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New Optical-Wireless CSK-MPPM System with Modified Prime Sequence Code

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Abstract: In this paper, a new hierarchical CSK(code shift keying)-MPPM(multi-pulse pulse modulation) system is proposed. The system improves reliability of intelligent transport systems. Although it is difficult to set the optinum threshold value, many conventional hierarchical systems use the threshold detector. The proposed system demodulates both of signals by comparative decision. In this paper, the bit error rate of the proposed system and the conventional MPPM-CNK(code number keying) is evaluated. It is shown that CSK-MPPM outperformes MPPM-CNK under the complete synchronization.

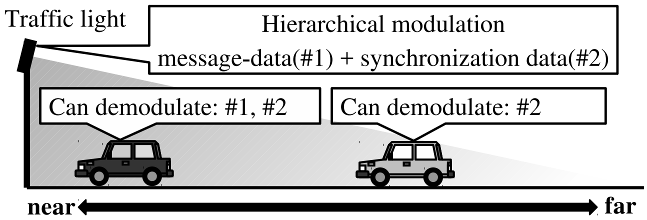

Figure 1. The model of the local broadcasting system with the hierarchical modulation scheme.

1. Introduction

Recently, together with the spread of light emitting diode (LED), there has been increasing interests in optical wireless communications and local broadcasting services on intelligent transport systems (ITS)[1][2]. The local broadcasting system transmits the traffic accident, traffic jam, information of parking lot and neighbor shops, and surrounding information. The hierarchical modulations[3][4] are the effective method to improve reliability of ITS. The hierarchical modulation systems can transmit several types of data at the same time because the systems unite several types of modulation method. The systems can broadcast message-data modulated by modulation #1 and synchronization data modulated by modulation #2 simultaneously. Even if the vehicle which is far from the broadcasting station does not receive message-data, it is expected that the vehicle can recive synchronization data only. The hierarchical modulation schemes make a receiver possible to demodulate some of the information even if the receiver is far from the transmitter.

Many studies have been investigated on the hierarchical modulations using generalized modified prime sequence code (GMPSC)[5] as a pseudo-noise (PN) code. The CSK-ASK system[4] which consists of code shift keying and amplitude shift keying, the CSK-CNK system[4] which unites CSK and code number keying, and the MPPM-CNK system[6] which fuses multi-pulse pulse position modulation and CNK, were proposed. These conventional systems demodulate the modulation #1's signal by comparative decision, and demodulate the modulation #2's signal by threshold decision. In these conventional systems, it is difficult to set an optimum threshold level because the received signal power fluctuates by background noise, scintilation and shadowing. It means that the bit error rate performance deteriorates when the system uses the threshold decision.

In this paper, we propose a new hierarchical CSK-MPPM system using GMPSC as a PN code. The proposed system is expected to improve the bit error rate performance because the system does not use the threshold decision. The proposed system demodulates both of modulations by comparative decision. In the proposed system, CSK is used as the modulation #1 and MPPM is used as the modulation #2. Although the conventional systems use MPPM as a modulation #1, the proposed system uses MPPM as a modulation #2. We evaluates the bit error rate performance by theoretical analysis. We compare the proposed system with the conventional MPPM-CNK system[6] under the complete synchronization.

2. Proposed System

Figure 1 illustrates the model of the local broadcasting system with the hierarchical modulation scheme. In Fig. 1, the traffic light broadcast message-data by modulation #1 and synchronization data by modulation #2 simultaneously. When the vehicle is near from the traffic light, the vehicle can receive both of data. Even if the vehicle which is far from the traffic light does not receive message-data, the vehicle can recive synchronization data. It means the vehicle can demodulate some of the information even if the vehicle is far from the traffic light.

Figure 2 illustrates the structure of the hierarchical CSK-MPPM system using GMPSC. In the CSK modulator, one PN code is selected from p PN codes according to CSK DATA. In the MPPM modulator, m slots are selected from M slots according to MPPM DATA. The transmitter of CSK-MPPM puts the selected PN code on the selected slots.

