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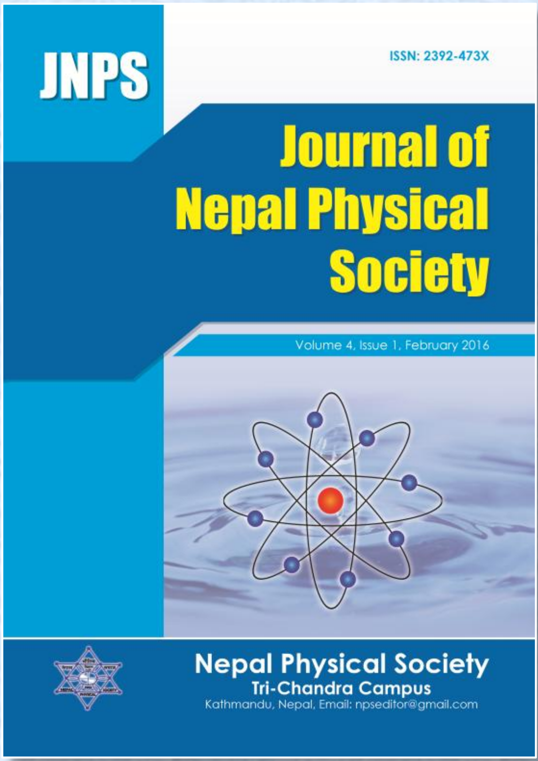

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Research Article

Hadamard Coded Modulation for Visible Light Communication

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ABSTRACT

In the recent days, Visible Light Communication (VLC), a novel technology that enables standard Light-Emitting-Diodes (LEDs) to transmit data, is gaining significant attention. However, to date, there is very little research on its deployment. The enormous and growing user demand for wireless data is placing huge pressure on existing Wi-Fi technology, which uses the radio and microwave frequency spectrum. Also the radio and microwave frequency spectrum is heavily used and overcrowded. On the other hand, visible light spectrum has huge, unused and unregulated capacity for communications (about 10,000 times greater bandwidth compared to radio spectrum). Li-Fi, the wireless technology based on VLC, is successfully tested with very high speed in lab and also implemented commercially. In the near future, this technology could enable devices containing LEDs, such as car lights, city lights, screens and home appliances, to form their own networks for high speed, secure communication. In this paper the performance analysis of Hadamard Coded Modulation (HCM) for Visible Light Communication (VLC) is carried out. Its performance is compared with that of Orthogonal Frequency Division Multiplexing (OFDM). Also wide overview of need of VLC, applications of VLC and design challenges for VLC are observed. The potential application areas of VLC that are identified include smart lighting of buildings, vehicular communication, defense & security, indoor positioning, road safety, hospitals & healthcare, aviation etc. Aside from the high bandwidth availability of VLC, it has the advantages of very high speed, enhanced security of local networks, less susceptible to interference, less expensive due to co-existence with illumination devices and obviously no fear of health hazards due to radiation.

Keywords: Visible Light Communication (VLC), Wi-Fi, Li-Fi, Light Emitting Diodes (LEDs), Radio Spectrum, Bandwidth.

INTRODUCTION

The use of light to send messages is a very old idea. Fire and smoke signalling were used in ancient civilizations. In the early 1800s, the US military used a wireless solar telegraph called "Heliograph" that signals using Morse code flashes of sunlight reflected by a mirror. In 1880, the first example of VLC technology was demonstrated by Alexander Graham Bell with his "photophone" that used sunlight reflected off a vibrating mirror and a selenium photo cell to send voice on a light beam (Mohammad and Maite, 2014).

Visible light communication (VLC) is a data communications scheme which uses visible light between 400 THz and 800 THz (780 nm–375 nm). VLC is a subset of optical wireless communications technologies (Choi *et al.*, 2014). It is new broad band communication technology, in which LEDs are used as data transmitter. Optical wireless communication contains Ultra Violet (UV) and Infrared (IR) communication but VLC is unique in nature than IR and UV because the light sources which used for illumination purpose are also used for communication purpose using same visible light energy.

