Proposal of a Variable N-CSK with MPSC for an intellectual illumination light data transmission system

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Abstract: In this paper, a variable N-parallel code shift keying (VN-CSK) with the modified prime sequence code (MPSC) for an illumination light data transmission system is proposed. In the proposed system, LED light is used not only for illuminating rooms but also for data transmission. The bit error rate performances are evaluated by theoretical analysis. Consequently, it is found that the proposed system can actualize the dimming control and data transmission simultaneously. The bit error rate performance for N=1 has better approximately 1.3[dB] than that for N=4 when BER is 10^{-6}.

Keywords— **Code Shift Keying, Visible light communication, Dimming control, Light emitting diode**

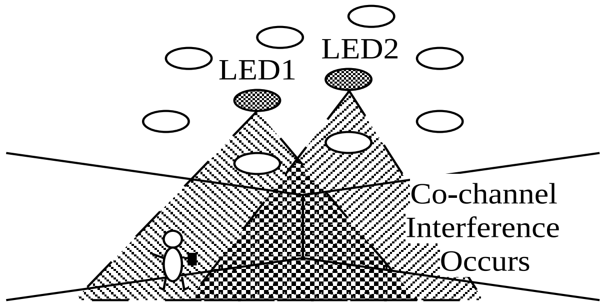

Figure 1. The system model of VN-CSK with MPSC

1. Introduction

The optical wireless communications (OWC), such as the infrared data communications and visible light communications utilizing LED light, have been increasing interest in future home networks and sensor networks due to easy network constitution. The visible light communications that are available for not only the illumination but also data transmission are of considerable interest for indoor communications. The dimming control function which the illumination level can be controlled should not be compromised by the data transmission function. To make data transmission compatible with the dimming control, several modulation methods have been proposed such as the variable pulse position modulation (VPPM) [1–3], the variable multi-pulse PPM (VMPPM) [4], the on-off keying (OOK) [5], the colour shift keying (CSK) [6] and so on. However, in these schemes, the performance of data transmission deteriorates by co-channel interference from neighboring illumination light. Thus, as a scheme which can reduce the influence of co-channel interference, we proposed the code shift keying (CSK) with the modified prime sequence code (MPSC) [7, 8]. However, this scheme is unable to cope with the dimming control. One of the important solutions encountered in the illumination light communication systems is designing an OWC scheme having local dimming function.

In this paper, we propose a variable N-parallel code shift keying (VN-CSK) with the modified prime sequence code (MPSC) which can realize the dimming control and data transmission simultaneously. The VN-CSK with MPSC can effectively suppress co-channel interference from neighboring illumination light. In this paper, we also evaluate the bit error rate (BER) performance by theoretical analysis.

The outlines of this paper are as follows. In section 2, we explain the sturucture of the proposed system. In section 3, we assume the theoretical formula for the proposed system which is applied to later evaluation. In section 4, we evaluate the bit error rate (BER) performances of the VN-CSK system with MPSC. Finally, we summarize the main results in Section 5 followed by acknowledgment and references.

2. System Structure

In this section, we propose VN-CSK with MPSC which has both data transmission function and dimming control function for an indoor illumination light communication.

Figure 1 illustrates an indoor optical-wireless communication model using LED light. LED lamps are mounted on the ceiling, each transmitting the desired information to users underneath the LED lamp. The interference from neighboring illumination light impacts the transmission quality.

Figure 2 illustrates the system structure of the proposed system where the number of codes M=5. In this case, it can be realized 4 stages of dimming degree.

At the transmitter, N codes are selected from M codes that belong to MPSC group #i (MPSC{i,j}, j=1, $\cdots$, M) according to dimming data. For instance, when N=2 codes are selected, the dimming level becomes 2 (the intensity is 50 %). After that, electric signal is converted into optical transmission signal, and transmitted to the receiver. The transmission signal is affected by transmission impairments such as scintillation and background noise.

