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SC-FDMA기술을 적용한 WLED 통신시스템

WLED Communication System Using SC-FDMA Techniques

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요약

본 논문에서는 SC-FDMA 기술을 적용한 WLED 통신 시스템을 제안하였다. 기존의 WLED 통신 시스템에서는 OFDM 기술을 이용하여 고속의 통신 기술이 구현 가능한 장점이 있지만, 비선형 왜곡에 의한 전송모드에서 PAPR이 발생함에 따라 시스템 성능이 저하되는 단점을 가진다. 더욱이 WLED 장치에서 PAPR에 따른 peak 전력에 의해 정류기가 갑작스럽게 과부하가 발생되면 사람의 시력뿐만 아니라 WLED 시스템에 큰 손상을 미치게 된다. 이를 해결하고자 OFDM에 비해 상대적으로 낮은 PAPR을 갖는 SC-FDMA 기술을 WLED 시스템에 적용하였다. 컴퓨터 시뮬레이션을 통해 본 논문에서 제안하는 WLED 시스템의 PAPR을 측정하고 서로 다른 변조 기법을 적용하였을 경우의 성능 또한 분석한다.

■ 중심어 : | 가시광통신 | 백색LED | OFDM | SC-FDMA |

Abstract

In this paper, a WLED communication system with SC-FDMA technique is proposed. OFDM is a promising technique to realize high-speed WLED communication system. However, because of the PAPR, the system performance can be significantly compromised by non-linear distortions in the transmission chain. Furthermore, the overload current due to peak signal power lead the WLED equipment over bright which is harmful to equipment life and human's eye. The novel WLED communication system proposed in this paper solved these problems by using SC-FDMA technique which has an inherent low PAPR property. The severity of PAPR performances expressed by CCDF curve and the BER performances under different modulation schemes are analyzed in this paper.

■ keyword : | VLC | WLED | OFDMA | SC-FDMA |

I. INTRODUCTION

LED (lighting emitting diode) offers more advantageous properties than the existing incandescent in terms of high brightness, reliability, lower power consumption and long lifetime. LED is used in full color displays, traffic signals, and many other means of illumination. Now, InGaN based highly efficient

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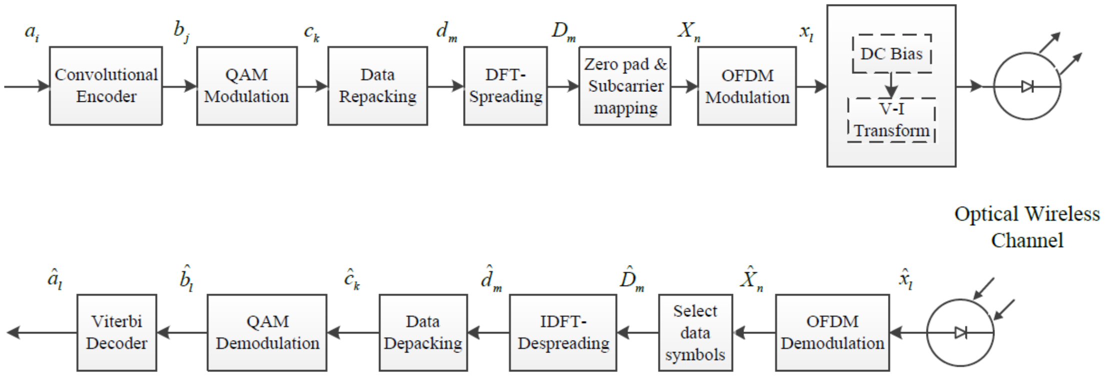

Fig 1. Block diagram of SC-FDMA WLED communication system

blue and green LED has become commercially available. By mixing three primary colors (red, green and blue), we can produce white. This white LED is considered as a strong candidate for the future lighting technology. An indoor visible-light communication (VLC) system utilizing white LED lights has been proposed by many researchers [1-3]. In those proposed systems, the devices are not only used for illuminating rooms but also a short range optical wireless communication system. It is gaining more and more interest in fast-growing markets such as industry automation, in-car communication, and home networking. The proposed systems have following advantages: few shadowing throughout a whole room is enabled by high power and distributed lighting equipment; lighting equipment with white LEDs is easy to install and aesthetically pleasing.

