An ICA based MIMO-OFDM VLC scheme

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In this paper, we propose a novel ICA based MIMO-OFDM VLC scheme, where ICA is applied to convert the MIMO-OFDM channel into several SISO-OFDM channels to reduce computational complexity in channel estimation, without any spectral overhead. Besides, the FM is first investigated to further modulate the OFDM symbols to eliminate the correlation of the signals, so as to improve the separation performance of the ICA algorithm. In the $4 \times 4$ MIMO-OFDM VLC simulation experiment, LOS path and NLOS paths are both considered, each transmitting signal at 100 Mb/s. Simulation results show that the BER of the proposed scheme reaches the $10^{-5}$ level at SNR $= 20$ dB, which is a large improvement compared to the traditional schemes.

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1. Introduction

VISIBLE light communications (VLC) is becoming popular because of the ability to provide illumination and data communications simultaneously. Meanwhile, VLC faces many challenges, such as the limited LED modulation bandwidth and non-line-of-sight (NLOS), causing inter-symbol interference (ISI) for high-speed transmission \cite{1,2}. To combat these, multiple-input multiple-output (MIMO) is considered to be a promising technique for reliable high data-rate VLC systems and provide uniform room illumination \cite{3}.

OFDM is found to be the most advantageous modulation scheme for digital systems, in fact has been adopted in several communication standards such as digital audio broadcasting, digital video broadcasting, broadband wireless local area network, and has found favor for VLC \cite{4,5}. Parallel data transmission by orthogonal subcarriers offers overall high data rates, high bandwidth efficiency, and reduced complexity in equalizers. Owing to its long symbol duration, OFDM is inherently very robust against multipath induced ISI, which is a major concern in indoor VLC \cite{6}. Besides, using multiple antennas at both the transmitter and receiver to provide the spatial diversity and multiplexing gains, the MIMO systems have been presented in high data rate systems \cite{7–10}. So, both the OFDM technique and MIMO technique are two key methodologies to fulfill high data-rate VLC systems.

Channel estimation is necessary for signal detection in OFDM systems to obtain great communication performance \cite{11,12}. Channel estimation methods have been investigated extensively in the past. Most methods in literatures fall into three categories: training-based or pilot-based, blind and semi-blind methods \cite{13}. In MIMO systems, while, the channel is so much more complicated than in single-input single-output (SISO) systems that these methods would reduce the communication efficiency of the system due to the training (or pilot) overhead or require huge computational complexity to obtain accurate statistics \cite{14}, and more importantly, these approaches did not improve the communication performance significantly. All in all, the existing channel estimation methods result in significant performance degradation and require huge computational complexity in MIMO-OFDM systems compared to in SISO-OFDM systems.

In this paper, we propose a novel MIMO-OFDM VLC scheme. The basic thought is to apply the existing blind source separation (BSS) algorithm to the signal detection in MIMO-OFDM VLC systems. Independent component analysis (ICA) is one of the most important and efficient blind source separation techniques which extract statistically independent components from a set of measured signals \cite{15}, and ICA algorithm is adopted in the proposed scheme. In MIMO system, the received signals are the mixing of sent signals. In the proposed scheme, ICA algorithm is applied to find a separation matrix to separate the mixed signals. Each separated signal contains only one sending end signal. Therefore, the MIMO channel is converted into several SISO channels to simplify channel estimation and get satisfactory communication performance.
In order to improve the separation performance of ICA algorithm when used in the communication system, signals of the sending end are designed into irrelevant with each other. Furthermore, the factors are studied influencing the performance of ICA algorithm. An MIMO-OFDM indoor VLC model is built by the channel characteristics of VLC communication system. Simulation results and performance analysis are also provided. Finally, we conclude the paper with some remarks.

2. System model

2.1. Indoor VLC geometric distribution model

There is a large amount of unregulated spectrum resource for optical wireless communication, which is a different situation than it in radio frequency (RF) wireless communication. The small modulation bandwidth of the single light emitting diode (LED) and the numerous LED light sources are existed in indoor [16]. All of this provided the conditions to achieve MIMO-OFDM VLC.

The indoor geometric distribution model of the MIMO-OFDM VLC system is shown in Fig. 1. In Fig. 1, Nt LEDs as the signal sending ends and the receiver includes Nr receiving nodes. The solid lines indicate the LOS transmission pathway and the dotted lines represent the NLOS transmission pathway. We assume that the LEDs are evenly distributed on the ceiling, H, W and L denote the height, width and length of the room in the indoor geometric distribution model.