In the CSK demodulator, M slots in one frame are summed by the chip integrater. The output signal of the chip integrater is correlated with p reference PN codes. The CSK signal is demodulated by comparing p correlation values. The value is compared with reference p PN codes. In the MPPM demodulator, the MPPM signal is demodulated by comparing M integrater output.

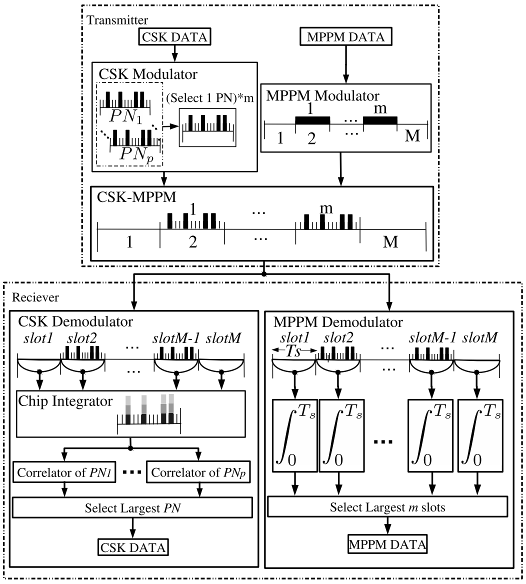

Figure 2. CSK-MPPM system.

3. Performance Analysis

3.1 Optical Wireless Channel

In our theoretical analysis, we take into account scintillation, background noise, APD noise, thermal noise, and depend noise. The probability that a specified number of photons are absorbed from an incident optical field by an APD detector over a chip interval with T_c is given by Poisson distribution[7]. We assume that the APD output during each chip interval is Gaussian random variable, so, the correlator output, which is the correlator output, which is the accumulated output during each chip interval, is also Gaussian random variable.

In the optical wireless communications, we need to take into account the scintillation which influences the attenuation and the fluctuation of the received optical power[8][9]. The scintillation X characterized by the stationary probability process. Its probability density function $P(X)$ can be written as

$$P(X) = \frac{1}{\sqrt{2\pi\sigma_s^2}X}\exp\left\{\frac{\ln X + \sigma_s^2/2}{2\sigma_s^2}\right\} \tag{1}$$

where the average of scintillation X is normalized to unity, and σ_s^2 is logarithm variance. The variance σ_s^2 is determined by the atmospheric state. When P_w is received optical power without the effect of scintillation X and background noise P_b, the received power P_{in} can be expressed as

$$P_{in} = \left\{\begin{array}{ll} P_w X + P_b & \text{for a mark} \\ \frac{P_w X}{M_e} + P_b & \text{for a space} \end{array}\right. \tag{2}$$

where M_e is the modulation extinction ratio. The average $\mu[P_{in}]$ of the electrons emitted by APD is given by

$$\mu[P_{in}] = GT_c(\frac{\eta P_{in}}{hf} + \frac{I_b}{e}) + \frac{I_s T_c}{e} \tag{3}$$

where G is the average APD gain, hf is the energy of a single photon, η is the quantum efficiency, e is the electronic charge, I_b is the average bulk leakage current and I_s is the average surface leakage current. The variance $\sigma^2[P_{in}]$ of the electrons emitted by APD is given by

$$\sigma^2[P_{in}] = G^2 F T_c(\frac{\eta P_{in}}{hf} + \frac{I_b}{e}) + \frac{I_s T_c}{e} + \frac{2k_B T_r T_c}{e^2 R_L} \tag{4}$$

where k_B is the Boltzmann constant, T_r is the receiver noise temperature and R_L is the load resistance. F is the excess noise index, which is given by

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

where k_{eff} is the effective ionization coefficient.

