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Iterative receiver design for indoor wireless visible light communication system

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Abstract

White LED will be a dominant device for lighting in the near future through which we can have the luminance and data transmission simultaneously. An indoor wireless visible light communication system (IWVLC) describes the communication during the indoor applications. This paper presents an iterative receiver design for the IWVLC system and proposes the Soft-Output-Viterbi algorithm to equalize and detect the signal at the receiver of the IWVLC system which is based on the numerical simulation. The performance of the proposed algorithm is better than the conventional Viterbi algorithm in terms of the bit error rate. The simulation results unveil the performance of the proposed iterative algorithm where it can be seen that the BER comes out to be less at the same SNR (dB) as compared to the conventional ones even when the data rate is very high.

Keywords: Visible light communication, LDPC, equalizer, SOVA

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1. Introduction

LED is light emitting diode that a semiconductor device can produce a light where LEDs obtain more energy. In the near future, LED will replace a conventional lamp because there are many benefits such as power consumption, life time, cooling operating system, small size, and high frequency response etc. Additionally, it can be used for communications system which is white LEDs. A higher power LED can produce 130 lumens per a single LED, so not sufficient for a typical room that requires luminance of 300 to 1,500 lx. Therefore, the lamp is made to be array LEDs. VLC system has many benefits compared to radio frequency system (RF). Since the radio frequency (RF) spectrum is so crowded, and the data transmission rate of RF communications cannot satisfy the great demand for huge data transmission, visible light communication (VLC) has proceeded as a possible state of the art for next generation communications. VLC systems in which white light emitting diodes (LEDs) are used as transmitters for communications. They can become the dominant indoor communication method.Their advantages are high speed, no electromagnetic interference and environmental protection. Also, they show potential prospects in hospital, indoor and outdoor short-distance communications, intelligent transportation and other areas. The interest in VLC system has rapidly increased due to it can combine the high speed communication and a luminance system at the same time by using an LED as a lighting source.

A basic model was first introduced by Toshihiko et al. [1] as the indoor wireless visible light communication link, used white LEDs arrays transmitter and illumination in a typical room. The photodetector used in the receiver to receive light from the transmitter and to convert the light to be electric signals. The light path divided into two parts which are the direct path and the diffusion path. Toshihiko et al. [1] found that the power distribution covered the typical room and the numerical result calculated average power of 2.5 dBm. However, when the data rate is sent with high speed, the signal to noise ratio will be low. The main effect of this system is the reflectivity of another path in the typical room and ambient light has been an inter-symbol interference (ISI). The suggestion to reduce ISI effect is using an equalizer before decoding the original data at the receiver. Lubin et al. [2] proposed a transmission in VLC system, found that it can improve a data rate from 16 Mbps to 30 Mbps by using a filter design. Nguyen et al. [3], a modulation technique was used as the same as configuring system such as the room dimension, and a parameter setting was as [1-2], the data modulation by NRZ-OOK schematic can improve

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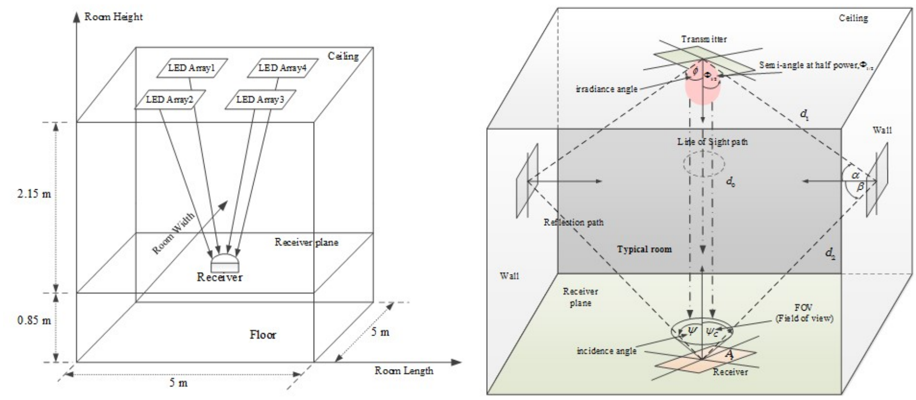


