Asian Journal of Electrical Sciences
ISSN: 2249-6297 (P) Vol.7, No.1, 2018, pp.42-46

DOI: https://doi.org/10.51983/ajes-2018.7.1.2056

Enhancement of VLC to Sushisen Algorithms Using BER Performance of the FSK Communication Network

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(Received 14 February 2018; Revised 4 March 2018; Accepted 3 April 2018; Available online 10 April 2018)

***Abstract* - In this article, wide menstruates a visible light verbal exchange (VLC) system upon eight meters fair space transmission based concerning a commercial LED yet a grantee between coalitions with an audio interface on a clever phone. The signal is in FSK modulation format. The profitable empirical accomplishment validates the probability regarding the proposed rule between future wi-fi communication networks.**
***Keywords:* VLC, Smartphone communication, *FSK*, wireless communication**

I. INTRODUCTION

Today visible light communication (VLC)is developing rapidly for its safety and large bandwidth [1-5]. Now the main research direction is to approach high speed transmission. One of the essential problem for future VLC application is how to make VLC connection with the existing mobile terminals. The mobile phone is the most pervasive personal communications and computing platform ever created. The only standard and universal interface of the smart phone is the headset port. The headset plug has four electrical components, they are left channel, right channel, microphone input and ground respectively. Since it is normal to collect audio signal through the headset port and convert the light signal to electrical signal, it is possible to carry out VLC through the headset port. The smart phone is able to sample electrical signal at a fixed sampling rate which is often been set to 44.1 KHz. If we adjust the transmitting signal and design the receiver correspondingly, we can complete the communication.

VLC-PLC (HVP) system architecture for the indoor downlink transmission and present the analytical framework for the data rate analysis of the HVP system[6].NHS-OFDM achieves superior bit error rate (BER) performance to that using HS-OFDM, with lower or nearly the same computational complexity[7].

In this paper we successfully demonstrated VLC transmission in FSK modulation using a commercial LED and a Smartphone. We design a master board in the transmitter to realize the signal generation and LED driver. A small adaptive receiver is designed to connect with a smart phone using the audio jack interface of the phone. A software based on Android platform is developed in the Smartphone to decode the signal. Two LCD are set in the transmitter and receiver to show our origin message and the received information. Various parameters including the decision threshold and FSK date rate are thoroughly investigated. Our experimental results validate the potential application of VLC in future wireless network.

A. Sushisen Algorithms

Input:
Dx (y) = estimate of least cost from x to y
Distance vector: Distance vector: Dx = [Dx (y): y є N]
Node x knows cost to each neighbor v:wi-fi
Node x knows cost to each neighbor v: c(x,v)
Node x maintains Node x maintains Dx = [Dx (y): y є N]
Node x also maintains its neighbors' VLC distance vec Node x also maintains its neighbors' distance vectors
For each neighbor v, x maintains
For each neighbor v, x maintains
Output:
Dv = [Dv (y): y є N] N = set of routers = { u, v, w, x, y, z }

1 Initialization:
2 N' = {u}
3 For all nodes v
4 If v adjacent to u
5 Then D(v) = c(u,v)
6 Else D(v) = ∞
7 N= set of routers = { u, v, w, x, y, z } 8 Loop
9 find w not in N' such that D(w) is a minimum
10Aadd w to N'
11 Update D(v) for all v adjacent to w and not in N' :
12 D(v) = min(D(v), D(w) + c(w,v))
13 N = set of routers = { u, v, w, x, y, z }
14 Shortest path cost to w plus cost from w to v */
Until all nodes in N'

