High Speed Wireless Access Based on Visible Light Communication Utilizing Maximum Ratio Combination of Multi-Detectors

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***Abstract*-In this paper, we propose and experimentally demonstrate a novel space-reception diversity model based on Maximal Ratio Combining (MRC) algorithm in Single Input Multiple Output (SIMO) Visible Light Communication (VLC) system. Different from the previous schemes, the data was received by two detectors located in different space positions at the same time, and then, combined using MRC algorithm. As a result, the Bit Error Ratio (BER) of receivers can be reduced to one to two orders of magnitude. The performance of VLC system is significantly improved.**

Keywords-LED; multi-detector; maximun ratio combining; visible light communication; spatial positions.

I. INTRODUCTION

Visible Light Communication (VLC) based on Light Emitting Diodes (LEDs) offers an entirely new paradigm in wireless technologies in terms of communication speed, flexibility, usability and security [1]-[3]. The VLC is being touted as one of the next generation wireless communication systems, because it can simultaneously support illumination and communication [4]. With the further advancement of the project in future, VLC can be a replacement to almost all indoor and short range communication purpose.

Multipath propagation is a key feature of wireless communication. It has been conceived of as a bottleneck that hampers the creation of efficient wireless communication systems [7]. In VLC system, the multipath interference effect is mainly caused by the distance difference between the light and the receiver and the light reflected the walls. In a multipath environment, the spatial diversity can average out a substantial part of defecting effects of sporadic fades between different detectors. In the simplest form of it, there is just a single transmitter (Tx), in which case the problem reduces to combining the signal from multiple receivers (Rxs) in the most efficient way. The optimum solution to it is well established. We called the algorithm Maximal Ratio Combining" (MRC). MRC weighted after the merger, significantly lower Bit Error Rate (BER) for receiving signals, which can effectively enhance the received signal [8]. Since it is optimum in Single Input Multiple Output (SIMO) transmission systems, it can be considered as a benchmark in comparison with more recently proposed Multiple Input Multiple Output (MIMO) systems.

This paper is organized as follows. Section Ⅱ introduces the related work information, Section Ⅲ introduces the proposed system model and its mathematical presentation. The simulation and experiment results are presented and discussed in Section Ⅳ, before we conclude this paper in Section Ⅴ.

II. STATE OF THE ART

The performance variation at the receiver is one of important issues for VLC. Due to the sensitivity of the detector the performance is not same, even though the same transmitter and receiver are being used. Many researchers proposed some methods for improving receiver performance in VLC system, but no one has considered the performance can be improve according to automatically weight two different receivers. *Lee et al*. [5] have proposed a receiver structure to improve the VLC system where separate receivers with specific spectral response are used for the detection of different colors of channels. *Muhammad et al.* [6] proposed a receiver considering the performance variation on the different color of channels according to the VLC band plan, and proved it functionality mathematically as well as by simulation, but they did not consider the performance variations of the receivers located in different space positions.

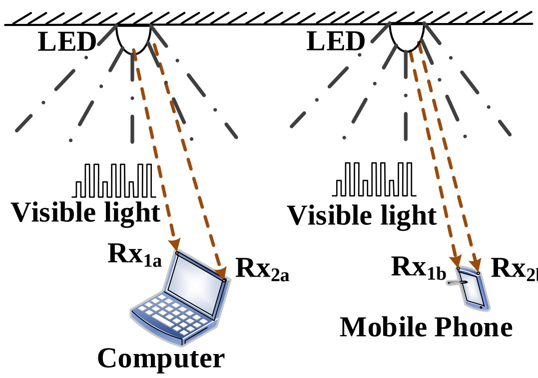

Figure 1. The schematic of VLC 1×2 SIMO system.

In this paper, we proposed a 1×2 SIMO transmission model considering two receivers located in different space positions. Figure 1 shows the sketches of VLC 1×2 SIMO system. This dual function of LED, for lighting and communication. MRC was used to combine the data with diversity from two detectors located in different space positions in the computer and mobile phone. Then, the data was outputted after combined. With the scheme, the transmission distortion will be improved efficiently in visible light communication system. As a matter of fact, our simulation and experiment results also proved it. Our proposition can be extended to more detectors to enhance the performance in the future.