The use of LEDs introduces a major disadvantage: low bandwidth. By using discrete multi-tone transmission technique such as orthogonal frequency division multiplexing (OFDM), it has been shown that such bandwidth limitations can be overcome [4][5]. However, the OFDM signal envelope with its high peak-to-average power ratio (PAPR) is still a design challenge that makes the OFDM signal suffers from in-band and out-bands distortions due to non-linearity introduced at the transmitter. The system performance can be significantly compromised by non-linear distortions. Furthermore, the overload current due to peak signal power lead the WLED device over bright which is harmful to device's life and human's eye.

SC-FDMA utilizes single carrier modulation and frequency domain equalization [6][7]. It has similar performance and essentially the same overall structure as OFDM system, but much lower PAPR. The SC-FDMA system has been adopted by 3GPP LTE standard for uplink multiple access scheme.

In this paper, we propose a new VLC system with SC-FDMA technique and analyze the PAPR of SC-FDMA signals in VLC system. We compared the PAPR of SC-FDMA with that of OFDM using complementary cumulative distribution function (CCDF). Bit error rate (BER) performances are also compared in various situations.

The remainder of this paper is organized as follows: Section II gives an overview of LED transmission system and SC-FDMA. Section III described the proposed system which integrates the LED transmission system. Section IV presents the simulations results.

Finally, conclusions are in section V.

II. Optical Wireless Channel

We assume an optical wireless channel, and this consideration is applied to later analysis.

In Monte Carlo ray-tracing algorithm, every ray is generated at the emitter position with a probability distribution equal to its radiation pattern. The power of each generated ray is initially the source power (1W for example) divided by the number of rays we generated. When the reflection is accorded, a new optical source is considered, and a new ray is generated with a probability distribution provided by the reflection pattern of the surface. This process continues during the simulation time. Finally, the power of the ray is reduced by the reflection coefficient (ρ) of the surface. Phong's model is used to describe the reflection pattern of surfaces [9]. Therefore, the total received power at the time t can be expressed as following,

$$p(t) = \sum_{i=0}^{N_t - 1} p_i(t) \tag{1}$$

where N_t is the number of rays arriving at the receiver at time t, and $p_i(t)$ is the power of i-th ray at the time t. The channel impulse response is given by

$$h(t) = \sum_{k=0}^{K-1} p(t)\delta(t - k\Delta t) \tag{2}$$

where $K = t_max / \Delta t$.

The noise is assumed to be an AWGN (additive white Gaussian noise). Thus, the received signal at the receiver by a photo diode without lens could be expressed as follows

$$r(t) = h(t) \bullet x(t) + n(t) \tag{3}$$

where $r(t)$ represents the received signal current, $h(t)$ represents channel impulse, and $x(t)$ is the transmitted optical pulse, $n(t)$ is the AWGN.

In multi-tone system, the signal could be expressed by matrix form as following,

$$\begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_M \end{bmatrix} = H \bullet \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_M \end{bmatrix} \tag{4}$$

where H is frequency domain channel response and M is the number of used subcarriers in multi-tone system.

III. WLED system with SC-FDMA

1. Transmitter and Receiver

A block diagram of White LED transmission system with SC-FDMA is shown in [Fig 1] First, transmit symbols are generated and encoded by forward error correction (FEC) coding and modulated by 2^P-QAM modulators to generate complex symbols $\{c_k : k = 1, 2, ..., K\}$. The modulation order P depends on channel states and noise level.

Due to the characteristic of LED, the final signals to DC-bias block must be real symbols. previous method in OFDM WLED is to add the complex conjugate of the mirror of the symbols to the latter before computing IFFT in OFDM modulator. This can be simplified to remove the image part of the modulated signal c_k firstly, and add the image part to the latter to generate M symbols $\{d_m : l = 1, 2, ..., M\}$ where $M = 2K$. Since the input symbols are real, after OFDM modulation, the output symbols are also be real.

After data repacking, the time domain data symbols are transformed to frequency domain by M-points FFT operation, by using a modified FFT process, which will be introduced in next section, the complexity can be reduced to half. The output symbols D_m is shown as following:

$$D_m = \sum_{p=0}^{M-1} d_p e^{-j2\pi pm/L}. \quad (5)$$

The operation of N-points IFFT in OFDM modulation block, where N is much larger than M. When $Q=N/M$, Q denotes the band spreading factor.

