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Performance of CSK Scheme for V2I Visible Light Communication

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ABSTRACT

These days, research related to Intelligent Transportation System (ITS) technology is being widely considered. ITS is inevitable for future transportation systems to reduce accidents, congestion, and offer a smooth flow of traffic. The use of Visible Light Communication (VLC) in ITS systems has been considered widely because of its EMC/EMI free and LED infrastructure reusable properties. Among the VLC schemes, this study analyzed the performance of the Color Shift Keying (CSK) scheme under a Vehicle-to-Infrastructure (V2I) downlink scenario to verify the capability of CSK as a communication tool for ITS. By modeling daylight noise using the modified Blackbody radiation model, this study examined the performance of V2I VLC under daytime conditions. The relationship between BER, the communication distance, and the amount of ambient-light noises under the pre-described V2I scenario were determined by simulations.

Key Words : Intelligent Transportation System (ITS), Visible Light Communication (VLC), Vehicle-to-Infra (V2I), Color Shift Keying (CSK)

Ⅰ. Introduction

Light-Emitting Diode (LED) light is being highlighted as the next generation illumination lighting. LED light has more advantages than fluorescent light and incandescent lamps, such as long life, low power consumption, high efficiency, and rapid switching[1-5]. Because LEDs are a kind of controllable digital device, studies of the convergence of LED and IT are being performed actively. Among them, Visible Light Communication (VLC), which is the convergence of illumination and communication, is considered widely. By reusing the LED infrastructure for VLC, the VLC system can provide illumination and communication functions at the same time[6-16].

These days, research related to Intelligent Transportation System (ITS) technology is being highlighted. ITS has been considered widely for the next generation transportation systems to reduce accidents, congestion, and offer a smooth flow of traffic. To implement the intelligence, ITS has taken advantage of Information and Communication Technologies (ICT) to provide several different technological systems that help their users. An ITS system based on Radio Frequency (RF), however, has serious problems related to EMC and EMI. On the other hand, ITS based on VLC can communicate with other RF systems without interference and EMC and EMI problems. In addition, transportation lighting infrastructures, such as street lamps, traffic lights, vehicular lamps, etc., are changing to LED lighting. The reuse of LED illumination infrastructure for ITS can provide better economical

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profit than RF-based ITS solutions. Therefore, many studies of the convergence of VLC technology with ITS systems have been performed[17-24].

This study analyzed the performance of the Color Shift Keying (CSK) scheme under a Vehicle-to-Infrastructure (V2I) downlink scenario. The CSK scheme is a type of VLC scheme proposed by the IEEE 802.15.7 VLC standard, which transmits data using multi-spectral LEDs, such as Red, Green, and Blue LEDs[8-10]. Therefore, it transmits data by changing the emitted power of each LED. To verify the possibility of a CSK scheme as the communication tool for ITS, this study considered the V2I scenario that street lamps broadcast to vehicles at daytime via the CSK scheme. Because VLC uses light for communication, its performance is strongly dependent on the ambient-light noise, particularly sunlight. By modeling the daylight noise using the modified Blackbody radiation model, this study examined the capability of V2I VLC downlink broadcasting at daytime. The relationship between BER, the communication distance, and the amount of ambient-light noises under the pre-described V2I scenario was determined by simulations.

Ⅱ. System and Environment Modeling

2.1 Color Shift Keying Scheme

The CSK scheme proposed in the IEEE 802.15.7 VLC standard transmits data through multi-spectral LEDs, such as red, green, and blue LEDs by changing the emitted power of each LED[8-10]. Fig. 1 gives an example of spectrum selection. In this example, three spectrum bands ($i-Band$, $j-Band$, $k-Band$)were selected among the 7 spectrum bands on xy color coordinates[9].

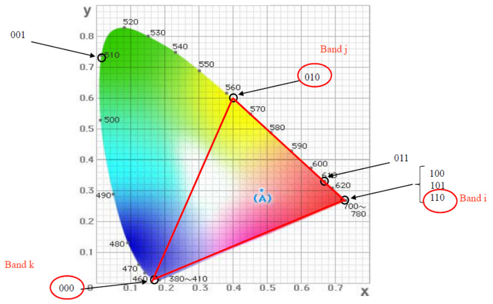


Fig. 1. Spectral selection example for codes (110, 010, 000)[9]