In the MIMO-OFDM VLC system, the receiving signals of the receiver include both line-of-sight (LOS) and NLOS signals from the sending end [17]. So, the communication process of Fig. 1 can be described as:

\[ R = HX + N \]  

(1)

Where R is received signal matrix, which is composed of Nr signal vector received by the Nr receiving nodes. X is the transmitted signal matrix which is composed of Nt signal vector sent by the Nt sending ends, and N is the additive Gaussian white noise (AWGN) matrix. H is the Nt \times Nr channel matrix as:

\[
H = \begin{bmatrix}
    h_{11}(t) & \ldots & h_{1N_r}(t) \\
    \vdots & \ddots & \vdots \\
    h_{N_t1}(t) & \ldots & h_{N_tN_r}(t)
\end{bmatrix}
\]  

(2)

Where \( h_{ij}(t) \) denotes the subchannel from the \( j \)-th sending end to the \( i \)-th receiving node.

2.2. Indoor MIMO-OFDM VLC scheme

Channel estimation methods have been extended to MIMO-OFDM cases such as least square (LS) and minimum mean square error (MMSE) based [18]. Although these methods did not achieve good performance due to the complexity of the channel matrix shown in Eq. (2). We expect to develop an MIMO-OFDM VLC scheme with low complexity and great communication performance. The basic thought is to apply the ICA algorithm to separate the received mixing signals to convert the MIMO-OFDM channel into several SISO-OFDM channels. Then, the existing SISO-OFDM channel estimation methods can be used in the MIMO-OFDM system directly and effective. The block diagram of the proposed MIMO-OFDM VLC scheme is shown in Fig. 2.

As shown in Fig. 2. At transmitter, the scheme is divided into three steps. Step 1: The input data is split into Nr-parallel bit streams \( x_i (i=1,\ldots,N_r;X=[x_1;x_2;\ldots]) \), one for each transmitter (TX) path. Step 2: In each path, the bit stream is passed to an OFDM modulator. The modulated signals are loaded into a digital-to-analog converter (DAC). Step 3: Then the OFDM symbol is passed to an analog modulator. The analog modulator is used to reduce the correlation between signals on different sending ends (studied in Section 3). The output of this modulator added a DC-bias current and the resulting waveform is applied to the LED acting as an optical transmitter.

At receiver, the scheme is divided into three steps. Step 1: Light from the LED units propagates to the Nr receiving nodes (RX). The received signals R are the combination of all \( x_i \). This process is expressed by Eq. (1).

Step 2: In order to decompose the MIMO-OFDM system to several SISO-OFDM systems that are independent of each other, the ICA technique is first applied to separate the signals. The ICA algorithm is to find a separation matrix \( W^T \) to maximize the mutual independence of the received signals. Detail is as follows:

\[ Y = W^T R = W^T H X + W^T N \]  

(3)

Where Y is the separated signal matrix and \( W^T \) is the separation matrix. Let \( E = W^T H, Z = W^T N \) in Eq. (3), the equation can be rewritten as follows:

\[ Y = EX + Z \]  

(4)

The element in (4) can be further expanded into:

\[
\begin{bmatrix}
    y_1 \\
    y_2 \\
    \vdots \\
    y_r
\end{bmatrix} =
\begin{bmatrix}
    \mathbf{e}_{11} & \mathbf{e}_{12} & \ldots & \mathbf{e}_{1N_r} \\
    \mathbf{e}_{21} & \mathbf{e}_{22} & \ldots & \mathbf{e}_{2N_r} \\
    \vdots & \vdots & \ddots & \vdots \\
    \mathbf{e}_{r1} & \mathbf{e}_{r2} & \ldots & \mathbf{e}_{rN_r}
\end{bmatrix}
\begin{bmatrix}
    x_1 \\
    x_2 \\
    \vdots \\
    x_r
\end{bmatrix} +
\begin{bmatrix}
    z_1 \\
    z_2 \\
    \vdots \\
    z_r
\end{bmatrix}
\]  

(5)