III. SIMULATION AND RESULTS

LEDs are used to transmit desired optical signal in VLC system. The desired optical signals then travel through air before reaching optical detector. The receiver collects some undesirable optical signals which cause severe degradation to the overall system performance. In a VLC system, the receiver performance variation is occurred due to the angle and space position. We proposed a visible light SIMO communication system, the combining algorithm of MRC is used to improve the performance of the receiver.

A. Sprinciple of MRC

As well as most of the receive diversity algorithm, MRC combiner linearly combines the individually received branch signals so as to maximize the instantaneous output Signal-to-Noise Ratio (SNR) [9]; that is to say, the output result is the weighted sum of different fading channels. MRC algorithm is applicable to any modulation way, arbitrary diversity route and branch decline.

A SNR can express the quality of a communication system. We assume that the transmitter transmits the signal using On-Off Keying (OOK) modulation technique. Among all modulation techniques for visible light communication link, OOK is the simplest one and very easy to implement. In a single receiver, the average SNR is defined as the ratio of the received signal to the aggregated noise, and the SNR is proportional to the detector area when the shot noise is the dominant noise source [10]. The signal component of the SNR is measured by *Uddin et al*. [6]:

$$S = \eta^2 \xi^2 (n_{Rx}) P_{rsignal}^2$$

The signal received power $P_{rsignal}$ is:

$$P_{rsignal} = \int_0^T \left(\sum h_i(t) \otimes P_i(t)\right) dt$$

where η represents the photo sensitivity of the photo-detector (in A/W), $P_i(t)$ is the instantaneous input power, the symbol " $\otimes$ " denotes convolution, $h(t)$ resembles the impulse response, $\xi(n_{Rx})$ is the performance variation balancing factor. The time average transmitted optical power is given by *Uddin et al*. [6]:

$$P_t = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} P_i(t) dt$$

where $P_i(t) \geq 0$ since the instantaneous input power must be nonnegative.

We assume OOK with rectangular transmitted pulses of duration equal to the bit period. Gaussian noise having a total variance N_0 that is the sum of contributions from shot noise, thermal noise and Inter-Symbol Interference (ISI) by an optical path difference:

$$N_0 = \sigma_{shot}^2 + \sigma_{thermal}^2 + \eta^2 P_{rISI}^2$$

Therefore, the SNR is given by:

$$SNR = \frac{\eta^2 \xi^2 (n_{Rx}) H^2(0) P_t^2}{\sigma_{shot}^2 + \sigma_{thermal}^2 + \eta^2 P_{rISI}^2}$$

And BER is given by:

$$BER = \frac{1}{2\pi} \int_{\sqrt{SNR}}^{\infty} e^{-y^2/2} dy$$

where $H(0) = \int_{-\infty}^{\infty} h(t) dt$ is the channel DC gain.

The received power by inter-symbol interference P_{rISI} is given by:

$$P_{rISI} = \int_T^{\infty} \left(\sum h_i(t) \otimes P_i(t)\right) dt$$

Short noise variance is given by:

$$\sigma_{shot}^2 = 2q\eta\left(P_{rsigal} + P_{rISI}\right) B_{en} + 2qI_{bg} I_2 B_{en}$$

where q is the electronic charge, B_{en} is equivalent noise bandwidth, I_{bg} is background current and I_2 is noise bandwidth factor.

The thermal noise variance is given by *Uddin et al*. [6]:

$$\sigma_{thermal}^2 = \frac{8\pi k T_k}{G} \delta A I_2 B_{en}^2 + \frac{16\pi^2 k T_k E}{g_m} \delta^2 A^2 I_3 B_{en}^3$$

where k is Boltzmann's constant, T_k is absolute temperature, G is the open-loop voltage gain, δ is the fixed capacitance of photo-detector per unit area, E is the Field-Effect Transistor (FET) channel noise factor, g_m is the FET transconductance.

B. Simulation of VLC system

The schematic of visible light SIMO system is shown in Figure 2. For high speed telecommunications, Quadrature Amplitude Modulation (QAM) technique that is used in the communication system would be helpful in which the desired waveform is modulated onto the instantaneous power of the carrier. On the other hand, QAM demodulation algorithm is the requirement proportional to the received data in receivers. In our channel model, the information carrier is a light wave. Moreover, detector dimensions are in the order of thousands of wavelengths, leading to efficient spatial diversity, which prevents multipath interference. Therefore, multipath interference can be greatly reduced in optical wireless transmitting.