(a) (b)

Figure 1: (a) a visible light using LEDs lamp in a typical room, (b) the position of light source related with the receiver LOS and Diffuse Path.

the bit error rate as the result shown in [3]. In their study, Kwonhyung et al. [4] studied a characteristic of the indoor wireless VLC channel of white LEDs shown wide bandwidth for the transmission in optical wireless communication compared with infrared channel. Brief of this paper was the bandwidth of channel which depends on LED lamp used and the coefficient reflection of materials in a typical room. Yan et al. [5] proposed a combination VLC and WiFi based indoor wireless network architecture which supports bidirectional high-speed data transmission, and a demo system was designed and implemented. Feng et al. [6] investigated on two recent indoor channels in future 5G networks based on mmWave and VLC, in their results showed that VLC and mmWave channels share some common characteristics while differing in others, which makes them appealing in different application scenarios. Adisorn et al. [7] proposed the receiver design based on a partial-response maximum-likelihood technique for the indoor wireless visible light communication system, where a transmitter is placed on the ceiling, a receiver is on the table, and the signal transmission is based on the on-off keying (OOK) intensity modulation. The result compared the performance between a conventional receiver design and the proposed, the receiver design based on PRML technique improved bit error rate for indoor wireless VLC system.

In this paper, we proposed an iterative receiver design for indoor wireless visible light communication system, organized as follows. In section 2, a model an indoor wireless VLC system is discussed and included to describe a light propagation and a received power distribution in the typical room. In section 3, iterative receiver design for indoor wireless VLC system is described. Then, in section 4, the results and discussion are described. Finally, the conclusion is given in section 5.

2. Indoor Wireless VLC System Modeling

Indoor wireless visible light communication system using arrays LED lamps is shown in Fig. 1 [1], so each array LED lamp is on the ceiling of the room, including a dimension of the room, a receiver, and a transmitter. All the parameters of typical system model are shown in the Table 1. The VLC system is shown on a Fig. 1 as four sets of LED arrays are on the ceiling. The receiver is placed on the receiver plane above the floor. The room size is 5.0 m × 5.0 m × 3.0 m., the distance between transmitter and receiver plane is 2.15 m. A coordinate system is set as following the Fig. 1, x and y - axis are the floor plane, the height direction is a z - axis. The illuminance expresses the brightness of an illuminate surface. The LED has an illuminous $I(0)$ on the optical axis and Lambertian distribution is assumed as its light distribution $I(\phi)$ spread around the typical room, the light distribution depends on the function of cosine and the irradiance angle of LEDs [1 – 3].

$$I\,(\phi) = I\,(0)\cos^{m}(\phi) \tag{1}$$

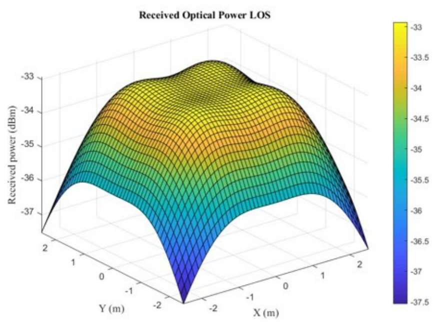
where $I(0)$ is the center illuminous intensity of the group LEDs, m is the order of Lambertian emission, which is relative to the semi-angle at half power of the LED denoted as , and is defined as (2).

$$m = \frac{-\ln(2)}{\ln\left(\cos\Phi_{1/2}\right)} \tag{2}$$

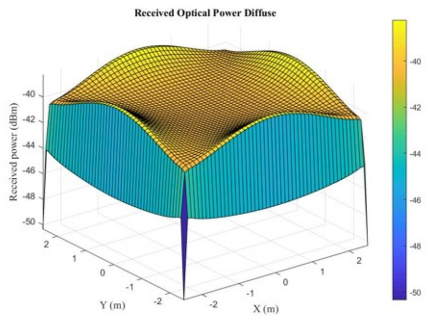
A horizontal illuminance E_{hor} is given by [1], represented as the Eq. (3), where $I(\phi)$ is the illuminous intensity in angle ϕ , and as Eq. (3) is divided by $\cos(\psi)$ is the cosine function of angle ψ.