Where \( r=N_r, t=N_t \), and

\[
\begin{bmatrix}
    y_1 \\
    y_2 \\
    \vdots \\
    y_r
\end{bmatrix} = E \begin{bmatrix}
    x_1 \\
    x_2 \\
    \vdots \\
    x_r
\end{bmatrix}, X = \begin{bmatrix}
    x_1 \\
    x_2 \\
    \vdots \\
    x_r
\end{bmatrix}, Z = \begin{bmatrix}
    z_1 \\
    z_2 \\
    \vdots \\
    z_r
\end{bmatrix}
\]  

(6)

Then in (6), there is a dominant value existing in each row of \( E \). The dominant value is the value much larger than the other. That is to say, each component of \( Y \) is dominated by only one component of \( X \). So, \( Y \) can be seen as the estimation of \( X \). The
mathematical express as:

\[ y_i = a_j x_j + \sum_{k=1}^{N} a_k x_k + z_i; \quad j \neq k, \quad a_j > a_k \]  

(7)

Where, \( y_i \) is the separated signal, \( x_j \) and \( x_k \) are the sending signals, \( z_i \) is the linear transformation of the AWGN. The reason \( y_i \) can be seen as the restoration of \( x_j \) is that the ICA algorithm act the key to making \( a_j > a_k \), and more detailed analyses are described in Section 3.

Step 3: then the separated signals \( Y \) can be seen as the composition of several SISO-OFDM signals independently transmitted from the sending end, and the SISO-OFDM channel estimation modes are used to further improve the performance after ICA separation.

3. ICA technique analysis and system improving

3.1. ICA technique analysis

Although the application of ICA in MIMO-OFDM VLC has significant advantages, there are a lot of problems to be resolved. The basic principle of ICA technique is statistical independence. While, it is impossible to measure the independence among signals. In practice, the independence between variables in ICA algorithm is measured by non-Gauss difference nonlinear irrelevance and mutual information [19]. In order to further study the specific factors which may influence the separation of ICA algorithm, the basic steps of ICA algorithm is shown in Table 1.

Whitening in step 1 is to find the components are uncorrelated. It means that the received signals must contain the signals are mutually uncorrelated. In conclusion, the ICA algorithm requires that the source signals (transmitted signals) are mutually uncorrelated.

As shown in steps 3–4, the independence is measured by non-Gauss. Therefore, the independence measure is not the influence factors due to the signals in VLC system are non-Gaussian signals. What’s more, because the degree of non-Gaussian is measured by high-order cumulant and the high order cumulant of Gaussian random variable is 0, ICA algorithm can theoretically remove Gaussian noise. Therefore, we expect that the separated signals have a higher SNR than the received signal. This is also an advantage of the ICA used in the proposed scheme.

3.2. System improving

In order to improve the separation performance of ICA, we want that the correlation between the transmitted signals can be minimized to improve the performance of ICA algorithm. In MIMO-OFDM VLC system, the parallel bits are unavoidably correlated. Theoretically, OFDM modulation will enhance the correlation coefficient because of the OFDM modulators with the same parameter in different paths. Then the analog modulators are designed to reduce the correlation between signals. The experiment results shown in Table 2 verified this inference.

In Table 2, where steps denote the signal form in different steps in Fig. 2; correlation denotes correlation between signals; performance denotes the separation performance of the ICA algorithm which is measured by the correlation between the separated signal and the source signal. Because of the correlation can be measured by the correlation coefficient in ICA algorithm [20], the correlation is measured by correlation coefficient in the experiment.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Parallel sequence</th>
<th>OFDM</th>
<th>AM/FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>0.0520</td>
<td>0.0752</td>
<td>0.0763/0.0065</td>
</tr>
<tr>
<td>Performance</td>
<td>0.7025</td>
<td>0.6135</td>
<td>0.5938/0.9982</td>
</tr>
</tbody>
</table>

Fig. 2. MIMO-OFDM VLC scheme block diagram.
Experiment result shows a strong correlation between the parallel sequences. After OFDM modulation, the correlation between OFDM signals is increased, and then to AM modulation, the correlation between modulated signals is further increased. While, when the OFDM signals are passed to FM modulation, the correlation between modulated signals reduced evidently. The separation performance presents an opposite tendency. So, we can draw the conclusion that the application of FM in this system can reduce the correlation between signals to improve the separation performance of ICA.