Fig. 2 shows a 4-CSK constellation example, which is proposed in the IEEE 802.15.7 standard. In the case of 4-CSK, a 2 binary data symbol is changed to color-coordinates on xy-coordinates. If (x_p, y_p) represents a point of constellations for 4-CSK, the color-coordinate is changed to the power of each spectrum band $(P_t^{(i)}, P_t^{(j)}, P_t^{(k)})$ using the equations shown below:

$$\begin{cases} x_p = P_t^{(i)} x_t + P_t^{(j)} x_j + P_t^{(k)} x_k \\ y_p = P_t^{(i)} y_t + P_t^{(j)} y_j + P_t^{(k)} y_k \\ P_t^{(i)} + P_t^{(j)} + P_t^{(k)} = 1 \end{cases} \quad . \tag{1}$$

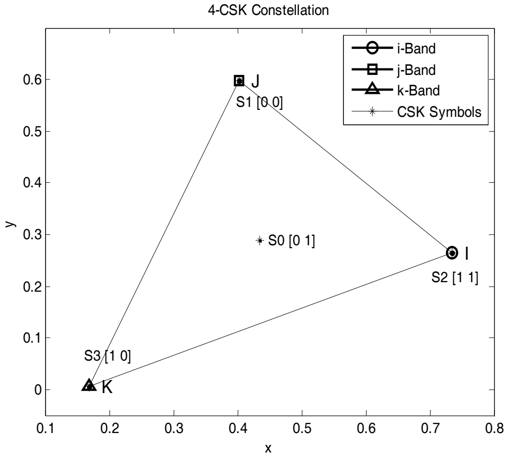


Fig. 2. 4-CSK constellation example for codes (110, 010, 000)[9]

2.2 VLC Channel Model

After passing through the VLC optical channel H, P_t is received by a photodiode (PD) producing the received signal P_r given as

$$\begin{bmatrix} P_r^{(i)}(t) \\ P_r^{(j)}(t) \\ P_r^{(k)}(t) \end{bmatrix} = \gamma \begin{bmatrix} H_{ii}(0) & H_{ij}(0) & H_{ik}(0) \\ H_{ji}(0) & H_{jj}(0) & H_{jk}(0) \\ H_{ki}(0) & H_{kj}(0) & H_{kk}(0) \end{bmatrix} \begin{bmatrix} P_t^{(i)}(t) \\ P_t^{(j)}(t) \\ P_t^{(k)}(t) \end{bmatrix} + \begin{bmatrix} n^{(i)}(t) \\ n^{(j)}(t) \\ n^{(k)}(t) \end{bmatrix} \tag{2}$$

where γ is the detector conversion efficiency $[A/W]$ and $n(t)$ is the Additive White Gaussian Noise (AWGN). $H_{mn}(0) = H(0)h_{mn}, (m,n = i,j,k)$

represents the channel DC gain from the m band to n band. In H, the diagonal elements are the LOS channel DC gain, which represents a one to link between the LED and PD in the same spectrum band, where $h_{mm}=1$ for $m=i,j,k$. The channels DC gain $H(0)$, which explains the attenuated light power due to the light distribution pattern, and the distance is represented as shown below[11]:

$$H(0)=\begin{cases}\frac{(m+1)A}{2\pi d^2}cos^m(\phi)T_s(\psi)g(\psi)\cos(\psi) & ,0\le\psi\le\Psi_c\\ 0 & ,\psi>\Psi_c\end{cases} \tag{3}$$

where m is the order of Lambertian emission, A is the physical detection area of PD, d is the distance between LED and PD, ϕ is the angle of irradiance, and ψ is the angle of incidence. $T_s(\psi)$ is the signal transmittance of the optical filter, $g(\psi)$ is the concentrator gain, and Ψ_c is the concentrator FOV. The order of Lambertian emission, m is related to the LED semi-angle at half power $\Phi_{1/2}$ according to the following equation[25],[27]

$$m=-\frac{\ln 2}{\ln(\cos(\Phi_{1/2}))}. \tag{4}$$

The optical concentrator $g(\psi)$ can be determined from the following expression[25],[27]:

$$g(\psi)=\begin{cases}\frac{n^2}{\sin^2\Psi_c} & ,0\le\psi\le\Psi_c\\ 0 & ,elsewhere\end{cases} \tag{5}$$

where n denotes the internal refractive index of the optical concentrator. The non-diagonal elements of the channel matrix H are the interference from other spectrum bands. The amount of interference h_{mn} is expressed as $\rho(h_{mn}=\rho,(m\neq n))$. The value of ρ depends on the PD response to the other color and optical filter gain $(0\le\rho\le 1)$.

2.3 Daylight Noise Model

To communicate at daytime, it is important to consider sun-light as the main outdoor noise source. Because VLC uses light for communication, its performance is strongly dependent on sunlight. The sun's spectral irradiance measured outside the Earth's atmosphere closely resembles a blackbody of approximately $6000K$. To analyze the effect of sunlight noise at daytime, the background noise was formulated using a blackbody radiation model with spectral irradiance given by[12]

$$W(\lambda,T_B)=\frac{2\pi h_p c^2}{\lambda^5}\left[\frac{1}{e^{h_p c/\lambda k T_B}-1}\right] \tag{6}$$

where h_p is Planck's constant, c is the speed of light, λ is the wavelength, k is the Boltzmann's constant, and T_B is the average surface temperature of the sun.