$$E_{hor} = \frac{I\,(\phi)}{d^2\cos(\psi)} \tag{3}$$

where ϕ is the irradiance angle of LEDs, a transmitter in VLC system, ψ is the incidence angle of photodetector that a receiver in the system and d is the



(a)



(b)

Figure 2: Optical power distribution in received optical plane for a semi-angle at half power 70°, (a) the distribution of direct lights received optical power (Ave. -34.0925 dBm) and (b) the distribution of reflective lights received optical power (Ave. -40.0851 dBm).

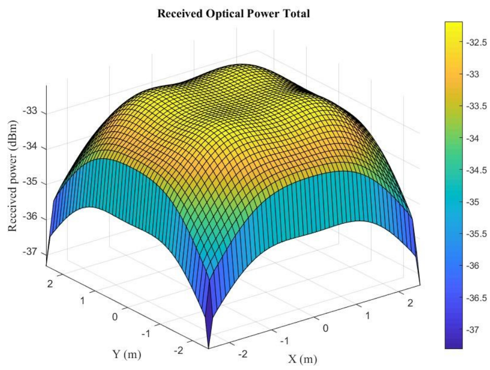


Figure 3: Total optical power including reflections distribution in received optical plane for a semi-angle at half power 70° (Avg. -33.0747 dBm).

distance between an LEDs and a photodetector. The illuminance of light is considered due to the lighting is required to standardize in office room.

The received optical power from a transmitter to a receiver is divided two paths, firstly, the channel DC gain of Light of sight path (LOS) given by [1 – 3] as Eq. (4)

$$H_d(0) = \begin{cases} \frac{(m+1)A}{2\pi d^2}\cos(\phi)\,T_s(\psi)\,g(\psi)\cos(\psi), \\ 0 \le \psi \le \Psi_c \\ 0, \psi > \Psi_c \end{cases} \quad (4)$$

where A is the physical area of the detector in a PD, d is the distance between a transmitter and a receiver, ψ is the angle of incidence, ϕ is the angle of irradiance, $T_s(\psi)$ is the gain of an optical filter, and $g(\psi)$ is the gain of an optical concentrator. Ψ_c denotes the width of the field of view of photodetector. The optical concentrator $g(\psi)$ can be given as:

$$g(\psi) = \begin{cases} \frac{n^2}{\sin^2(\Psi_c)}, 0 \le \psi \le \Psi_c \\ 0, \psi > \Psi_c \end{cases} \quad (5)$$

where n is the reflective index, and the received optical power P_r is derived by the transmitted optical power P_t multiplied by the channel DC gain $H_d(0)$ as shown in Eq. (6).

$$P_r = H(0)\,P_t \quad (6)$$

In this paper, the all parameters are shown in the Table 1. A semi-angle at half power (FOV) of the receiver is 70.0 deg., and the detector physical area is 1.0 cm^2., The gain optical filter is 1.0, and the reflective index of an optical concentrator lens is 1.5. Fig. 2 shows the distribution of received power of direct light from the LEDs to the receiver plane, Fig. 2 (a) and (b) depicted the received optical power of LOS and diffuse link, respectively. In Fig. 2 (a) and (b), the received optical power is -37.5328 to -32.9261 dBm and -50.3478 to -38.2263 dBm respectively, in all the places of the room.

We consider the effect of reflective light by walls. The received optical power is given by the channel DC gain on directed path $H_d(0)$ and reflected path $H_{ref}(0)$.

$$P_r = \sum^{LEDs}\left[P_t H_d(0) + \int_{walls} P_t dH_{ref}(0)\right] \quad (7)$$

The channel DC gain on the first reflection is [1]:

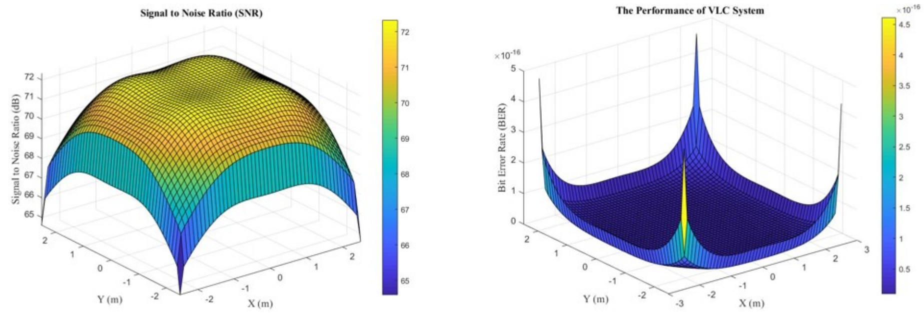
$$dH_{ref}(0) = \begin{cases} \frac{(m+1)A}{2\pi d_1^2 d_2^2}\rho dA_{wall}\cos^m(\phi)\cos(\alpha)\cos(\beta) \\ \times T_s(\psi)\,g(\psi)\cos(\psi), 0 \le \psi \le \Psi_c \\ 0, \psi > \Psi_c \end{cases} \quad (8)$$

where d_1 is the distance between an LED on the ceiling and a reflective point at the walls, d_2 is the distance between a reflective point and a receiver, ρ is the reflectance factor, dA_{wall} is a reflective area of small region, ϕ is the irradiance angle at LEDs, α is the irradiance angle to a reflective point, β is the irradiance angle to the receiver, psi is the incidence angle at the receiver as Fig. 1 (b).

Fig. 3 shows the distribution of received optical power including the reflection. In all the places of

Table 1. All parameters for setting in the simulation.

Parameters	Values	Parameters	Values
Room size	5 x 5 x 3 m^3	Wall reflectivity	0.7
Desk height from the ceiling	2.15 m	FOV at the receiver	120°
Single LED power PLED	30 mW	Detector physical area of PD	1.0 cm^2
LED response time	150 ns	Transmission coefficient of optical filter	1.0
Semi-angle at half power	70°	Refractive index of lens at PD	1.5
Number of LEDs arrays	4	Photodiode responsivity (R)	0.4 A/W
Number of LEDs per array	25 (5 x 5)	Turning Parameter (P)	2
LED pitch	1 cm	Amplifier noise density	5 pA
Floor reflectivity	0.15	Ambient light photocurrent	5840 uA
Ceiling reflectivity	0.8	Noise-bandwidth factor (I_2)	0.562



(a) (b)

Figure 4: (a) The signal to noise ratio distribution for a semi-angle at half power 70°, (b) bit error rate distributions.

the room the received optical power is -37.3114 to -32.1806 dBm. The received maximum and average power are -32.1806 dBm. and -33.0747 dBm. respectively. The photodiode is used to convert the received optical power into the electrical current, and the output current is $i = P_r * R$ where R is the photodiode responsibility (denotes 0.4 A/W as Table 1). The SNR is given by [2]:

$$SNR(dB) = 10\log_{10}\left(\frac{P_r R}{\sigma^2_{total}}\right) \tag{9}$$

where σ^2_{total} is total noise variance and it is given by [2] $\sigma^2_{total} = \sigma^2_{shot} + \sigma^2_{amplifier}$, and the shot noise variance σ^2_{shot} is given by $\sigma^2_{shot} = 2qRB_n\left(P_r + P_n\right)$ where B_n is the noise bandwidth, P_n is the noise power of ambient light around the room, $B_n = I_2 R_b$, where R_b is the data rate and I_2 is the noise bandwidth factor. The amplifier noise variance is given by $\sigma^2_{amplifier} = i^2_{amplifier} B_a$, where B_a is noise amplifier bandwidth. The bit error rate is calculated as:

$$BER = Q\sqrt{(SNR)} \tag{10}$$

where $Q\left(x\right) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-y^2/2}dy$. AS followed the signal to noise ratio distribution in Fig. 4 (a) and the Fig. 4 (b) shows the performance of the IWVLC system. The bit error rate calculated from the signal to noise ratio (SNR). At all corners of the room, it can be seen that the bit error rate raised more than the other place of the receiver plane as shown in Fig. 4 (b) bit error rate distribution. The low BER area is increased by at the corners of the room that is low illuminance.