In order to go deep into the origin of the separation performance, it is necessary to theoretically analyze whether the separated signals meet the communication requirements. As mentioned in Section 2, the relationship between separated signals and the transmitted signals can be expressed as Eq. (7). The correlation coefficient express as

\[ C(x_1, x_2) = \frac{E(x_1x_2) - E(x_1)E(x_2)}{\sqrt{D(x_1)D(x_2)}} \] (8)

Where \( C(x_1, x_2) \) is the correlation coefficient between \( x_1 \) and \( x_2 \); \( E(\bullet) \) denotes the mathematical expectation; \( D(\bullet) \) denotes variance. In Eq. (7), \( y_i \) is the estimation of \( x_i \), substituting \( y_i \) and \( x_i \) into formula (8):

\[ C(x_j, y_j) = \frac{E((x_j)(a_jx_j + \delta)) - E(x_j)E(a_jx_j + \delta)}{\sqrt{D(x_j)} \sqrt{D(a_jx_j + \delta)}}; \ j \neq k \] (9)

Where

\[ \delta = \sum_{k=1}^{N_t} a_k x_k + Z_i \] (10)

With theorem: \( C(x, y) = 1 \), then \( y = ax + b \) (a and b are constant). In practice, we could consider that \( y_i \) is the linear transformation of \( x_i \) and \( \delta \) can be seen as a constant if \( C(x_i, y_i) \approx 1 \) in Eq. (9). What’s more, in high signal-noise ratio (SNR) condition, Eq. (10) can be simplified as:

\[ \delta = \sum_{k=1}^{N_t} a_k x_k \] (11)

So, \( a_j > a_k \) is the unique solution to make \( \delta \) as constant. Then the relationship between \( y_i \) and \( x_j \) is \( y_i \approx a_jx_j \) on the condition of \( C(x_j, y_j) \approx 1 \) and high SNR. In the above experiment result, the performance reached 0.9982 when the FM modulation is used. It means that the received mixing FM signals can be perfect separated by ICA technique in the proposed MIMO-OFDM VLC scheme on condition of high SNR. So, FM is adopted as the analog modulation in the proposed MIMO-OFDM VLC scheme. The SISO-OFDM channel estimation modes can be used to eliminate the effect of \( a_i \) in Eq. (7). The performance of the proposed scheme is studied in Section 4.

### 4. System simulation

#### 4.1. System description

In this section, the performance of the proposed ICA based MIMO-OFDM VLC scheme is evaluated by simulations. The system setup shown in Figs. 1 and 2 consists of four independent Txs, and four independent RXs. Transmitters are fed with the cyclic and independent random data of length \( 2^{20} \). Rician block fading channel model is employed because of the LOS component and NLOS component are existed in indoor VLC [20]. Single reflection path and second reflection path are considered. The LED light source is seen as a point source. All system parameters are given in Table 3. Since the VLC channel has a considerable greater channel bandwidth, we did not consider the bandwidth limitation seriously.

#### 4.2. Simulation procedure

We assume that the LEDs are evenly distributed on the ceiling and the position of receiver is set at the central of the room, and each of the LEDs has the same out power. The delay of the reflected signals are calculated according to the received position and room area, as the input parameters of Rician block fading channel model.

By setting different reflected signal intensity, the influence on the performance of the proposed system scheme caused by the reflected signals (NLOS signals) is analyzed. The position of the receiver in the central and corner of the room are simulated respectively. We also illustrate the bit error rate (BER) performance of the proposed ICA based MIMO-OFDM VLC scheme. The BER performances of the channel estimation based schemes are shown for comparison.

#### 4.3. Simulation result and analysis

To begin with, we first examine the influence on the performance of the proposed system scheme caused by the reflected signals (NLOS signals). Fig. 3 shows the BER performance on different reflected signal strength. The simulation context is SNR=25 dB, LS based SISO-OFDM channel estimation method, and the receiver is placed in the central of the room. The intensity of the NLOS signal is measured by the ratio to the LOS. The single reflection intensity (R1) is defined as the intensity of the single reflection signal ratio to the LOS signal at the receiving nodes. Likewise, the second reflection intensity (R2) is defined as the intensity of the second reflection signal ratio to the LOS signal at the receiving nodes.