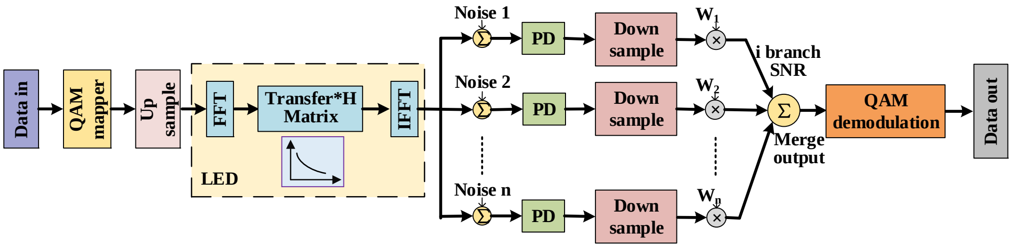

Figure 2. The simulation model of visible light SIMO system.

C. *The results*

When studying the performance with QAM modulation, the abscissa of the curves is the QAM order and delta frequency of the two detectors. The simulation results are depicted in Figure 3 and Figure 4. These curves are essential to understand the diversity gain that is attainable by concatenation of the SIMO. A threshold line for BER is set as 3.8×10^{-3}.

Figure 3 shows the receive BER variation for different detectors and proposed MRC combining according to the different QAM orders. It can be intuitively explained by noting that MRC weighted can significantly improve the performance of the separate detectors even though the BER of the MRC algorithm and separate channels looks almost the same when 128 QAM or higher. The BER curve has a lowest point with the QAM order increasing, due to the high frequency fading of low-order signal is faster [11]. The 4-QAM order (16QAM) shift is worth noting between the SIMO schemes. When the QAM order is 4 or below, the BERs of the detector change little, but above 4-QAM order, the BERs increase exponentially. This further illustrates that the MRC algorithm is suitable for low-order QAM modulation rather than high-order.

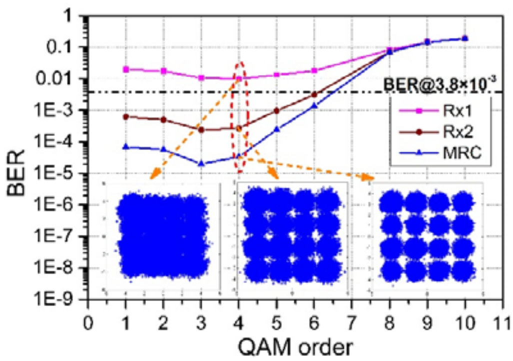

Figure 3. Simulation BER versus QAM order.

The simulation results show that it is hard to discern any differences in performance between the optimum and sub-optimum 16QAM demodulations. Considering the transmitting speed, we determine the optimal modulation format for 16QAM. From Figure 4, the receiver BER increases with the increase of transmission frequency difference. It illustrates that the higher the delta frequency, the greater the noise in the receiver, the easier to produce error. The BER of MRC weighted combining significantly lower than the separate detector. When the delta frequency bellow 7Hz, the receiver has a better performance, and the BER of MRC weighted combining is below the Forward Error Correction (FEC) limit of 3.8×10^{-3}.

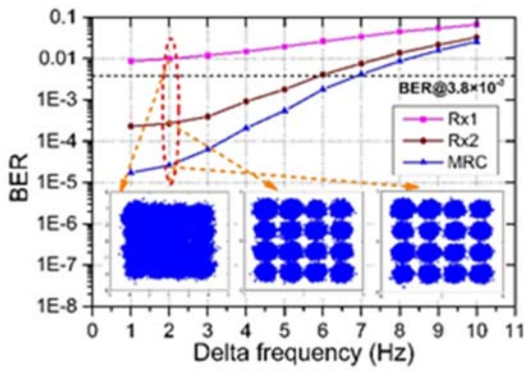

Figure 4. Simulation BER versus delta frequency.