At the receiver, the received signal is detected and converted back to electrical signal by the chip-level avalanche photo diode (APD). It is then correlated with {-1,+1}-valued MPSC{i,j} (i:group number, j:sequence number). The receiver has M correlators. The largest correlation value is selected in output values of the correlators. After MPSC bring-

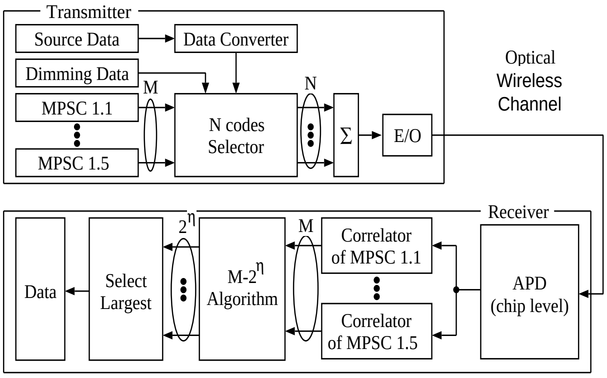

Figure 2. The system structure of VN-CSK with MPSC

Table 1. The dimming control and data transmission utilizing VN-CSK

dimming level	intensity	M	N	η
1	25%	5	1	2[bit/symbol]
2	50%	5	2	2[bit/symbol]
3	75%	5	3	2[bit/symbol]
4	100%	5	4	2[bit/symbol]

ing the maximum value is estimated, data is demodulated. The transmitted data is reconstructed by the estimated data.

2.1 A variable N-parallel code shift keying

In this paper, a variable N-parallel code shift keying (VN-CSK) is used for not only the dimming control but also the data transmission.

VN-CSK can realize the dimming control by varying the number of transmission codes N depending on the dimming degree.

The data transmission efficiency (η) is given by

$$\eta = \lfloor \log_2 {}_M C_N \rfloor [\text{bit/symbol}] \tag{1}$$

where M is the number of MPSC and N is also the number of selected codes for transmission. Table 1 shows the data transmission efficiency of the VN-CSK system with MPSC according to a dimming degree (dimming level). In the proposed system, the data transmission efficiency is constant regardless of the dimming level.

Figure 3 illustrates an instance of the transmission signal and dimming control where the number of codes M=5. In this case, the proposed system can implements 4 stages of dimming degree. VN-CSK can augment the number of dimming stages by increasing M value.

2.2 The modified prime sequence code

We suppress the influence of co-channel interference by using the group characteristics of MPSC [9].

MPSC is constructed over a Galois field $GF(P)$ and has P codes with code lengths of P^2. All the codes have a unique weight value of P. The set of the P^2 codes can be divided into P groups. Each group consists of P codes. The correlation

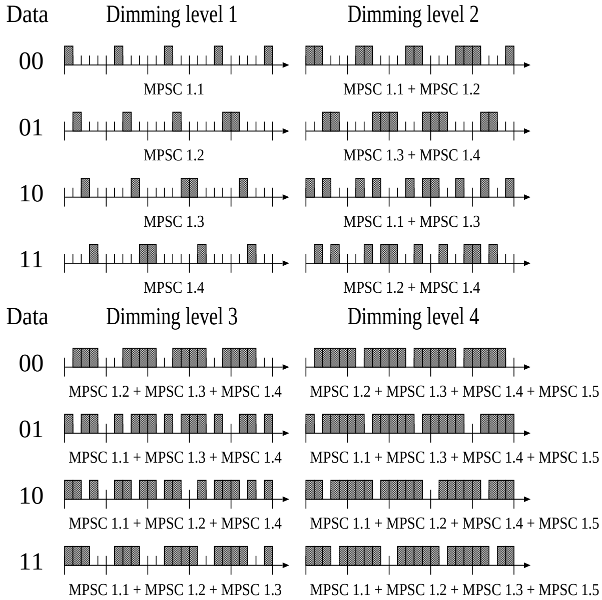

Figure 3. An instance of the transmission signal and dimming control

value between MPSC{i,j} and MPSC{i,k} is 0. The correlation value between MPSC{i,j} and MPSC{m,n} is always 1. In the proposed system, the interference from an adjacent LED is even against all codes because we assign a different MPSC group to other LED.

3. Performance Analysis

In this section, we assume the theoretical formula for the proposed system which is applied to later evaluation.

In this paper, we derive the BER performance from a comparison of the electrical charge at APD.

3.1 Optical wireless channel

In the optical wireless channel, scintillation and background noise are taken into account which influences the received optical signal.