All the parameters are mentioned in Table 1, where the LED response is a function of exponential as described in [2], and can be written as: $h_{LED}\left(t\right) = e^{-\omega_c t}$ where $\omega_c = p\big/\left(T_r + T_f\right)$. p is an experiment tuning function. T_r is the rise time and T_f is a the fall time, there is defined to 20 nsce and 130 nsec. [2] respectively as shown in Fig. 5 (d). Fig. 5 shows the normalized impulse response at corner of the typical room (x, y, z)=(0.5, 1.0, 0.85). From Fig. 5 (a), (b), and (c), it can be seen that the different of impulse response in each path of optical channel that included LOS path, diffuse path and total impulse response as respectively. The optical wireless channel model is expressed as follows [1]:

$$y(t) = Rx(t) \otimes h(t) + n(t) \tag{11}$$

where $y(t)$ represents the received signal current that is converted by the PIN photodetector, is the detector responsivity of the photodiode, $x(t)$ represents the transmitted optical pulse that is a digital signal input convolution with the LED response base on a simulation model, $h(t)$ is the optical impulse response, $n(t)$

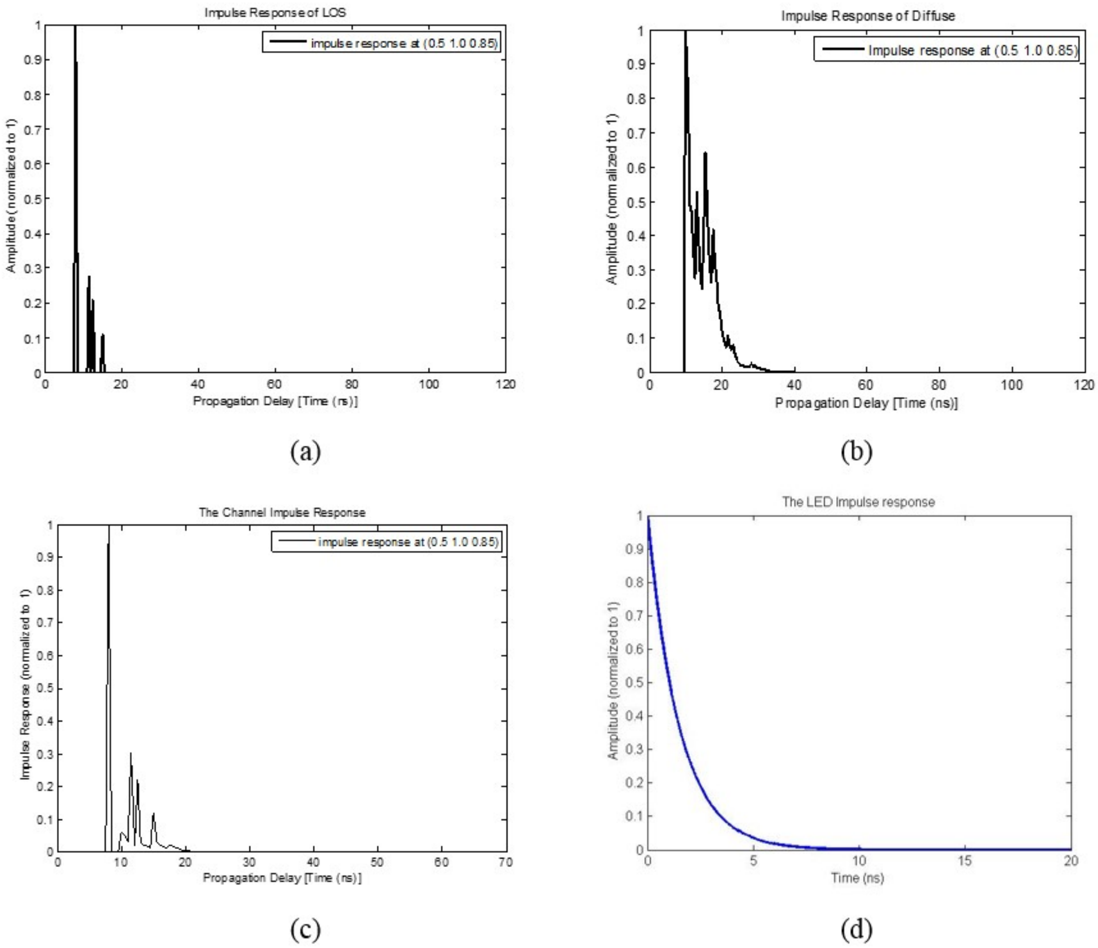


Figure 5: Impulse response of the typical room IWVLC system at (0.5, 1.0, 0.85) (a) impulse response of LOS path (b) impulse response of diffuse path (c) the total channel impulse response and (d) the LED impulse response.

represents the AWGN, and the symbol ⊗ denotes convolution.

3. Iterative Receiver Design for the IWVLC System