Different modulation techniques have been used for VLC to achieve extending bandwidth, high data rate and bit-error-ratio within the forward error correction limit. The basic principle of modern modulation techniques for VLC is to convey information using intensity modulation (IM). This means that the information resides in the way how the intensity (power) of the light is varied. The commonly used modulation techniques for VLC are: On - off keying (OOK), Pulse Width Modulation (PWM), Pulse Position Modulation (PPM), Orthogonal Frequency Division Multiplex (OFDM) etc.

ADVANTAGES AND APPLICATION AREAS OF VLC

The visible light frequency spectrum is10000 times higher than RF frequency spectrum. In addition, visible light spectrum belongs to ISM (Industrial, Scientific, and Medical) band which is unlicensed and cost free. Nearby 1000×data density of RF can be achieved in VLC as RF spread out and produces interferences in nearby while visible light is inflexible in lighting boundary. VLC system having high device bandwidths, high intensity optical output and low interference can be used to achieve high data rates. RF is invisible and makes network planning complicated.

VLC is cost effective too. It requires fewer components than radio technology. It is a low cost solution. Data transmission requires negligible power using LED light sources and LED light is efficient (Wang, Zhu and Zhang, 2010). In under water communication, VLC works well than RF transmission. Under water RF communication is extremely difficult as attenuation of signals is more (Noshad and Brandt, 2014). There is no known medical health issue or protection in relation with VLC. In VLC like RF communication, complex antennas are not required for data transmission through the light from the light source. RF antennas are hazardous in locations like chemical plants, hospitals (Obrien *et al.*, 2008).

VLC is more secure than radio technology. Boundaries of communication in VLC are restricted to illumination region only as visible light does not cross walls of the illuminated region. Major areas of application for VLC are Indoor communication in home, hospital, office, Vehicle Transport etc. VLC is used to interconnect mobile phones, computers, tablets, printers and accessories. VLC does not produce any interference like EMI or RFIdue to which there is no interference with medical instruments like CT scan, MRI scanners (Lee, Park and Barry, 2011). LED light sources can be utilized for communications between two vehicles and as well as a vehicle to way side equipment like road traffic light signals. VLC can be used in airplane traveler light to listen music and watch video. Also, it can be used in airplane navigation lights for transmission of identification (Mesleh, Elgala and Has, 2011).

OFDM AND HCM FOR VLC

Orthogonal frequency division (OFDM) is a method of encoding digital data on multiple carrier frequencies, in which input data stream is divided into lower data rate parallel sub streams which modulates several subcarriers. As the transmission rate is made slower in parallel subcarriers, a frequency selective channel appears to be flat in each subcarrier. Hence, OFDM effectively converts a wideband frequency selective channel into a collection of parallel narrowband flat fading channel. OFDM is advantageous compared to Frequency Division Multiplexing (FDM) in terms of spectral efficiency. The OFDM system consists of Fast Fourier Transform (FFT) and parallel to serial convertor at the transmitting side. At the receiving side, it consists of Inverse Fast Fourier Transform and serial to parallel convertor. The channel is optical channel in which light signal from an optical source (e.g. LED) is propagated.

The Hadamard transform (also known as the Walsh–Hadamard transform, or Walsh transform) is an example of a generalized class of Fourier transforms. It performs an orthogonal, symmetric, linear operation on 2^m real numbers (or complex numbers, although the Hadamard matrices themselves are purely real). Hadamard coded modulation (HCM), which uses a binary Hadamard matrix to modulate the input data is an alternative to OFDM. The HCM signal $x = [x_0, x_1 .... x_{N-1}]^T$ is generated from the data sequence $u = [u_0, u_1 .... u_{N-1}]^T$ as:

$$x = (H_N u + \bar{H}_N \bar{u}) \qquad (1)$$

Where, H_N is the binary Hadamard matrix of order N, $\bar{H}_N$ is the complement of H_N, and the matrix (H_N-$\bar{H}_N$) is the bipolar Hadamard matrix. The components of u are assumed to be M-ary pulse amplitude modulated (PAM). The complexity of HCM is the same as OFDM since an N-size FWHT also has a computational complexity of order N $\log_2 N$.

Binary Hadamard matrices are used to encode the input data stream. If N is a nonnegative power of 2, the N×N Hadamard matrix, denoted H_N, is defined recursively as follows:

$$H_{2N} = \begin{bmatrix} H_N & H_N \\ H_N & -H_N \end{bmatrix} \qquad (2)$$

The N×N Hadamard matrix has the property that

$$H_N {H_N}^T = N I_N \qquad (3)$$

Where, I_N is the N-by-N identity matrix.

