and zeros and then it is encoded by the ZRC encoder for the dimming control. Figure 3 illustrates an example of the pulse structures from the spread chip sequence to the encoded chip sequence by ZRC in the transmitter where the encoding type (5, 4) of ZRC is adopted. Also, the spread code $\vec{C}$=[1,-1,-1,1] with SF = 4 are applied and the target dimming level is set to 80%.

From Fig. 3, we can find that there are only two patterns of the input data to the ZRC encoder, so, we can select a set of dimming codes with the ratio of 1 data higher. Therefore, the proposed ZRC coding scheme can achieve a higher dimming level than the conventional ZRC coding scheme. Next, in order to normalize the average power of the transmission signal to P, P/γ is multiplied to the encoding data and the normalized transmission signal is emitted into air after converting the optical signals by O/E (optical to electrical) converter.

At the receiver, the received optical signal is converted into the electrical signal by the Photo Diode (PD) and performed of the ZRC decoding operation. In the ZRC decoding process, the decoded data can be detected through the correlation operation. In the proposed ZRC

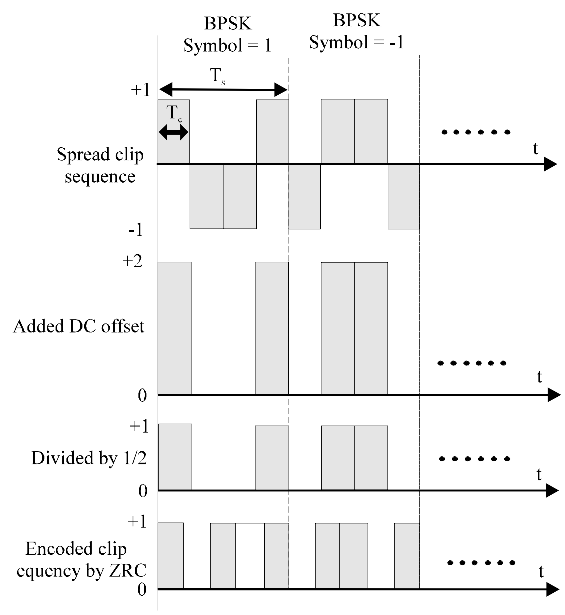

Fig. 3: An example of the pulse structures from the spread chip sequence to the encoded chip sequence by ZRC in the transmitter

decoding process, even if an error occurs in the received ZRC codes, the decoding error can be reduced compared with the conventional ZRC decoding process. This is because there are only a set of the ZRC codes with two patterns, so, the number of decision region is reduced compared with the existing system. Then, the chip level data decoded by the ZRC decoder are recovered to the bit level symbols via. the cross correlation operation which is represented as follows:

$$\tilde{S}n = (\vec{r}_n . \vec{c}) \quad (3)$$

Where:

$(\cdot)$ = The inner-product operation
$\tilde{s}_n$ = The recovered n-th transmission symbol
$\vec{r}_n$ = The n-th received symbol which is consisted of the spread chips

Finally, we can detect the output binary data by performing the BPSK demodulation. The purpose of the proposed system is to reduce the error probability in the decoding process by decreasing the pattern of input data blocks to the ZRC encoder. To this end, the DSSS technique is adopted to our proposed system.

RESULTS AND DISCUSSION

As mentioned earlier, the white LED lighting is consisted of three color LED chips and the white color can be accomplishable by properly mixing the colors of the three chips. Table 2 shows 4 types of mixture ratios and O/E conversion efficiencies to achieve white color based on the results in (Barry *et al.*, 1993; Carruthers and Kahn, 1997).

In Table 2, the O/E conversion efficiency is the best of type 4, so, it is the most suitable for the lighting function. However, in terms of communication, the difference in mixture ratios between sub-LED devices is large, so, the BER performance is degraded in comparison with other types. Therefore, type 2 is able to achieve the best BER performance because the difference of mixture ratios between sub-LED devices is the smallest among them. In addition, the powers in the wavelength of R, G and B are different from each other according to the mixture ratios but the total transmission power of the white LED lighting is equal to all four types. Figure 4 shows the average BER performance according to mixture ratio types.

In Table 3, the mainly simulation parameters of the proposed system are summarized. In our simulations, the noise model of the wireless optical channel which is shot noise or ambient background noise can be typically defined as Adaptive White Gaussian Noise (AWGN) (Komine and Nakagawa, 2004; Yuichi *et al.*, 2003).

Figure 5 shows the results of dimming performance in accordance with various dimming control techniques based on OOK, where note that the dimming performance is evaluated at the transmitter. In this simulation, the ZRC encoding type with (5, 4) is used and in order to accomplish the dimming level of 80% in the proposed system, the sets of ZRC codes with 10111 and 01111 were selected. This is because Euclidian distance between those code sets is maximum on the signal constellation. Also, we assumed that the original input ratio of ones and zeros is equal to each other. From the simulation results, we can demonstrate that the proposed coding scheme is able to achieve the highest dimming level as compared with other dimming control schemes. In particular, the proposed ZRC dimming coding scheme can achieve higher dimming level than the conventional ZRC coding scheme.