II. PRINCIPLES

A. The Block of the VLC system through the headset port

FSK modulation has high sensibility but call for larger bandwidth. A lower signal rate is chosen to make sure the transmitting signal could be decoded correctly in the receiving terminal. The period of each symbols fixed and the number of pulse in each symbol can be set different to represent 0 or 1 bi t. The number of the pulse during one symbol is calculated in order to make the receiving easy to synchronize. In theory, the less the number of pulses, the faster the communication rate is. However, improving the communication rate can make the performance of BER worse. The principle of the transmitter and the receiver is shown in Figure 1. The first step is to generate or input valid binary data which includes useful information. Then each bit is coded to do FSK modulation and after this step PWM Pulse Generation can be generated. Prefix and postfix are added in order to extract frame synchronization signal. After determining the waveform it is easy to load the signal to LED driver and modulate the LED. In the receiving terminal, PIN is the key component in the first stage. PIN can convert visible light signal to electrical signal which can be handled by the latter circuit. After PIN is a pre-handle circuit trying to amplify the small signal so that the AD sampler embedded in the Smartphone can recognize the signal and collect it. It is possible to collect receiving signal when the pre-handler has already convert the signal to valid voltage signal. The collected signal will be coded by the Smartphone in PCM format and there is an interface for the developer to read the PCM data. The most important issue in the receiving terminal is to get synchronization. In the transmitting terminal, we add prefix and postfix to indicate the start and the end of a frame. In the receiving terminal, synchronization is judged first and it is necessary to continue to find a frame if the Smartphone have not get synchronization. As the PCM data changes, it is easy for us to set a threshold to decide which voltage level is high level and by doing this we can find the rising and falling edge of the receiving data. The appearance of a rising edge means it is time to record the lasting time of the pulse. The length of pulse used to code 1 or 0 bit is different so we can recognize the type of one single pulse. Counting the number of the same type of pulse to determine the type of the binary information we get. Combing all the bit we get we can convert them to meaningfulmessage.

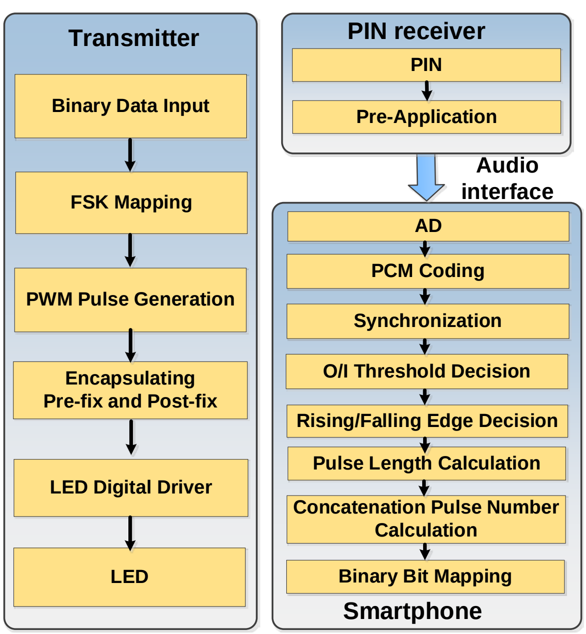

Fig. 1 The principle of the transmitter and the receiver using in the FSK communication system

B. The priciple to Test the BER performance of the FSK communication system

The real time FSK communication system is not convenient to test the performance of this system such as BER performance. An offline system is setup for testing the BER performance. The principle block is shown in Figure 2. At first, the PC generates a sequence in random as the valid data and then these data should be coded and mapped to realize FSK modulation. The modulated data is suitable to be transmitted in the channel so it is loaded to the LED driver. The LED driver can be digital or analog. In this experiment we use analog modulation because using this way we can change the depth of our modulation and see how the peak to peak voltage will affect our communication performance. By the way, the bias voltage or the quiescent current of the LED can be changed by the LED driver. Then the signal is transmitted by the LED and here white LED is been used. After the light signal being collected by the receiving PIN and amplified by the amplifier. The Smartphone is able to get the signal and using PCM format to save all collected data to an mp3 file. At last the mp3 file is delivered to PC by the micro-USB interface. We can use this mp3 file and handle it to test the BER performance.

$$s(t) = 4/\pi[\sin(2\pi ft) + FSK1/3\sin(2\pi(3f)t)] \quad (1)$$

*Bandwidth=5f-f =4f;If f=1Mhz, then the bandwidth = 4Mhz;T=1 microsecond; we can send two bits per microsecond so the data rate = 2 * 106 = 2Mbps*

The mp3 file can be read by MATLAB and done some special handling. From the waveform file, we can see how the signal change with time and it is called analyzing in the time domain. Doing FFT using these data can help carry out analyzing in frequency domain. Since the modulation way is chosen to be FSK, the frequency spectrum of the receiving signal should has typical character. However, the AWG will send the same data constantly and there is no need to cover all the data to analyze the receiving signal. The first step to handle the receiving data is to find sync peaks using correlation analysis. Then it is easy to extract useful piece to analyze. The distribution of negative value and positive value can be drawn in histogram to see the quality of the transmitting channel. Since it is required to decide 0 or 1 bit, a threshold value is needed. However, the best threshold of the communication system could not be known in advance and in many application areas people useeye patterns to help decide the best threshold. Our test principle is to test a group of threshold value to find which the best for our communication system is.