3.2 Bit Error Rate under the complete synchronization

We present the bit error rate of the proposed system in complete synchronization. The symbol error rate of CSK, denoted SER_{CSK}, can be written as,

$$\begin{aligned}
&SER_{CSK} \\
=&(p-1)\int_0^{\infty} P(X) \\
&\int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi\sigma_{ADe}{}^2(X)}}\exp\Big(\frac{-(q_1-\mu_{ADe}(X))^2}{2\sigma_{ADe}{}^2(X)}\Big) \\
&\int_{-\infty}^{q_1} \frac{1}{\sqrt{2\pi\sigma_{ADc}{}^2(X)}}\exp\Big(\frac{-(q_p-\mu_{ADc}(X))^2}{2\sigma_{ADc}{}^2(X)}\Big)dq_p \\
&\Big\{\int_{-\infty}^{q_1} \frac{1}{\sqrt{2\pi\sigma_{ADe}{}^2(X)}} \\
&\exp\Big(\frac{-(q_s-\mu_{ADe}(X))^2}{2\sigma_{ADe}{}^2(X)}\Big)dq_s\Big\}^{p-2} dq_1 dX \\
=&(p-1)\int_0^{\infty} P(X)\int_{-\infty}^{\infty}\frac{1}{\sqrt{\pi}}\exp(-z^2) \\
&\Big\{\frac{1}{2}\mathrm{erfc}(-\frac{\sqrt{\sigma_{ADe}{}^2(X)}}{\sqrt{\sigma_{ADc}{}^2(X)}}z - \frac{\mu_{ADe}(X)-\mu_{ADc}(X)}{\sqrt{2\sigma_{ADc}{}^2(X)}})\Big\} \\
&\Big\{\frac{1}{2}\mathrm{erfc}(-z)\Big\}^{p-2} dz dX
\end{aligned} \tag{6}$$

The average $\mu_{csk}(X)$ and the variance $\sigma_{csk}(X)$ of correlator output are given by,

$$\mu_{csk}(X) = \left\{\begin{array}{l} \mu_{ADc}(X) \text{ for a mark} \\ \mu_{ADe}(X) \text{ for a space} \end{array}\right. \tag{7}$$

$$\sigma^2_{csk}(X) = \left\{\begin{array}{l} \sigma^2_{ADc}(X) \text{ for a mark} \\ \sigma^2_{ADe}(X) \text{ for a space} \end{array}\right. \tag{8}$$

where the $\mu_{ADc}(X)$, $\sigma_{ADc}(X)$, $\mu_{ADe}(X)$, $\mu_{ADe}(X)$ are expressed as,

$$
\begin{aligned}
\mu_{ADc}(X) &= mp\mu[P_wX+P_b] \\
&\quad +(M-m)p\mu[\frac{P_wX}{M_e}+P_b] \qquad (9)\\
\sigma^2_{ADc}(X) &= mp\sigma^2[P_wX+P_b] \\
&\quad +(M-m)p\sigma^2[\frac{P_wX}{M_e}+P_b] \qquad (10)\\
\mu_{ADe}(X) &= Mp\mu[\frac{P_wX}{M_e}+P_b] \qquad (11)\\
\sigma^2_{ADe}(X,\tau) &= Mp\sigma^2[\frac{P_wX}{M_e}+P_b] \qquad (12)
\end{aligned}
$$