Figure 6 shows the BER performance comparison of several dimming control schemes. In this simulation, a bit slot duration is fixed to 10 nsec, so, chip per rate (cps) of

Table 2: Mixing ratio of white LED

Types		Red	Green	Blue	O/E conversion efficiency 1 m/(w)
1	Wavelength λ (nm)	600	555	480	291
	Mixing ratio	1	0.89	2.51	
2	Wavelength λ (nm)	610	555	475	317
	Mixing ratio	1	1.43	2.29	
3	Wavelength λ (nm)	610	555	450	391
	Mixture ratio	1	2.62	1.96	
4	Wavelength λ(nm)	610	565	450	413
	Mixing ratio	1	11.17	7.19	

Table 3: Simulation parameters

Parameters	Values
Spread chip rate	800 Mpcs
Spread codes	Walsh codes
Spreading Factor (SF)	4
Encoding type of ZRC	(5, 4)
Background noise power	1 mW
Noise mode	lAWGN
Optical channel model	Line of Sight (LOS) channel
Original input conditions of ones and zeros	Under equally ratio of ones and zeros
Field of view of a receiver	74.0 deg.
Index of optical concentrator	1.5
Physical of a PD	1.0 cm^2

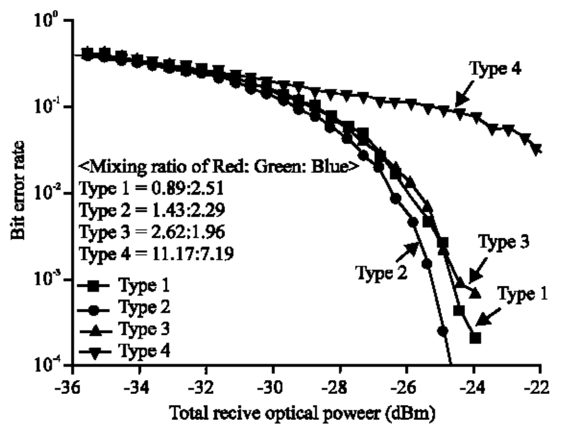

Fig. 4: BER performance comparison in accordance with four color mixing types of white LED lighting

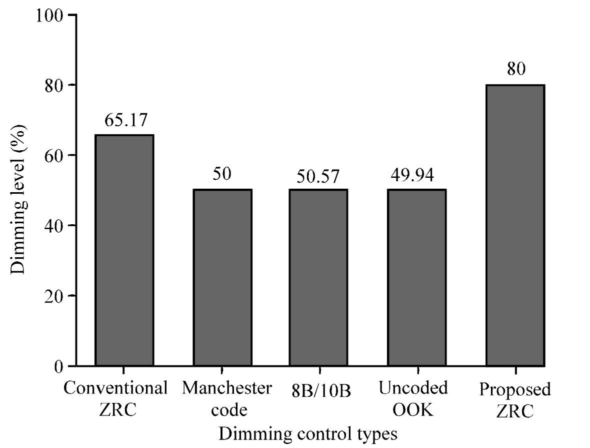

Fig. 5: Dimming performance comparison in accordance with various dimming control techniques based on OOK

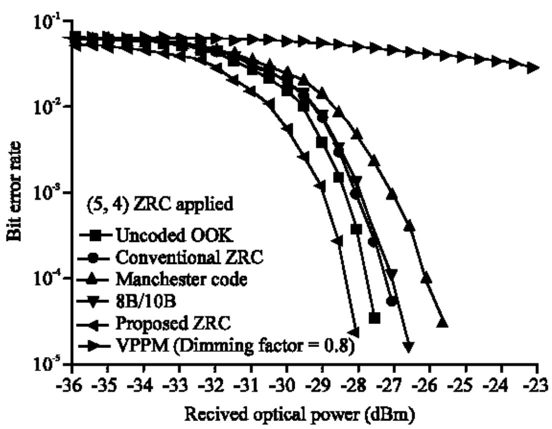

Fig. 6: BER performance comparison in accordance with various dimming control techniques

the proposed system can be determined as 500 Mcps. In VPPM, the worst BER performance is achieved as compared with other dimming control schemes based on OOK. Among the dimming control schemes based on OOK, the proposed ZRC coding scheme can accomplish the best BER performance. In particular, the BER performance of the proposed system can be improved in comparison with uncoded OOK modulation. Therefore, the proposed ZRC coding scheme is superior to the conventional dimming coding schemes in terms of the BER and dimming performance.

CONCLUSION

VLC is able to provide lighting and communication functions simultaneously in an indoor environment. Therefore, the effective dimming control techniques should be required and to this end, we proposed the ZRC coding scheme based on DSSS technique for dimming control. The proposed scheme can reduce the pattern of input code sets to the encoder by using the DSSS technique. This is led to decreasing the number of decision regions. Therefore, the error probability can be reduced in the ZRC decoding process and the effectiveness in terms of BER and dimming performance was demonstrated via. the simulation results. Based on those results, we will need to be studied on the effective dimming control in multi-user environment in the future works.

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