The analytic daylight noise model presents a simplified but reliable approach to generating the terrestrial spectral irradiance (between $0.3\mu m$ and $4.0\mu m$) by taking the global solar irradiance E_{global} measurements as the input. The peak spectral irradiance S_{peak} (in $W/m^2/\mu m$) was determined to be[12]

$$S_{peak}=0.0001E_{global}^2+1.5768E_{global} \tag{7}$$

The simplified global spectral irradiance $W_{app}(\lambda)$ is given by the following[12]:

$$W_{app}(\lambda)=S_{peak}\frac{W(\lambda,6000)}{\max[W(\lambda,6000)]} \tag{8}$$

The irradiance falling within the spectral range of the receiver $E_{\det}$(in W/m^2) was calculated using Eq. (9)[12],

$$E_{\det}=\int_{\lambda_1}^{\lambda_2}W_{app}(\lambda)d\lambda \tag{9}$$

where λ_1 and λ_2 is the lower and upper spectral limits of the optical band pass filter, respectively. Therefore, the receiver background noise power, which is required to determine the variance of the shot noise in (13), is given by[12]

$$P_{bg} = E_{\det} T_0 A n^2 \qquad (10)$$

where T_0 is the peak filter transmission coefficient.

Fig. 3 presents the spectral distribution of background noise affected by the selected spectrum bands for the CSK scheme. To analyze the performance of the CSK scheme, 3 spectrum bands corresponding to the code numbers (110, 010, 000) were considered[9]. In fig. 3, black line represents the spectral distribution of the modified blackbody radiation model. To evaluate the performance of the outdoor V2I VLC at daytime, this study assumed the worst case scenario when the global irradiance is a maximum ($E_{global} = 1100 mW$). Table 1 lists the detected background noise power per selected spectrum band at the receiver.

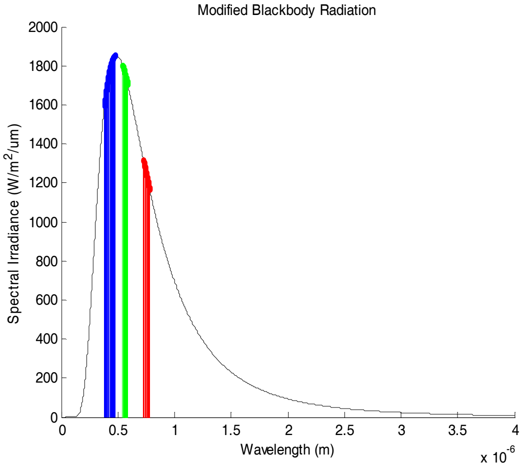


Fig. 3. Spectral distribution of background noise affected by selected color-band for CSK scheme

Table 1. Calculated background noise power affected by selected color-band for CSK scheme

Color-Band	Spectrum Range	$P_{bg}(W)$
Blue	$380nm \sim 478nm$	$31.5mW$
Green	$540nm \sim 588nm$	$15.5mW$
Red	$726nm \sim 780nm$	$12.3mW$

2.4 Total Noise Model

The total noise source affecting the CSK scheme was calculated using the daylight noise model. The Gaussian noise $n(t)$ was assumed to have a total variance N that consists of shot noise, thermal noise, and inter symbol interference P_{rISI} caused by the reflected light signals given as

$$N = \sigma_{shot}^2 + \sigma_{thermal}^2 + \gamma^2 P_{rISI}^2 \qquad (11)$$

The ISI is negligible if the duration of the signal is relatively longer than the channel delay spread[26]. Therefore, the main noise sources become shot and thermal noises. The shot noise variance is given by[11]

$$\sigma_{shot}^2 = 2q\gamma(P_{rSignal} + P_{rISI})B + 2q\gamma P_{bg} I_2 B \qquad (12)$$

where q is the electronic charge, $P_{rSignal}$ is the received signal power, B is the equivalent noise bandwidth, I_2 is the noise bandwidth factor for a rectangular transmitter pulse shape[27], and P_{bg} is the background noise power calculated using eq. (10). Following the analysis of Smith and Personick[29],[30], the thermal noise variance is given as[11]