$$x_n = \frac{1}{N}\sum_{q=0}^{N-1} X_q e^{j2\pi qn/N}, \quad (6)$$

where $\{X_q : q=0,1,\cdots,N-1\}$ are the frequency domain samples after subrarrier mapping. subcarrier mapping has to be done before going through OFDM modulator. Interleaved FDMA (IFDMA) and localized FDMA (LFDMA) subcarrier mapping schemes are considered in this paper, which are illustrated in [6]. In IFDMA, DFT with equidistance between occupied subcarriers, whereas consecutive subcarriers are occupied by the DFT outputs in the LFDMA. At each of the user equipment, zeros occupy unused subcarriers. For IFDMA,

$$X_n = \begin{cases} D_{n/Q}, & l = Q \bullet m (0 \le m \le M-1) \\ 0 \quad , & otherwise \end{cases} \quad (7)$$

and for LFDMA,

$$X_n = \begin{cases} D_n, & 0 \le n \le M-1) \\ 0 \quad , & otherwise \end{cases} \quad (8)$$

After insert cyclic prefix, the real value baseband signal is modulated onto the instantaneous power of the optical carrier resulting in intensity modulation. The power amplifier is the last stage driving the antenna in radio frequency communication. However, it was changed in LED based communication. The signals need to be biased to avoid low power clipping before applying the signal for intensity modulation. The biasing point should be carefully selected to consider the maximum allowable forward current and minimize signal clipping and magnitude distortion [8].

At the receiver, the received data delete CP and OFDM demodulated by OFDM demodulator. The FFT operation here is also a modified FFT scheme to reduce the computation complexity. Data symbols are selected from allocated subcarriers. After IDFT despreading and data depacking, the transmit signal can be recovered by 2^P-QAM demodulator and FEC decoding.

2. Modified FFT algorithm for real sequence

Assume $g(n)$ is a real-valued sequence of $2N$ points. We outline the equations involved in obtaining the $2N$-point DFT (FFT) of $g(n)$ from the computation of one N-point complex-valued DFT. First. we subdivide the $2N$-point real sequence into two N-point sequence as follows:

$$x_1(n) = g(2n) \quad (9)$$

$$x_2(n) = g(2n+1) \quad (10)$$

where $0 \le n \le N-1$. And define $x(n)$ to be the N-point complex-valued sequence:

$$x(n) = x_1(n) + jx_2(n) \quad (11)$$

The DFT (FFT) of $g(n)$ can be computed using

$$G(k) = X(k)A(k) + X^{*}(N-k)B(k) \tag{12}$$

where $k = 0, 1, ..., N-1$, and $X(N) = X(0)$.

$$A(k) = (1 - je^{-j2\pi k/2N})/2 \tag{13}$$

$$B(k) = (1 + je^{-j2\pi k/2N})/2 \tag{14}$$

3. PAPR of SC-FDMA WLED system

In our research, we use a raised-cosine pulse, which is widely used pulse shape in wireless communications, defined as follows in the time domain [8], where T is symbol time, α is the roll-off factor which ranges between 0 and 1.

$$r(t) = \sin(\pi \frac{t}{T}) = \frac{\cos\left(\frac{\pi \alpha t}{T}\right)}{1 - \frac{4\alpha^2 t^2}{T^2}} \tag{15}$$

The PAPR of the transmit signal can be expressed as

$$PAPR = \frac{\max |x(t)|^2}{\frac{1}{NT}\int_0^{NT} |x(t)|^2 dt} \tag{16}$$

Without pulse shaping, that is, using rectangular pulse shaping, symbol rate sampling will give the same PAPR as the continuous case since the SC-FDMA signal is modulated over a single carrier. Thus, PAPR without pulse shaping with symbol rate sampling can be expresses as follows [9],

$$PAPR = \frac{\max |x_n|^2}{\frac{1}{N}\sum_{n=0}^{N-1} |x_n|^2} \tag{17}$$

Ⅳ. NUMERICAL RESULTS

We have evaluated the detrimental effects of LOS channel and AWGN noise over the proposed WLED system for M-QAM modulation schemes (QPSK, 16QAM). In the simulations, the total number of subcarriers M was set to 256, input data block size N is set to 64, and Q is 4. Two situations have been considered: The LED amplifier back-off value of 3dB and 6dB. The detailed simulation parameters are listed in [Table 1] CCDF (complementary cumulative distribution function) of PAPR, which is the probability that PAPR is higher than a certain PAPR value PAPR0 (Pr{PAPR>PAPR0}), is calculated by Monte Carlo simulation. CCDFs of PAPR for IFDMA,

Table 1. Simulation parameters

Parameters	Value
DFT size	64
IFFT size	256
CP length	16
LED back-off	3dB, 12dB
Modulation scheme	QPSK, 16QAM
Channel	LOS
Pulse shaping	Raised cosine filter

