Adaptive spreading factor assignment for VLC-OFDM-IDMA with PIC

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Abstract: This letter proposes a signal-to-Noise Ratio (SNR) based spreading factor adaptation for orthogonal frequency division multiple interleave division multiple access (OFDM-IDMA) incorporated with parallel interference cancellation (PIC) on visible light communication (VLC) systems. Orthogonal variable spread factor (OVSF) code is an effective solution to eliminate multiple access interference (MAI) in exchange for spectral resource consumption. Channel ranking based spreading factor optimization can maximize the system throughput performance. The major contribution of this letter is to achieve its adaptive allocation according to the estimated value of SNR. The computer simulation results clarify its effectiveness.

Keywords: VLC, OFDM, OVSF codes, channel ranking

Classification: Wireless Communication Technologies

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1 Introduction

Visible light communication (VLC) has received significant attention in recent years as an alternative to wireless communication technology that operates in the RF band [1]. In VLC, optical signals are spatially multiplexed at the receiver side. Orthogonal frequency division multiplexing (OFDM) and interleave division multiple access (IDMA) have already been proposed [2]. To further improve the multiuser detection capability of OFDM-IDMA, an orthogonal variable spread factor (OVSF) codes [3, 4, 5] and parallel interference cancellation (PIC) [6] are supportive. OVSF codes spread the mapped symbol to some subcarriers with a specified sequence orthogonal to all users [7, 8, 9]. We have previously studied optimal combinations of spread factors based on channel gains for each user in order to maximize overall throughput performance [6]. For more practical use, this letter provides an adaptive spread factor allocation algorithm based on the estimated signal-to-noise power ratio (SNR). The combinations of spread factors are determined with reference to the predefined throughput–SNR characteristics. Simulative evaluation makes it possible to verify that the proposed system works and maximizes throughput performance.
2 System model: VLC-OFDM-IDMA with PIC

In VLC-OFDM, the means of transmission between the transmitter and receiver is visible light, so the transceiver needs to generate signals only in the amplitude range [2]. To support VLC modulation, the frequency-domain symbol sequence would have to be rearranged such that its time-domain transformation becomes a real-valued signal [10, 11]. Let $N_c$ and $X_u(k)$ ($k \in \{0, 1, \cdots, N_c - 1\}$) denote the number of subcarriers and the mapped symbol of the $u$-th user whose information data is interleaved with the specified pattern, OFDM symbol for intensity modulation (IM) can be generated as,

$$X_u(2N_c - k) = X_u^*(k),$$
$$X_u(0) = X_u(N_c) = 0,$$

where $(\cdot)^*$ stands for the complex conjugate. The output signal after inverse discrete Fourier transform (IDFT) is expressed by

$$s_u(t) = \sum_{k=0}^{2N_c-1} X_u(k) e^{j2\pi kt/2N_c},$$

$s_u(t)$ is a time-domain OFDM having real values suitable for IM and visible light transmission. The photodetector receives the signal but it contains interference from other transmitters. The received symbol $r(k)$ at the $k$-th subcarrier is given as,

$$r(k) = \sum_{l=1}^{U} H_l(k)X_l(k) + n(k),$$

where $U$ is the number of users, $H_l(k)$ is the channel coefficient at the $k$-th subcarrier of the $l$-th user, and $n(k)$ is an additive white Gaussian noise (AWGN). Rewrite (4) for the $m$-th user as,

$$r(k) = H_m(k)X_m(k) + \sum_{l=1,l\neq m}^{U} H_l(k)X_l(k) + n(k),$$

$$= H_m(k)X_m(k) + \gamma(k).$$

Here, multiple access interference (MAI) is replaced with $\gamma$ and it can be removed by PIC [6]. As the number of users increases, the impact of MAI also becomes significant. Forward error correction (FEC) and OVSF code are generally utilized to solve this problem. In addition, adaptive optimization is the key technology to achieve high-quality communications [12]. This letter focused on the OVSF code and its adaptive optimization to maximize throughput performance.

3 Proposed framework

3.1 Orthogonal variable spreading code and channel ranking

In OVSF codes, orthogonality is guaranteed between the codes even with the different spreading factors. Doubling the spreading factor halves the information bits of data to be transmitted. Appropriate use of OVSF codes facilitates multiuser detection [13]. There is a trade-off between the MAI suppression capability and
throughput performance. We have already introduced channel ranking to assist the MAI suppression function to maximize the throughput performance [6]. When the influence of MAI is significant, a large spreading factor should be assigned and vice versa. Based on the estimated CSI, the path gain of each user is calculated and sorted in descending order. Optimal spreading factors are then assigned to each user.

3.2 Adaptive spreading factor assignment based on SNR estimation

Our previous study investigated that the possibility of determining the optimal spreading factors based on average SNR in users [6]. The key proposal of this work is to adaptively assign OVSF codes based on the predefined relationship between the spreading factors and SNR in order to maximize the system throughput performance. As shown in Fig. 1(a), the receiver determines the combination of spreading factor based on the estimated SNR and instantaneous channel gain of each user. The transmitters (users) then use the spread factor fed by the receiver.