The general equation used for finding the BER of FSK signal where the noise contribution is considered to be a Gaussian distribution can be expressed by:

$$\text{BER} = 1/4\left[\text{erfc}\left(\frac{I_1 - I_D}{\sigma_1\sqrt{2}}\right) + \text{erfc}\left(\frac{I_D - I_0}{\sigma_0\sqrt{2}}\right)\right] \quad (2)$$

Where I_0 and I_1 are the intensities of a 0- and a 1-bit respectively. σ_0 and σ_1 are the standard deviation of the 0- and the 1-bit respectively and I_D is the decision threshold.

Using this equation can help us easily find out the BER of our communication system in different threshold.

C. Proof : BER performance FSK Frequency

Determine (a) the peak frequency deviation, (b) minimum bandwidth, and (c) baud for a binary FSK signal with a mark frequency of 49 kHz, a space frequency of 51 kHz, and an input bit rate of 2 kbps.

a. The peak frequency deviation is determined from Equation $\Delta f = |149\text{kHz} - 51\text{ kHz}| / 2 = 1\text{ kHz}$

b. The minimum bandwidth is determined from Equation: $B = 2(1000 + 2000) = 6\text{ kHz}$

c. For FSK, $N = 1$, and the baud is determined from Equation as baud = 2000 / 1 = 2000

III. EXPERIMENTAL SETUP

The experiment set up is shown in Figure 2. Two different test scheme are applied in our system. The first case is the off-line testment. The signal is generated by a ar bitury waveform generator (AWG520). We generate a F SK signal based on MATLAB software with various date rate and frequency spacing. This data pattern is then uploaded into the AWG to do signal generation. The electrical signal from AWG input to the LED driving circuit thus the electrical to optical conversion is accompolished and the output light of LED is now bearing the signal. A speical designed PIN receiver is then plugged on the smartphone via the audio jack interface. In this way the optical signal with power fluctuation depending on the input signal pattern is then converted into electrical signal and is collected by the audio I/O. The smartphone in the receiving terminal is an android device.The smartphone is connected with the computer through the micro-USB interface. The detected signal is stored into mp3 file and is processed offline based on a computer installled with the demodulation program based on MATLAB.

The second case in the real-time testing. In this senario the FSK coded is generated by the development board. The function of the development board includes the programable signal generation and the LED current driver. The detector is quite the same as the first case. However in this time the signal is no longer downloaded into a computer but is processed locally based on the pre-installed decoding smartphone app. The data is then transmitted through VLC channel and demodulated and display simultaneously on the screen of the smartphone.

IV. THE RESESULT OF THE EXPERIMENT

A.The BER performance of the VLC system

The waveform is collected in an MP3 file with 44.1KHZ sample rate. We can plot the waveform in time domain in Figure 3. The dense area means bit 0 is being transmitted and the sparse area indicate bit 1 is being transmitted and it is apparent to see in the origin data figure and the receiving data. It is possible to recover the origin signal after transmitting through the optical channel.

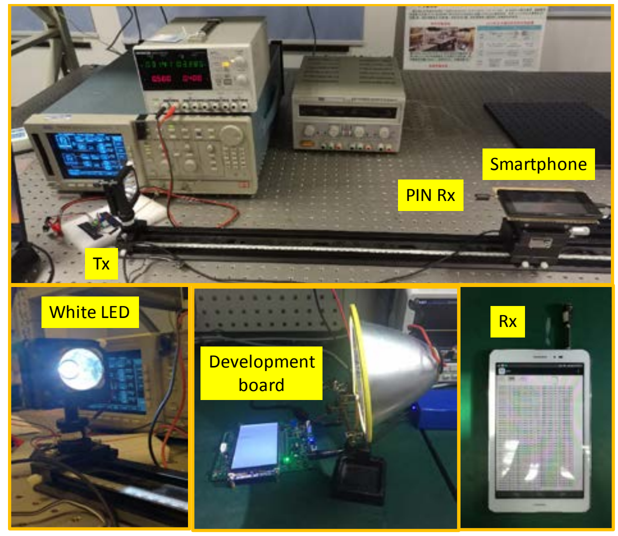

Fig. 2 The VLC mobilephone transmission system.

