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An ICA based MIMO-OFDM VLC scheme

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ABSTRACT

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 4×4MIMO-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.

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 [1,2]. To combat these, multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) is considered to be a promising technique for reliable high data-rate VLC systems and provide uniform room illumination [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 [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 [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 [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 [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 [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 [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 measure signals [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. Thereby, the MIMO channel is converted into several SISO channels to simplify channel estimation and get satisfactory communication performance.

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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, N_t LEDs as the signal sending ends and the receiver includes N_r 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 are 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:

$$R = HX + N \tag{1}$$

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

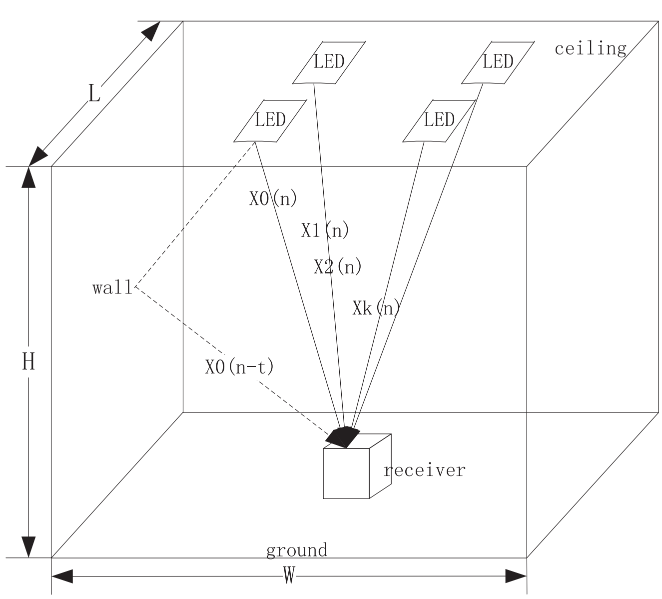

Fig. 1. Indoor geometric distribution model of the system.

$$H = \begin{bmatrix} h_{11}(t) & \dots & h_{1N_t}(t) \\ \vdots & \ddots & \vdots \\ h_{N_r1}(t) & \cdots & h_{N_rN_t}(t) \end{bmatrix} \tag{2}$$

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 N_t-parallel bit streams x_i ($i=1, \ldots, N_t$; $X=[x1; x2; \ldots]$), 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 N_r 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:

$$Y = W^T R = W^T HX + W^T N \tag{3}$$

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:

$$Y = EX + Z \tag{4}$$

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

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_r \end{bmatrix} = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1t} \\ e_{21} & e_{22} & \cdots & e_{2t} \\ \vdots & \vdots & \vdots & \vdots \\ e_{r1} & e_{r2} & \cdots & e_{rt} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_t \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_r \end{bmatrix} \tag{5}$$

Where $r=N_r$, $t=N_t$, and

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_r \end{bmatrix}, E = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1t} \\ e_{21} & e_{22} & \cdots & e_{2t} \\ \vdots & \vdots & \vdots & \vdots \\ e_{r1} & e_{r2} & \cdots & e_{rt} \end{bmatrix}, X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_t \end{bmatrix}, Z = \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_r \end{bmatrix} \tag{6}$$

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