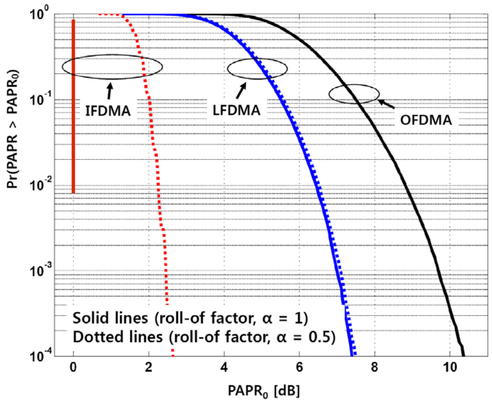

Fig 2. Comparison of CCDF of PAPR for IFDMA, LFDMA,and OFDMA with QPSK

LFDMA and in the case of OFDMA, was assumed and 8 times oversampling was used when calculating PAPR. No pulse shaping was applied in the case of OFDMA.

In [Fig 2], plots of CCDF of PAPR for IFDMA, LFDMA, and OFDMA for QPSK are shown. First, in case of no pulse shaping, IFDMA has lower PAPR than the case of OFDMA by almost 9 dB and LFDMA has lower PAPR than that of OFDMA 2.5 dB approximately, with the probability of PAPR exceeded the PAPR0 less than 0.1-percentage. With raised-cosine pulse shaping with roll off factor of 0.5, it can be seen that PAPR increases significantly of IFDMA whereas PAPR of LFDMA hardly increases. We can see that IFDMA and LFDMA have lower PAPR than OFDMA consistently.

[Fig 3] shows link level performances of White LED communication system with QPSK modulation, and when signal is clipped due to White LED device's characteristic. It is observed that when clipping occurs at 12 dB level above the normalized power, the performance degrades slightly because the probability of peak power exceeds 12 dB level is small. However, the performance degrades significantly when clipping occurs at 3 dB level.

[Fig 4] shows the similar results while the digital signals are modulated by 16-QAM. The performance degrades slightly when clipping occurs at 12 dB level and it degrades significantly when clipping occurs at 3 dB level. On the other hand, all performances of 16-QAM degrade due to the power per bit degrades comparing to the system which modulated by QPSK.

In the simulations above, the clipping generates both in-band and out-band frequency components which take effects to the orthogonality between subcarriers, therefore the BER performances degrade a lot. In any situation above, the WLED communication system with SC-FDMA technique outperforms that with OFDM.

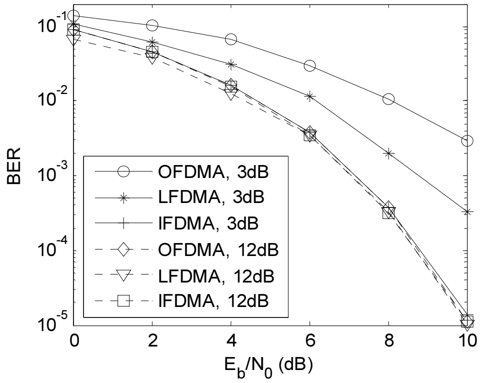

Fig 3. BER performance, VLC+SC-FDMA (QPSK)

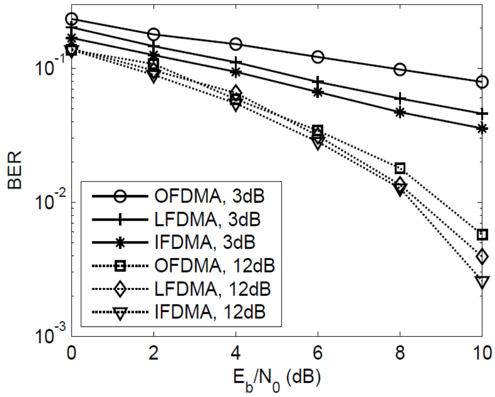

Fig 4. BER performance, VLC+SC-FDMA(16-QAM)

V. CONCLUSIONS

A novel WLED communication system with SC-FDMA was proposed. The PAPR performance and BER performance are compared respectively under various considerations. Our research indicates that White LED communication system combined with SC-FDMA outperforms that which combined with OFDM when non-linear distortion is considered. Moreover, the low PAPR system provided the devices over bright due to over high current which caused by peak signal power. This guarantees the LED device's lifetime and harmless to human's eye as well.

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