A conventional receiver for the IWVLC system [2], the received signal from a PIN photodetector is filtered by a low pass filter that is an analog filter to equalize the received signal, then [2] decided by a threshold detector to recover a data. However, in [7] used Partial-response maximum-likelihood (PRML) combined with a Viterbi detector to improve the performance of the IWVLC system at a receiver. Additionally, in this paper proposed a new approach for IWVLC receiver. As Fig. 6 shows a block diagram of an iterative receiver for IWVLC system. Low density parity check (LDPC) codes proposed by Gallager in 1962 [8], there are many communication technologies that have been used LDPC algorithm to improve the performance of their system. Yishuo et al. [9] proposed to use the LDPC code for the VLC system to study a performance of VLC based on LDPC code. In [9], found that the QC-LDPC code is suitable channel code for VLC, and to reduce a complexity to a large extent on covering the BER performance of the VLC system. In [10] studied run-length code for VLC system to improve many performance factors, including spectral efficiency, power efficiency, DC balance and flicker avoidance, and the results confirm the superb performance of the RS-eMiller schemes. However, this work is continued from [7] and the diagram that a new receiver is proposed as shown in Fig. 6.

According in the Fig. 6, the data from equalizer is a digital input y_k through the soft output Viterbi algorithm (SOVA) detector that is a Viterbi detection. The output of SOVA detector transfers the data iteratively with LDPC decoder until the iteration finished. Equalizer taps can be expressed as Eq. (12) in the domain D. The equalizer target is designed by using the Eq. (12) and (13) based on the minimum mean squared er-

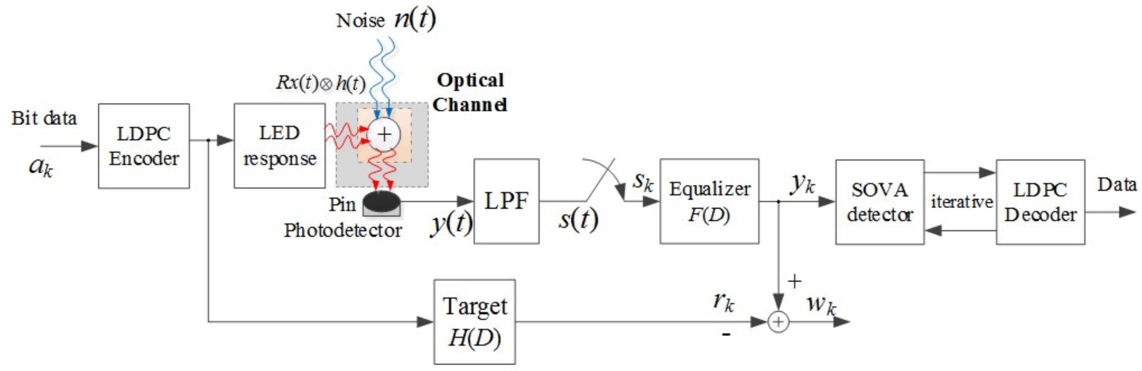


Figure 6: Iterative receiver block diagram for the IWVLC system.

ror (MMSE) [11].