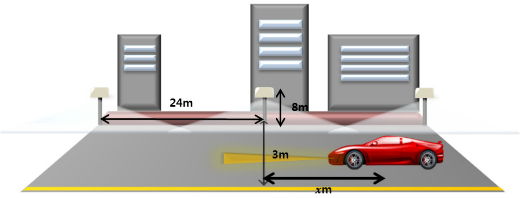
$$\sigma_{thermal}^2 = \frac{8\pi k T_k}{G}\eta A I_2 B^2 + \frac{16\pi^2 k T_k \Gamma}{g_m}\eta^2 A^2 I_3 B^3 \qquad (13)$$

where the first two terms represent the feedback-resistor noise and FET channel noise, respectively. T_k is the absolute temperature, G is the open-loop voltage gain, η is the fixed capacitance of a photo detector per unit area, Γ is the FET channel noise factor, g_m is the FET transconductance, and I_3 is the noise bandwidth factor for a full raised cosine equalized pulse shape[27].

Ⅲ. Simulation Results

3.1 Scenario Setting

This paper presents the simulation result to validate the possibility V2I VLC in a daytime scenario. Fig. 4 shows the V2I scenario in a metropolitan street road. The height of street lamp is $8m$, and the interval between street lamps is $24m$.



x : the horizontal distance between street lamp and vehicle

Fig. 4. V2I scenario in the metropolitan street road

Table 2. Simulation parameters

Parameter	Value	Parameter	Value
A	$0.8\,cm^2$	n	1.5
$T_s(\psi)$	1.0	T_k	$300\,K$
Ψ_c	70°	G	10
γ	$0.53\,A/W$	g_m	$30\,mS$
Γ	1.5	I_2	0.562
η	$112\,pF$	I_3	0.868
$\Phi_{1/2}$	13°	E_{global}	$1100\ W/m^2$

The width of the car lanes is $3m$. The simulation assumed that a car moves horizontally along the lane. Table 2 lists parameter setting for the simulation.

3.2 Simulation Results

The transmitter (street lamp) always faces toward the receiver (vehicle) and receiver was assumed to have been installed vertically to the ground. The transmitting power (P_t) of a street lamp was set to change from $3\,W$ to $6\,W$. Fig. 5 shows the SNR results of the downlink case according to the horizontal distance between the street lamp and vehicle.

As shown in Fig. 5, the transmitted power increases with increasing the SNR performance. From the SNR result, a SNR greater than $15dB$ is possible, even in daytime if the transmitted power of a LED street lamp larger than $5\,W$ can be allocated.

Fig. 6 shows the corresponding BER performance of the CSK downlink scenario according to the distance between street lamps and vehicle in the metropolitan street road scenario. From the result, a BER less than 10^{-3} is possible using the CSK scheme under all road condition at daytime if the transmitting power of the LED street lamp is greater than $6\,W$.

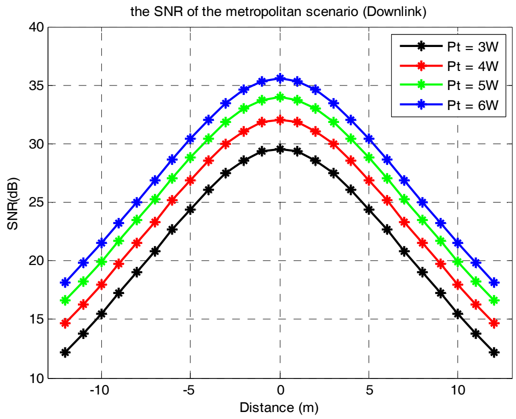


Fig. 5. SNR of the metropolitan street road scenario

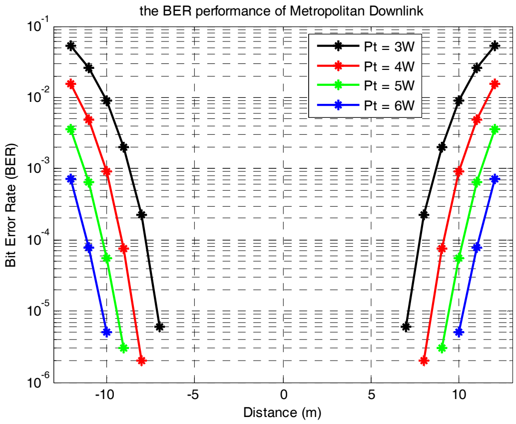


Fig. 6. BER performance according to the horizontal distance in V2I downlink

Ⅳ. Conclusions

This study analyzed the performance of the Color Shift Keying (CSK) scheme under Vehicle-to-Infra (V2I) metropolitan street road to verify the possibility of the proposed scheme as a communication tool for ITS. The capability of the V2I downlink VLC via the CSK scheme at daytime was investigated by modeling daylight noise using the modified blackbody radiation model. Through the simulation, the V2I VLC using the CSK scheme is possible in a metropolitan street road scenario, even in daytime.

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