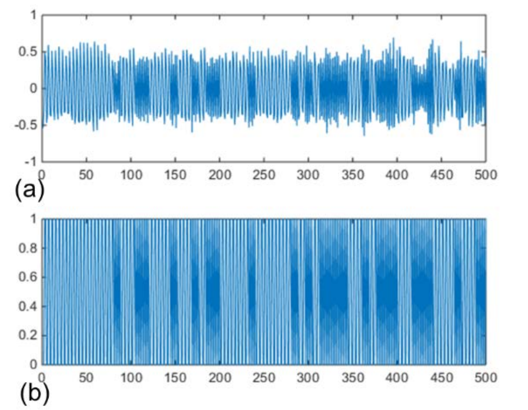

Fig. 3 (a) Waveform of the received FSK signal with 5 times upsample, (b) Orignal FSK signal

We analyze the signal before it is transmitted and after the transmission. The frequency spectrum of both signals is shown in Figure 4. Clearly there are two main peaks representing the two tones of the FSK signal. The massive side lobes are induced by the square pulse shape in time domain, which has a Sinc function envelop in frequency domain. It is shown in the figure that the high frequency componentin the origin signal is decayed a lot. The figure is tested when we take 5 times up-sample. The low frequency component is maintained well so the character of the VLC channel is suitable to transmit signal atrelatively low speed.

In the off-line evaluation test, the clock recovery is very critical for the signal detection. The incorporate system retiming may result in failure detection, i.e., the signal is sampled with wrong phase shift in one-bit duration thus the eye-opening of the resampled signal tends to closure. In order tosee how the retime derivation can affect the BER performance, we analyze the original data and the receiving data and plot them in the same histogramwith different color. From Figure 5 we can see bad re-timing can indistinctthe receiving data and affect our judge. The effect of good re-timing is shown in Figure 5(b).

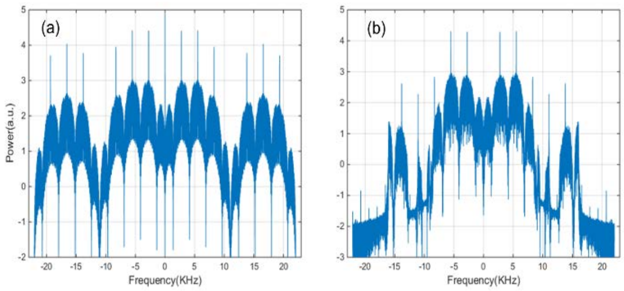

Fig. 4 The frequency spectra of (a) signal before VLC transmission, (b) the received FSK signal with5 times upsample

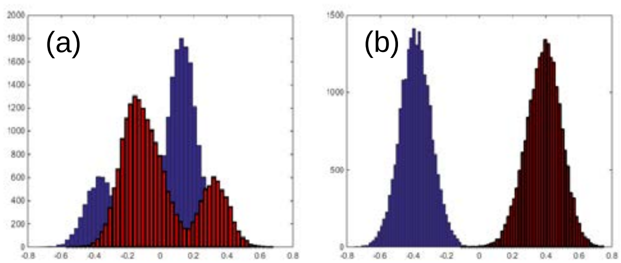

Fig. 5 The influence of the re-timing deviation of the histogram for the received FSK signal when (a) bad re-timing, (b) good re-timing

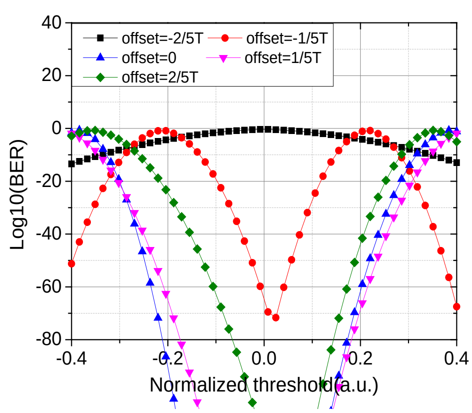

Fig. 6 The measured BER as a function of the decision threshold with various timing offset.

After doing resembling to the receiving signal, we do research on how the threshold can affect the BER performance and show it in Figure 6. Assuming the best re-timing is with zero offset, the measured BER as a function of the decision threshold are shown in this figure with different offset to bit duration ratio. It is clearly that when the offset changing from 0 to 1/5 time duration, a relatively wider threshold operation range can be achieved for acceptable BER. However as soon as the off-set departure from these range, the operation range of the threshold could be deteriorated severely due to the eye-closure. This phenomenon also reveals the fact that giving the good time recovery in the receiver, the system can have a very robust attribution to the decision electrical level. While if the system has no good time recovery at the first step, the whole system performance will be decayed.