$$F(D) = \sum_{k=-K}^{K} f_k D^k \tag{12}$$

where D is the delay operator unit, f_k is the filter coefficient of equalizer $F(D)$, h_k is the filter coefficient of target $H(D)$ as Eq. (12) and (13) respectively.

$$H(D) = \sum_{k=0}^{L-1} h_k D^k \tag{13}$$

$F(D)$ and $H(D)$ are vectors that K and $L-1$ are lengths of the filter coefficient of equalizer and the filter coefficient of target, respectively. In simulations, the values of K and L are set to be 5 and 3 respectively, to determine the minimum mean square error $E\left[\omega_k^2\right]$ in the (14) [11-16], where $\otimes$ is the convolution operator, $E[.]$ is the expectation operator.

$$E\left[w_k^2\right] = E\left[\{(s_k \otimes f_k) - (a_k \otimes h_k)\}^2\right] \tag{14}$$

Following the Fig. 6, a_k , bit data is created randomly from the simulation program. A sequence of bit data is encoded by the LDPC encoder. Parity check matrix H is created in [8-9] and [16] by based a quasi-cyclic (QC-LDPC). A log-likelihood ratio based propagation (LLR) decoding algorithm of LDPC code proposed to use include with SOVA detector in IWVLC system. The input sequence of SOVA detector is denoted by y_k. Detailed decoding steps of LLR BP (Belief Propagation) algorithm are as follows [8-9] and [16]. Assume that the prior probability of the information is given:

$$L^{(0)}\left(q_{ij}\right) = L(P_i) = \ln\left(\frac{1+\exp\left(2y_i/\sigma^2\right)}{1+\exp\left(-2y_i/\sigma^2\right)}\right) = \frac{2y_i}{\sigma^2} \tag{15}$$

where y_i is the output sequences from SOVA detector, σ^2 is the total noise variance. Check nodes updating. Calculate the information of check nodes received form variable nodes as Eq. (16), [8-9] and [16] where the Tanner Graph and Trellis of SOVA diagram are described, respectively.

$$L^{(l)}\left(r_{ji}\right) = 2\tanh^{-1}\left(\prod_{i'\in R_j/i} \tanh\left(\frac{1}{2}L^{(l-1)}\left(q_{i'j}\right)\right)\right) \tag{16}$$

The variable nodes updating, to calculate the information of variable nodes received form check nodes:

$$L^{(l)}\left(q_{ij}\right) = \frac{2y_i}{\sigma^2} + \prod_{j'\in C_i/j} L^{(l)}\left(r_{j'i}\right) \tag{17}$$

Then, the information of variable nodes is decoded as follows:

$$L^{(l)}(q_i) = L(P_i) + \prod_{j\in C_i} L^{(l)}\left(r_{ji}\right) \tag{18}$$

when reach the maximum iterating time the bit data is 1 if $L^{(l)}(q_i) \geq 0$ and is 0 if $L^{(l)}(q_i) < 0$ .The simulation parameters for iterative receiver of the IWVLC system which the size of LDPC code parity check matrix is denoted by 445 x 4095, code length is 4095 and the code rate is 8/9.

4. Results and Discussion

In Fig. 7 illustrates the BER performance between the Viterbi detector and SOVA detector at the different data rate 50, 100, 150, and 200 Mbps. It can be seen that a new approach receiver gave the better BER performance more than 10^{-4} at the same data rate and SNR (dB). An iterative receiver at all data rate, it can accept BER 10^{-5} as differences the signal to noise ratio (SNR) about 6, 10, 12, and 15 dB., respectively, as shown in Fig. 7.