The received optical power P_{in} taking background noise and scintillation into account is

$$P_{\mathrm{in}} = \begin{cases} \frac{P_{\mathrm{w}} X}{N} + P_{\mathrm{b}} & \text{(for a mark)} \\ \frac{P_{\mathrm{w}} X M_{\mathrm{e}}}{N} + P_{\mathrm{b}} & \text{(for a space)} \end{cases} \tag{2}$$

where P_{w} is the original received optical power without the effect of scintillation and background noise, X is the scintillation, N is the number of selected codes for transmission, P_{b} is the background noise, M_{e} is the modulation extinction ratio. The scintillation X is characterized by stationary random process.

The average number of the electrical charges at APD $\mu[P_{\mathrm{in}}]$ is given by

$$\mu[P_{\mathrm{in}}] = GT_{\mathrm{c}} \left(\frac{\eta_{\mathrm{q}} P_{\mathrm{in}}}{hf} + \frac{I_{\mathrm{b}}}{e} \right) + \frac{I_{\mathrm{s}} T_{\mathrm{c}}}{e} \tag{3}$$

where G is the APD gain, T_c is the chip interval, η_q is the quantum efficiency, hf is the energy of a single photon, I_b is the APD average bulk leakage current, I_s is the APD average surface leakage current, e is the electric charge.

The variance of the electrical charge at APD $\sigma^2[P_{in}]$ is given by

$$\sigma^2[P_{in}] = G^2 F T_c \left(\frac{\eta_q P_{in}}{hf} + \frac{I_b}{e} \right) + \frac{I_s T_c}{e} + \frac{2 K_B T_r T_c}{e^2 R_L} \quad (4)$$

where F is the excess noise factor, K_B is the Boltzmann' constant, T_r is the receiver's noise temperature, R_L is the load resistance.

The excess noise factor F is given by

$$F = k_{eff} G + (1 - k_{eff}) \left(\frac{2G - 1}{G} \right) \quad (5)$$

where k_{eff} is the APD effective ionization ratio. The more the value of k_{eff} close to one, the more the value of F is high.

3.2 Bit error probability

The bit error probability BER is described by

$$BER = 1 - \frac{1}{\eta} \int_0^{\infty} \int_{-\infty}^{\infty} P(X) \frac{1}{\sqrt{\pi}} \exp(-z^2) \left\{ \frac{1}{2} \mathrm{erfc}\,(y) \right\}^{2^{\eta}-1} dz dX \quad (6)$$

where η is the data transmission efficiency.

y can be described by

$$y = -\frac{\sqrt{\sigma_1^2(X)}}{\sqrt{\sigma_0^2(X)}} z - \frac{\mu_1(X) - \mu_0(X)}{\sqrt{2\sigma_0^2(X)}} \quad (7)$$

$\mu_1(X)$,$\sigma_1^2(X)$,$\mu_0(X)$,$\sigma_0^2(X)$ can be written as

$$\mu_1(X) = \begin{cases} M\mu_{mark}(X) - 4M\mu_{space}(X) & (N=1) \\ 2M\mu_{mark}(X) - 3M\mu_{space}(X) & (N=2) \\ 3M\mu_{mark}(X) - 2M\mu_{space}(X) & (N=3) \\ 4M\mu_{mark}(X) - M\mu_{space}(X) & (N=4) \end{cases} \quad (8)$$

$$\sigma_1^2(X) = \begin{cases} M\sigma_{mark}^2(X) + 4M\sigma_{space}^2(X) & (N=1) \\ 2M\sigma_{mark}^2(X) + 3M\sigma_{space}^2(X) & (N=2) \\ 3M\sigma_{mark}^2(X) + 2M\sigma_{space}^2(X) & (N=3) \\ 4M\sigma_{mark}^2(X) + M\sigma_{space}^2(X) & (N=4) \end{cases} \quad (9)$$

$$\mu_0(X) = \begin{cases} -M\mu_{mark}(X) - 3M\mu_{space}(X) & (N=1) \\ -M\mu_{space}(X) & (N=2) \\ M\mu_{mark}(X) & (N=3) \\ 2M\mu_{mark}(X) + M\mu_{space}(X) & (N=4) \end{cases} \quad (10)$$

$$\sigma_0^2(X) = \begin{cases} M\sigma_{mark}^2(X) + 4M\sigma_{space}^2(X) & (N=1) \\ 2M\sigma_{mark}^2(X) + 3M\sigma_{space}^2(X) & (N=2) \\ 3M\sigma_{mark}^2(X) + 2M\sigma_{space}^2(X) & (N=3) \\ 4M\sigma_{mark}^2(X) + M\sigma_{space}^2(X) & (N=4) \end{cases} \quad (11)$$