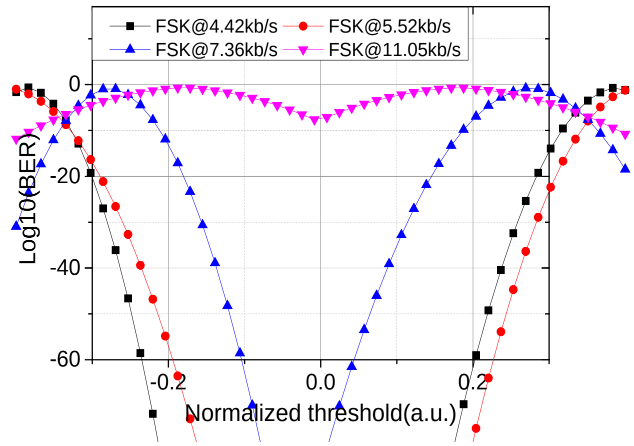

Fig. 7 The measured BER as a function of the decision threshold with various FSK data rate.

We analyze the system performance of different FSK data rate, as shown in Fig.7. It worth noting that audio interface has a build-in ADC at 44.1K Sa/s. This component will limit the FSK signal to be less than 22 Kbit/s due to the nyquist theorem. The measured results show a good tolerance on the decision threshold level at low data rate from 4.42 Kbit/s to 7.36Kbit/s. However for the case of FSK signal at 11 Kbit/s, the measured BER has a cliff style drop. Therefore our system would have a good performance for a FSK data rate below than 7Kbit/s.

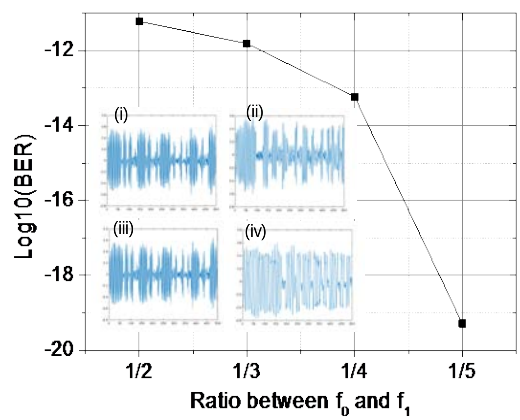

Fig. 8 The measured BER vs. ratio between f_0 and f_1.

We test the influence of the FSK tone spacing, as shown in Fig.8. Obviously the measured BER is decreasing when the ratio between FSK two tones are reduced, indicating a large spacing is preferred in the VLC system to make a g ood seperation between FSK ‘1’ tone and ‘0’ tone. The inset figures show the received waveform at different cases. Due to the large flucturation of VLC frequency response, the signal voltage will be dramatically changed.

Finally the real-time operation is carried out. The system parameters are set to the optimum point as we obtained from the off-line measuement. The signal from the development board are well modulated on the LED light and go all the way from the free space transmission over around 8 meters. The smartphone app can correctly demodulated the received signal and display the final result on the screen. As shown in Fig.2, the detected signal has zero bit error compared with the input signal.

B. System Description

The Toshiba Portege R600 U2530 laptop is powered by Intel Core 2 D uo SU9400, 1400 M ega Hertz (Mhz) processor. This Portege series laptop from Toshiba comes with 3072 Megabytes (MB) of RAM, which is expandable up to Megabytes (MB). Toshiba Portege R600 U2530 laptop or notebook PC has a 128Solid State Drive Gigabytes (GB) hard disk capacity, and HDMI Port. The display of Toshiba Portege R600 U2530 is with 1280 x 800 pixels resolution. This Toshiba laptop has a battery life of hours and weighs around 1 kgs. Operation system Windows 10 running the MATLAB 2017 Software programs.

V. CONCLUSION

A novel visible light communication system based on a commercial LED and a audio interface smartphone receiver are demonstrated based on FSK modulation. The system performance is thoroughly studied in terms of the FSK data rate and the decision electrical level. The real-time operation clearly validate the shceme as a promising cadidate for the future applications in wireless communication network.

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