METHODOLOGY

System Parameters:

Basic parameters are chosen to be same for the both cases, so that performance comparison is easier and reasonable. Prior to perform the necessary transform e.g. FFT, IFFT, FWHT, IFWHT the following parameters are set for both OFDM and HCM.

System Parameters for OFDM:

FFT size: 64, Number of tones used 52 (12 zero tones), Number of pilots 4 (data tones = 52-4 = 48 tones), Bandwidth: 20MHz, Subcarrier spacing: Δf = 20 MHz / 64 = 312.5 kHz, OFDM symbol duration: $T_{FFT} = 1/\Delta f = 3.2\mu s$, Cyclic prefix duration: $T_{GI} = 0.8\mu s$, Signal duration: $T_{OFDMsignal} = T_{FFT} + T_G$

System Parameters for HCM:

FWHT size: 64, Number of tones used 52 (12 zero tones), Number of pilots 4 (data tones = 52-4 = 48 tones), Bandwidth: 20MHz, Subcarrier spacing: Δf = 20 MHz / 64 = 312.5 kHz, Noise levels: −30 dBm, Cyclic prefix length: 4, Cyclic prefix duration: 0.8μs

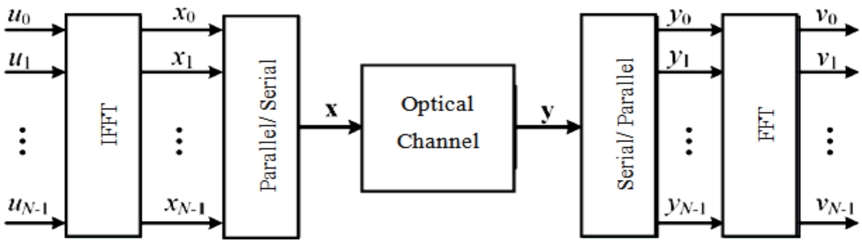

Fig. 1. Overall Block Diagram of an OFDM System.

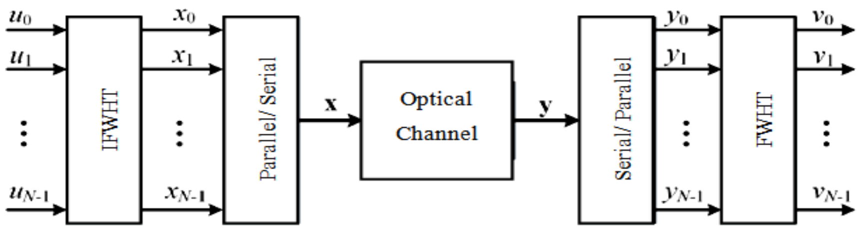

Fig. 2. Overall Block Diagram of a HCM System.

Hadamard Code Generation:

The Hadamard Code Generator generates a Hadamard code from a Hadamard matrix, whose rows form an orthogonal set of codes. Orthogonal codes can be used for spreading in communication systems in which the receiver is perfectly synchronized with the transmitter. The Hadamard codes are the individual rows of a Hadamard matrix. Hadamard matrices are square matrices whose entries are +1 or -1, and whose rows and columns are mutually orthogonal.

Hadamard Coded Modulation:

The HCM transmitter performs Hadamard Coded Modulation of the input data. As shown in the figure 4.1, the components of ***u*** are assumed to be modulated using M-ary pulse amplitude modulation (PAM). The HCM signal $x = [x_0, x_1 .... x_{N-1}]^T$ is generated from the data sequence $u = [u_0, u_1........u_{N-1}]^T$ as:

$$x = (H_N u + \overline{H}_N \bar{u}) \tag{5}$$

Where, H_N is the binary Hadamard matrix of order N, $\overline{H}_N$ is the complement of H_N, and the matrix $(H_N - \overline{H}_N)$ is the bipolar Hadamard matrix.