Table 2. The numerical conditions

Name	Value
Bit rate	156[Mbps]
Laser wavelength	565[nm]
Background noise	-45[dBm]
Scintillation logarithm variance	0.01
Modulation extinction ratio	0.01
Quantum efficiency	0.6
APD gain	100
APD effective ionization ratio	0.02
APD bulk leakage current	0.1[nA]
APD surface leakage current	10[nA]

$\mu_{mark}(X)$,$\mu_{space}(X)$, $\sigma_{mark}^2(X)$,$\sigma_{space}^2(X)$ can be expressed as

$$\mu_{mark}(X) = \mu \left[\frac{P_w X}{N} + P_b \right] \quad (12)$$

$$\mu_{space}(X) = \mu \left[\frac{P_w X M_e}{N} + P_b \right] \quad (13)$$

$$\sigma_{mark}^2(X) = \sigma^2 \left[\frac{P_w X}{N} + P_b \right] \quad (14)$$

$$\sigma_{space}^2(X) = \sigma^2 \left[\frac{P_w X M_e}{N} + P_b \right] \quad (15)$$

4. Performance Evaluation

In this section, we evaluate the performance of the proposed system.

Figure 4 shows the bit error rate (BER) performance of the proposed system with respect to P_w/N values ranging from -60[dBm] to -50[dBm] when there is no co-channel interference from neighboring illumination light.

P_w is the average received optical power per bit. In the proposed system, N codes are transmitted according to dimming degree. In other words, the N times optical power is required for the equivalent data transmission. Therefore, P_w/N is used as the index of horizontal axis. The numerical conditions are shown in Table 2.

The performance for N=1 has better 1.3[dB] than that for N=4 when BER is 10^{-6}. Therefore, the proposed system can realize the dimming control and data transmission at the same time.

5. Conclusion

In this paper, we have proposed VN-CSK with MPSC for illumination light data transmission. Moreover, we evaluated the bit error rate performances in optical wireless channel by theoretical analysis. The bit error rate performance for N=1 has better 1.3[dB] than that for N=4 when BER is 10^{-6}. The proposed system can achieve the constant data transmission rate regardless of dimming levels. Since the performance does not vary with a dimming level, the proposed system can realize the dimming control and data transmission at the same time. The future work is to analyze the bit error rate performance taking into account the interference from other LEDs using

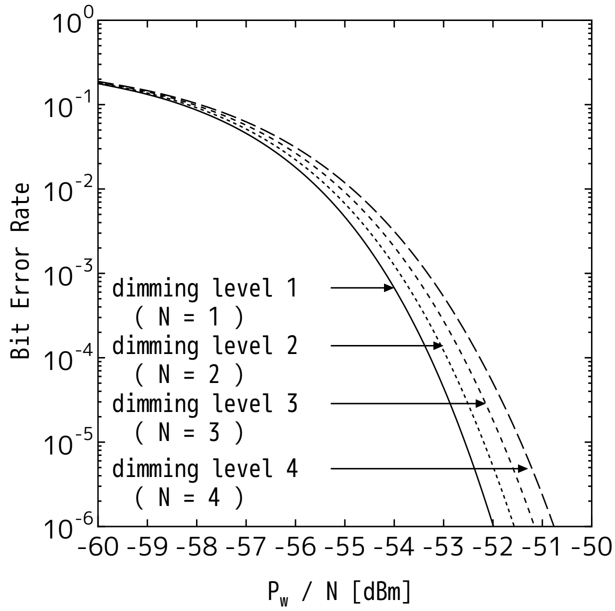

Figure 4. The BER performance of the proposed system (M=5)

the same MPSC. Moreover, we will investigate how we assign MPSC to LED, and find a most suitable assignment method.

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