Fig. 8 shows the performance of bit error rate of the IWVLC system by comparison with a different iteration 5, 10, 20, and 30, it can be seen that the more iteration the bit error rate is low as SNR 4 dB and at 30 iterations the BER performance is lower than 10^{-5} as well. According to Fig. 8, the SNR is low, the iteration of decoding hardly improved decoding LDPC

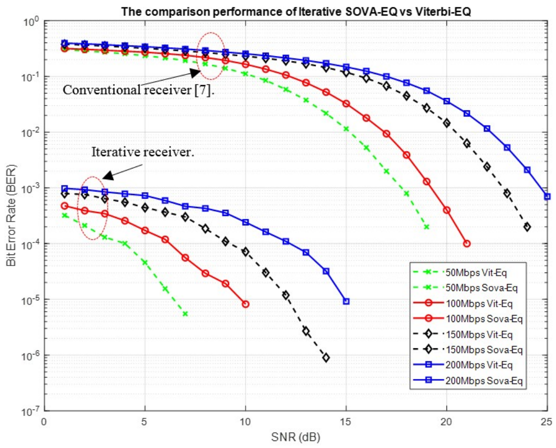


Figure 7: The performance of the IWVLC system comparison between LDPC and Viterbi detector.

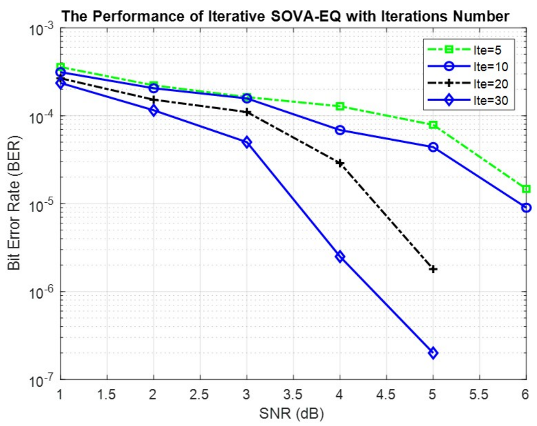


Figure 8: The performance of the IWVLC system comparison between a different iteration.

algorithm. When the SNR is 2 dB, the BER performance is higher than 10^{-4} of all the iteration. And when the SNR is 5 dB, the iteration of decoding can improve the bit error rate of the IWVLC system significantly. Moreover, there is a large difference between 30 and 5 iterations.

Fig. 9 shows the BER performance of the IWVLC system when the data rate is high. As Fig. 9, the bit rate 200 Mbps and 500 Mbps gave the bit error rate that can accept at 10^{-4} by SNR(dB) at 12 and 14 dB, respectively. However, as the bit rate is over up to 1 Gbps and 2 Gbps, the IWVLC system needs alternative techniques to support and that is the challenge to the next work.

VLC technology has advantages which make it a good candidate solution for indoor wireless access network, and it can combine the RF with the Wi-fi network for indoor at the specific places. Recently, VLC technology is one of complementary technology for future 6G network [17] that is to exploit the visible spectrum with visible light communication (VLC) techniques for short range (up to few meters) links, which compared to classically adopted RF bands offers ultra-high bandwidth (THz), zero electromagnetic interference, free unlicensed abundant spectrum, very high frequency reuse [18]. Therefore, researchers keeping on VLC technology will have opportunities to investigate in the future 6G network area.

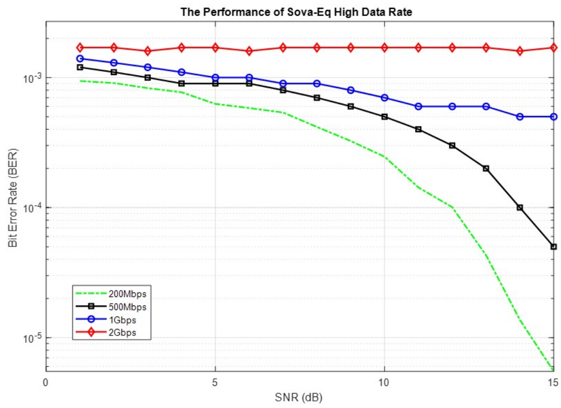


Figure 9: The performance of the IWVLC system comparison between a different high data rate.

5. Conclusions

This paper proposes a receiver design for indoor wireless visible light communication system. This work has reported an investigation of the performance of the schemes LDPC coding and the detector SOVA equalize of the IWVLC transmission system by combining both techniques. The performance shows the bit error rate of new schemes better than the conventional schemes. In addition, the more iteration number used its BER performance improved. The proposed method is useful and suitable for the IWVLC system. But, at high data rate needs a new approach to improve the performance of the IWVLC system.

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