The symbol error rate of MPPM, denoted SER_{MPPM}, can be written as,

$$
\begin{aligned}
& SER_{MPPM}(\tau) \\
=& 1-m\int_0^{\infty}P(X) \\
& \int_{-\infty}^{\infty}\frac{1}{\sqrt{2\pi{\sigma_{SLc}}^2(X,\tau)}}\exp\Big(\frac{-(q_1-\mu_{SLc}(X,\tau))^2}{2{\sigma_{SLc}}^2(X,\tau)}\Big) \\
& \Big\{\int_{-\infty}^{q_1}\frac{1}{\sqrt{2\pi{\sigma_{SLe}}^2(X,\tau)}} \\
& \qquad \exp\Big(\frac{-(q_s-\mu_{SLe}(X,\tau))^2}{2{\sigma_{SLe}}^2(X,\tau)}\Big)dq_s\Big\}^{M-m} \\
& \Big\{\int_{q_1}^{\infty}\frac{1}{\sqrt{2\pi{\sigma_{SLc}}^2(X,\tau)}} \\
& \qquad \exp\Big(\frac{-(q_p-\mu_{SLc}(X,\tau))^2}{2{\sigma_{SLc}}^2(X,\tau)}\Big)dq_p\Big\}^{m-1}dq_1dX \\
=& 1-m\int_0^{\infty}P(X)\int_{-\infty}^{\infty}\frac{1}{\sqrt{\pi}}\exp(-z^2) \\
& \Big\{\frac{1}{2}\mathrm{erfc}(-\frac{\sqrt{{\sigma_{SLc}}^2(X,\tau)}}{\sqrt{{\sigma_{SLe}}^2(X,\tau)}})z \\
& -\frac{\mu_{SLc}(X,\tau)-\mu_{SLe}(X,\tau)}{\sqrt{2{\sigma_{SLe}}^2(X,\tau)}}\Big\}^{M-m}\Big\{\frac{1}{2}\mathrm{erfc}(z)\Big\}^{m-1}dzdX
\end{aligned}
\qquad (13)
$$

The average $\mu_{mppm}(X)$ and the variance $\sigma_{mppm}(X)$ of correlator output are given by,

$$
\mu_{mppm}(X)=\begin{cases}\mu_{SLc}(X) \text{ for a mark}\\ \mu_{SLe}(X) \text{ for a space}\end{cases} \qquad (14)
$$

$$
\sigma^2_{mppm}(X)=\begin{cases}\sigma^2_{SLc}(X) \text{ for a mark}\\ \sigma^2_{SLe}(X) \text{ for a space}\end{cases} \qquad (15)
$$

where the $\mu_{SLc}(X)$, $\sigma_{SLc}(X)$, $\mu_{SLe}(X)$, $\mu_{SLe}(X)$ are expressed as,

$$
\mu_{SLc}(X) = p\mu[P_wX+P_b]+(p^2-p)\mu[\frac{P_wX}{M_e}+P_b] \qquad (16)
$$

$$
\sigma^2_{SLc}(X) = p\sigma^2[P_wX+P_b]+(p^2-p)\sigma^2[\frac{P_wX}{M_e}+P_b] \qquad (17)
$$

$$
\mu_{SLe}(X) = p^2\mu[\frac{P_wX}{M_e}+P_b] \qquad (18)
$$

$$
\sigma^2_{SLe}(X) = p^2\sigma^2[\frac{P_wX}{M_e}+P_b] \qquad (19)
$$

4. Numerical Results

In this section, we analize the bit Error rate (BER) performance of CSK-MPPM and MPPM-CNK in the optical wireless channel. Table 2 shows the numerical parameters.

Figures 3 and 4 show BER of CSK-MPPM and MPPM-CNK where total bit rate of two modulations is 156[Mbps]. In Fig. 3, the background noise is -45[dBm]. In Fig. 4, the average received laser power per bit is -35[dBm]. In the CSK-MPPM system, $M=4$, $m=2$, $p=4$. In the MPPM-CNK system, the maximum number of selecting PN codes in the CNK modulator is 4, the number of slots in one frame is 4 and the number of selecting slots in the MPPM is 2. Table 1 shows information bit rates.

In Fig. 3, when BER is 10^{-6}, the BER performance of the proposed system is about 5[dB] better than that of the conventional system in the modulation #1. In the modulation #2, the performance of the proposed system is about 9.5[dB] better than that of the conventional system. In the proposed system, it is found that the BER performance of MPPM is close to that of CSK. Although the BER performance of difference between modulation #1 and modulation #2 in conventional system when the bit error rate is 10^{-6} is about 5.5[dB], that of the proposed system is about 0.4[dB]. This means that performance improvement of the modulation #1 was performed. In Fig. 4, when BER is 10^{-6}, the BER performance of the proposed system is about 12[dB] better than that of the conventional system in the modulation #1. In modulation #2, the performance of the proposed system is much better than that of the conventional system. In the conventional system, the BER performance of the modulation #2 significantly deteriorates from that of modulation #1 under the smaller background noise environment. In the modulation #2 of the proposed system, the BER performance degradation from the modulation #1 is sightly 0.2[dB]. It is found that the background noise resistance of the conventional system can be enhanced.