Figure 1(b) shows the combination of spreading factors that can achieve the maximum throughput performance in each SNR region. From (4), estimate values of average SNR at the receiver side, \( \Gamma_{\text{est}} \) can be calculated as,

\[
\Gamma_{\text{est}} = \frac{1}{U} \sum_{k=0}^{N_c-1} |r(k)|^2.
\]

In the proposed scheme, an appropriate spreading factor is assigned to each user according to instantaneous estimated SNR in (6) and predefined in Fig. 1(b).

4 Computer simulation

4.1 Simulation parameters

Table I lists the simulation parameters. The proposed scheme assigns spreading factors as 2, 4, 8, and 16 for each user and optimizes them based on estimated instantaneous SNR. The terminal bit of the convolution code is 64. The propagation environment is assumed to be the line-of-sight (LOS), and the channel coefficient, \( H \), is defined as [1],

\[
H = \frac{(e + 1)A}{2\pi d^2} \cos^e(\phi)\Gamma(\theta)G(\theta)\cos(\theta),
\]
Table I. Simulation parameters.

| Parameters                      | Values                     |
|---------------------------------|----------------------------|
| Transmission scheme             | VLC-OFDM-IDMA              |
| Modulation                      | QPSK                       |
| Transmission bandwidth          | 20 MHz                     |
| Number of subcarriers           | 128                        |
| FFT size                        | 128                        |
| Guard Interval                  | 16                         |
| Number of pilot symbols         | 2                          |
| Number of data symbols          | 64                         |
| Channel model                   | Line of sight              |
| Number of users                 | 4                          |
| Number of PIC iterations        | 2                          |
| Error correction code           | Convolutional code, rate 1/2 |
| Spreading factor                | 2, 4, 8, 16                |
| Input data bits                 | 1888, 880, 376, 124        |
| Interleaver type                | Random                     |

where $\phi$ is the angle of irradiance, $\theta$ is the angle of incidence, $T(\theta)$ and $G(\theta)$ denote the gains of an optical filter and concentrator, respectively. $e$ is the order of Lambertian emission. This evaluation assumes $T(\theta)$, $G(\theta)$, and $e$ are 1.0. Users are located in the distance $d$ from 1 ~ 4 m range, which provides the difference of channel gain among them. Angles $\theta$ and $\phi$ are with randomly determined in $0 \sim \pi/3$ rad. The evaluation metric is the throughput performance; one transmission frame is composed of 64 OFDM symbols.

4.2 Simulation results
First, Fig. 2(a) plots throughput performances versus transmit SNR with various spreading factor patterns, creating the spreading factor assignment table in Fig. 1(b). It shows the sum-rate performance of all four users. It demonstrates that the optimal

![Fig. 2. Simulation results.](image)

(a) Sum-throughput performances with various spreading factor.

(b) Sum-throughput performances cases for A and B.
combination of spreading factors can be determined by the average SNR. The maximum-value and throughput performance in the low SNR region differ. The optimum spreading factor is assigned according to the SNR value.

Figure 2(b) then presents throughput performance obtained by the proposed scheme. The dashed line shows the envelope of the throughput values of Fig. 2(a) as a reference. This result verifies our proposed adaptive spreading factor assignment can maximize the throughput performance at given SNR conditions. Actual SNR varies depending on the users’ location. To maximize the throughput performance, it is necessary to assign the spreading factor according to the instantaneous SNR. The reference (dashed line) determines the spreading factor assignment fixedly as regard average SNR. On the other hand, the proposed method can refer to the instantaneous SNR. Therefore, it shows superior performance compare to the reference method in all SNR regions.

5 Discussion

Adaptive control methods based on average SNR are superior in terms of computational cost and are commonly used. Since this method cannot account for instantaneous SNR variations, there is still a potential for improvement in terms of maximum throughput. In particular, this letter deals with adaptive control in multiple users; thus, there is an instantaneous SNR variation for each user. In the proposed method, the improvement by considering the instantaneous SNR can be obtained for each user, and the throughput can be significantly improved.

The estimation error of SNR is an important factor that affects the communication performance. When adaptive control is performed using average SNR, it is strongly affected by this error because of the error enhancement that occurs during averaging. However, when the control is performed using instantaneous SNR, the error can be rounded off, and this effect can be minimized because the control is performed successively. In this letter, SNR used for the control is idealized, but from the above, the proposed method is effective even in an environment where estimation error exists.

6 Conclusion

This letter proposed the adaptive spreading factor assignment by the instantaneous SNR estimation and channel ranking to further improve the throughput performance of the VLC-OFDM-IDMA system. Simulated evaluation justified its effectiveness in the scenario of four users sharing the visible light communication channel. We can conclude that our proposed method is one of the most effective solutions for high system functionality.