IV. EXPERIMENTAL SETUP

In a VLC system, every receiver expects the same performance, even though the two receivers have different SNR. Therefore, our scheme focuses on reducing the performance variation at the receiver side. In order to verify the simulation results, we tried to send an image with our proposed VLC system. At the receiving end, we placed two receivers at in different spatial positions to receive signal at the same time. Due to the limited experiment conditions, two receives are used. Then the received data was analyzed with MRC algorithm. The experiment system is shown as Figure 5. To increase the separation distance between a light transmitter and a receiver, lenses are often used. A light receiver may use a lens to collect the weak light from the transmitter and focus it onto the optical detector for processing. However, the lens will always collect extra light from the environment that is not wanted. Hence, all of the received data from detectors in different spatial positions are combined by MRC algorithm, then the output data requires further signal processing to restore the desired image. As a result, the performance of the VLC system will be significantly improved.

 ISBN: 978-1-61208-356-8

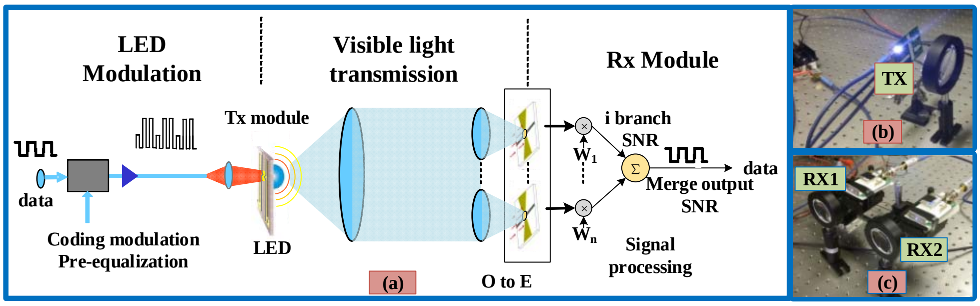

Figure 5. The experiment system: (a) the schematic of VLC system; (b) the transmitter (Tx); (c) the receives (Rx).

We measured the BER performances versus bias voltages of red LED. In this demonstration, the distance between transmitter and receivers is 0.6m, and the electrical input power is fixed at 12dbm, which is relatively small to avoid reaching the saturation area of LED. The modulation format is 64QAM-OFDM, considering the actual data transfer rate. The BER versus bias voltage results are depicted in Figure 6, and the constellations are shown for the bias voltage of 2.2V. We can find the BER of MRC algorithm can improve one to two orders of magnitude compared with any separate detector. Therefore, it is very effective that space diversity reception with MRC algorithm adopts multiple receivers in order to improve the performance of the VLC system.

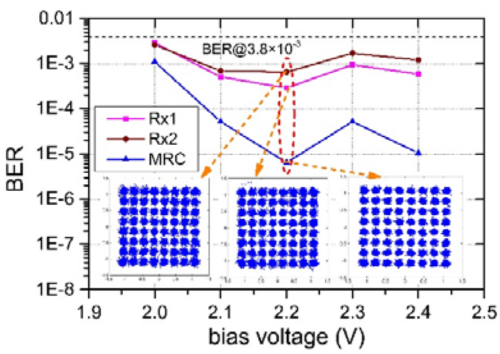

Figure 6. Measure BER versus bias voltage.

V. Conclusions

Diversity combining, which skillfully combines multiple replicas of received signals has long been as one of the most efficient techniques to overcome the destructive effects of multipath fading in wireless communication systems [5]. In this paper, we have proposed a novel 1×2 SIMO transmission model in VLC system based on two detectors located in different space positions. With the scheme, the transmission distortion of images can be improved efficiently. The BER of receivers can be reduced to one to two orders of magnitude. The BERs of signal combining algorithm of MRC are always below the FEC limit of 3.8×10^{-3}. Therefore, space-reception diversity based on MRC algorithm could be an effective technique to achieve high data rate and high fidelity transmitting images in visible light communication system.

Acknowledgment

This work is partially supported by NHTRDP (973 Program) of China (Grant No. 2010CB328300), NHTRDP (863 Program) of China (No. 2013AA013603), NNSF of China (No. 61177071), and Key Program of Shanghai Science and Technology Association (No. 12dz1143000).

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