The equation 5 can also be written as:

$$x = u(H_N - \overline{H}_N) + \frac{N}{2}[0, 1, 1, ...1] \tag{6}$$

The first component of u is set to zero, and hence, the rate of M-PAM HCM is (N − 1)/N log2M. Then due to the fixed cross-correlation between these remaining N − 1 rows, the interference of the Hadamard codewords on each other can be removed at the receiver side. Assuming the noise due to channel to be additive white Gaussian noise (AWGN) the BER of M-PAM HCM is calculated as:

$$BER_{HCM} = \frac{M-1}{M\log_2 M} Q\left(\sqrt{\frac{3}{M^2-1}}\frac{\sigma}{\sigma_n}\right) \tag{7}$$

The reciever for the HCM technique is shown in figure 2. The decoded vector ***v*** is obtained from the received vector y as:

$$v = \frac{1}{N}\left(y\, H^T{}_N - y\, \overline{H}^T{}_N\right) + \frac{1}{2}\,[1 - N, 1, 1, ... 1] \tag{8}$$

RESULTS AND DISCUSSION

Simulation Result and Analysis using Rayleigh Fading Model:

First, the simulation has been carried out under the Rayleigh channel in OFDM and HCM case. Here, two modulation techniques namely the BPSK and PAM have been used for OFDM and HCM respectively and the result is compared between these two modulations in Rayleigh fading channel.

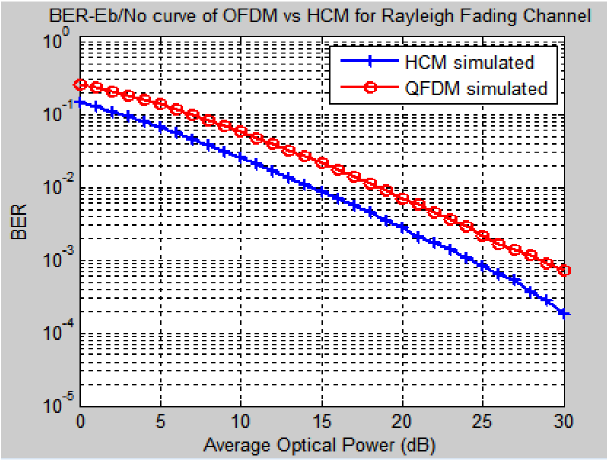

Fig. 3. BER vs. SNR plot of OFDM and HCM using Rayleigh Fading Model.

Analyzing the graph plots of figure 3 for the OFDM and HCM in the Rayleigh fading channel, it can be conclude that the BER of both OFDM and HCM decreases as the average optical power is increased and the HCM system exhibits better BER performance than OFDM for VLC.

Simulation Result and Analysis using Rician Fading Model:

From the figure 4 it can be again conclude the HCM system exhibits better BER performance than OFDM in the case of the Rician fading channel. When the performance between Rayleigh and Rician channel compared the Rician channel gives the better results for the same modulation due to the line of sight component present in this channel.

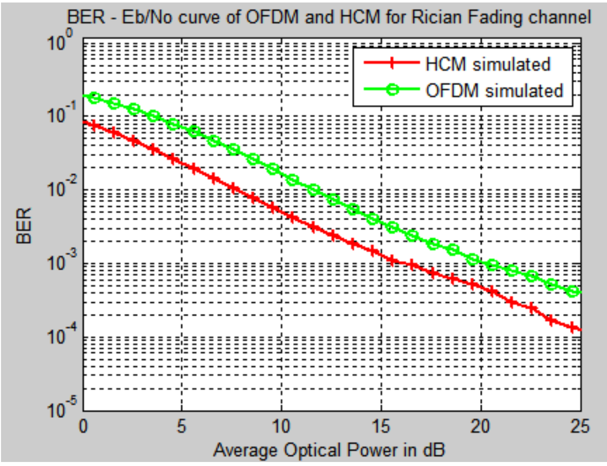

Fig. 4. BER VS SNR plot of OFDM and HCM using the Rician Fading Model

CONCLUSION

The Hadamard Coded Modulation (HCM) achieves a lower error probability than Orthogonal Frequency Division Multiplexing (OFDM). The bit error rate in HCM is shown to have reduced values as compared to OFDM for all power levels in visible light communication because of the fact that the HCM transmits a signal with substantially lower PAPR. For the average optical power of 10 dB, the bit error rate achieved is about 8×10^{-2} for OFDM whereas only 2×10^{-2} for HCM. The result is also satisfactory because the BER performance directly dependent over PAPR performance. In HCM, the average power required to achieve a given BER is reduced. Thus, it can be concluded that HCM is better suited in terms of bit error probability for visible light communication.

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