5. Conclusion

In this paper, CSK-MPPM is proposed. The bit error rate performance of the proposed system is better than that of the conventional MPPM-CNK system under the complete synchronization. The future task is to analize of the bit error rate performance when the synchronization error occurs.

Table 1. Information Bit Rate

System	**Modulation 1**	**Modulation 2**
CSK-MPPM	$\lfloor\log_2 p\rfloor=2$	$\lfloor\log_2 {}_MC_m\rfloor=2$
MPPM-CNK	$\lfloor\log_2 {}_MC_m\rfloor=2$	$\lfloor\log_2 N\rfloor=2$

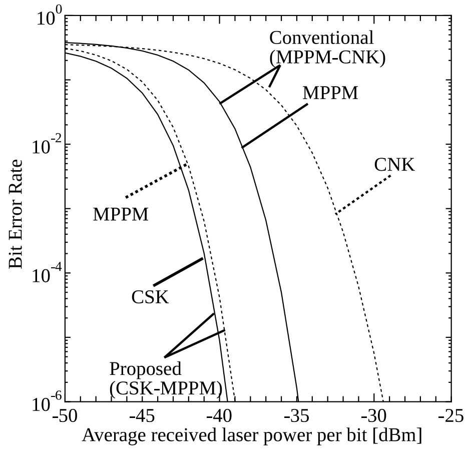

Figure 3. Bit Error Rate vs. average received laser power per bit where background noise=-45[dBm]

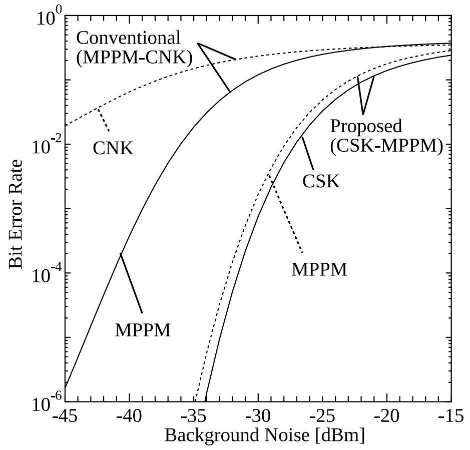

Figure 4. Bit Error Rate vs. background noise where the average received laser power per bit is -35[dBm]

Table 2. Information Bit Rate

Scintillation logarithm variance	σ_s^2	0.01
Modulation extinction ratio	M_e	100.0
APD Gain	G	100.0
Quantum efficiency	η	0.6
Excess noise index	F	3.9502
Energy of a single photon	hf	$23.94939759{\times}10^{-20}$
Electronic charge	e	$1.60217646 \times 10^{-19}$
Bulk leakage current	I_b	10^{-10}
Surface leakage current	I_s	10^{-8}
Boltzmann constant	k_B	$1.3806503 \times 10^{-23}$
Receiver noise temperature	T_r	1100.0
Receiver load resistor	R_L	1030.0
Total bit rate of modulation 1 and 2	R_b	156[Mbps]
Chip interval	T_c	$\frac{\log_2 {}_M C_m + \log_2 p}{Mp^2 \times 156 \times 10^6}$ $= \frac{\log_2 N + \log_2 {}_M C_m}{Mp^2 \times 156 \times 10^6}$
Background noise	P_b	-45.0 [dBm]
Length of GMPSC	p^2	16
The number of codes in CSK	p	4
The number of slots in MPPM frame	M	4
The number of selected slots in MPPM	m	2
The number of codes in CNK	N	4

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