It is observed from Fig. 3 that the intensity of reflected signal can badly affect the system’s performance when R1 > −10 dB and R2 > −00 dB. When R1 > −20 dB and R2 > −200 dB, the proposed scheme can achieve excellent performance with a BER less than \( 10^{-4} \). Fortunately, it is not difficult to meet R1 > −20 dB and R2 > −200 dB through reasonable arrangements for LED arrays. So, we can conclude that the proposed scheme is feasible.
To get a simpler and more intuitive understanding of this, the signals at TX and RX are shown in Fig. 4 when RI1 = -20 dB, RI2 = -200 dB, SNR = 25 dB and LS is used. Fig. 4 shows the time signals of TX and RX at different processing stages. Fig. 4(a) shows the signals at 4 × LED Sending Ends, Fig. 4(b) shows the received mixing signals which received by the 4 × Receiving Nodes. From the graph we can see it obviously that the received signals have a serious distortion. While, as shown in Fig. 4(c), signals after ICA separation are basically can be restored to the source signals with some amplitude and phase changes. However, the changes of the phase do not influence the proposed communication scheme. In order to eliminate amplitude distortion, each separated signal is sent into an independent OFDM demodulator with LS channel estimation. The constellations of RXs shown in Fig. 4(d) indicate that the system can achieve the communication. So, the simulation results demonstrate that the proposed ICA based MIMO-OFDM

![Fig. 3. BER performance versus reflected signal intensity.](image)

![Fig. 4. Communication signal processing: (a) the transmitted signals, (b) the received signals, (c) the separated signals and (d) the constellations of the RXs.](image)
VLC scheme is perfect.

Next, we measured the BER performance versus different analog modulations used in the proposed scheme. For the purpose of comparison, the method without analog modulation is also plotted. The results are depicted in Fig. 5. Simulation environment: RI1 = −20 dB, RI2 = −200 dB, LS channel estimation.

In Fig. 5, FM denotes the frequency modulation, AM denotes the amplitude modulation, PM denotes the phase modulation, NO denotes without analog modulation. It is shown that the FM based approach outperforms the others significantly, while the PM based approach outperforms the AM approach slightly, the AM based approach has no performance improvement in contrast to without analog modulation. At SNR = 20 dB, there are error floors at BER = 10−5 for the case of FM used in the proposed scheme which is far less than the level at BER = 10−2 for the case of without analog modulation. The performance improvement is due to the weaker relation of the FM signals which improved the ICA separation performance, as discussed in Section 3.

5. Compare the proposed scheme with the conventional schemes

5.1. BER performance and efficiency analysis

In this section, the performances of the proposed scheme are compared with the conventional MIMO-OFDM schemes. The traditional schemes are based on channel estimation such as LS and MMSE, and, compared to the proposed, no analog modulation and ICA employed in the tradition schemes. In the simulation, the system parameters are the same with Section 4 and the pilots at different transmitters are set orthogonal to each other in the conventional MIMO-OFDM schemes. The BER comparison result is shown in Fig. 6 under the simulation environment: RI1 = −20 dB, RI2 = −200 dB.

In Fig. 6, Without Process means that there is no additional processing in system; Perfect Channel denotes that the channel matrix is an identity matrix which is an ideal case. Since the low SNR, all schemes obtain almost identical BERs when SNR < 10 dB. But on the whole, the proposed scheme outperforms the traditional schemes significantly when SNR > 10 dB. Compared to the ideal case (the Perfect Channel curve), the proposed scheme obtains a similar BER performance at BER = 10−3 with a gap less than 2 dB, while the proposed scheme outperforms the MMSE based scheme with a gain of 3 dB at BER = 10−3. With the improvement of SNR, the performance of the proposed scheme improves significantly. The BER reaches the 10−3 level at SNR = 20 dB which is a large improvement compared to the traditional schemes.

We can conclude that the proposed scheme has a better BER performance than the LS or MMSE based conventional schemes under the same communication conditions and pilot consumption. In order words, the conventional schemes need more pilot consumption or a better communication environment to reach the same BER performance. What’s more, the pilots at different transmitters are set orthogonal to each other in conventional MIMO-OFDM schemes at the expense of more transmission efficiency wastage than that in SISO-OFDM system. However, the proposed scheme has no such problem due to the conversion from MIMO-OFDM system to several SISO systems, there is no need to set orthogonal pilots to each other at different transmitters. So, it is illustrated that the proposed MIMO-OFDM VLC scheme outperforms than those channel estimation based traditional schemes.

5.2. Computational complexity

Compared with the conventional MIMO-OFDM schemes, the computational complexity of the proposed scheme is mainly reflected on ICA separation process and LS estimation process, and the computational complexity of the conventional MIMO-OFDM schemes can be analyzed from channel estimation process. In this paper, LS algorithm and MMSE algorithm are compared as the representative of channel estimation algorithm. The analysis process is still using the parameters of Section 4. The computational complexity is measured by Floating-point operation.

LS channel estimation can be described as: a total of $M$ pilots $P$ are inserted into the OFDM block at known locations, then the channel can be estimated from the received pilots $\hat{P}$. The estimated channel frequency response is shown in Eq. (12).

$$\hat{H}_{LS} = \frac{\hat{P}}{P}$$

(12)

It is apparent from Eq. (12) that the LS based channel estimation is simple, but affected by noise. So the computation complexity of LS estimation algorithm is $M^2N_cN_s$ in MIMO-OFDM system, $N_c, N_s$ are the number of sending ends and receiving ends.
The MMSE is based on the least mean square error, that is to minimize \( E \left[ \| \hat{p} - H p^* \|^2 \right] \). The estimated channel frequency response is shown in Eq. (13).

\[
\hat{R}_{MMSE} = R_{HH} \left[ R_{HH} + \sigma_n^2 (p^p-1)^{-1} R_{LS} \right]^{-1}
\]

Where \( R_{HH} \) is the autocorrelation matrix of channel parameter; \( \sigma_n^2 \) is the variance of noise. For ease of calculation, \( (p^p-1)^{-1} \) can be substituted by \( E \left[ (p^p-1)^{-1} \right] \), and

\[
E \left[ (p^p-1)^{-1} \right] = E \left[ \| P_{k} \| \right] I \quad \text{and} \quad \text{SNR} = E \left[ \| P_{k} \| \right] / \sigma_n^2
\]

Thus, Eq. (13) can be simplified as:

\[
\hat{R}_{MMSE} = R_{HH} \left[ R_{HH} + \frac{\beta}{\text{SNR}} \right]^{-1} R_{LS}
\]

where, \( \beta = E \left[ \| P_{k} \| \right] \cdot E \left[ \| P_{j} \| \right] \). It is apparent from Eq. (15) that the MMSE based channel estimation is complex. The computation complexity of MMSE estimation algorithm is \((4M^3 + 18M - 12)N^*N_\), in MIMO-OFDM system.

In the process of ICA separation, the total cost of the ICA algorithm can be measured by iteration times and the computation complexity of per iteration. RobustICA algorithm is used in the proposed scheme, whose computation complexity is \((5K + 12)T \) per iteration. Where \( K \) is the number of the source signals; \( T \) is the sampling length. The number of source signals is equal to the number of sending ends and sampling length is FFT length \( N \). In the simulation, the average iteration times is 12, so the computation complexity of ICA separation process is \( 10^4 \cdot (5N + 12)N^*N_\). After ICA separation, the LS estimation process is an SISO-OFDM channel estimation process. So the total computation complexity of the proposed scheme is \( 12^\ast (5N + 12)N^*N_\). In summary, in this MIMO-OFDM system, the LS estimation with \( M^*N^*N_\), computation complexity, MMSE is \((4M^3 + 18M - 12)N^*N_\), and the proposed scheme is \( 10^4 \cdot (5N + 12)N^*N_\) and, conventional orthogonal pilot design methods require that the pilot length \( M \geq \max (2^{2L-1}, L, N_L) \) (L is the maximum delay length of the channel) [21]. So, the computation complexity of the proposed scheme is much smaller than the MMSE based scheme and close to LS by comparison. On the whole, the proposed scheme can achieve great communication performance with a lower cost of computation complexity.

6. Conclusions

We have proposed an ICA based MIMO-OFDM VLC scheme. The ICA algorithm is first presented to convert the MIMO channel into several SISO channels to reduce the system's computational complexity and the mutual interference of source signals. FM is used to further modulate the OFDM symbol to eliminate the correlation between the signals, so as to improve the separation performance of the ICA algorithm. The specific factors which may influence the separation of ICA algorithm is studied to make the ICA technique can be employed. The applicability of the communication scheme is also studied in the indoor geometric model which included LOS and NLOS transmission path. Meanwhile, in the proposed scheme, each of the sending ends works on the spectrum band to achieve spatial multiplexing. The simulation experiments have shown that the proposed scheme can offer better performance compared with the traditional scheme which based on channel estimation.

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