Li-Fi Communication using OFDM Visual Light Communications

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***Abstract*—In this paper wireless communication using white, high brightness LEDs (light emitting diodes) is considered. In particular, the use of OFDM (orthogonal frequency division multiplexing) for intensity modulation is investigated. Li-FI have a unique modulation technique called single carrier techniques multi-carrier techniques and color modulation techniques. Modulation techniques are as On-Off keying, Pulse width Modulation, Pulse Amplitude Modulation, Orthogonal Frequency Division Modulation and alternative digital modulation technique are summarized. Simulation is the imitation of the operation of a real-world methodology. The act of simulating requires that a model be developed and simulates the operation of the system over time. This paper tends to analyze the single carrier modulation techniques such as BPSK, QAM, and also tends to provide information on digital modulation technique parameters as Bit Error Rate, and its Performance.**

Keywords—VLC; QPSK ; QAM ;BER.

I. INTRODUCTION

In an optical communication system, it is possible to modulate the transmitted optical signal in a variety of ways. The phase/frequency, polarization, or the intensity of the optical signal can be modulated. Intensity modulation has the advantage of being particularly easy to implement; the optical output power of the source is simply varied according to the modulating signal. The optical signal thus produced is also easy to detect - the modulating signal is easily recovered from the output of a photodiode. The inherent robustness of OFDM against multipath effects makes it an excellent choice for situations where multiple transmitters are used simultaneously (to avoid shadowing effects) and a path difference to the receiver exists. One of the major disadvantages of an OFDM based system is the characteristic high crest factor of the time domain signal. In traditional RF based systems, this usually necessitates a transmitter with a high dynamic range and hence results in reduced power efficiency. In the proposed optical LED system, this disadvantage is turned to an advantage - the time domain OFDM signal is used to modulate (IM-DD) the optical source. The signal variations are around an operating point determined by the particular LED in use. It is chosen such that the LED operates in the linear region of the current vs. intensity curve.

II. SYSTEM DESIGN

The communication chain is implemented using a pair of digital signal processing development kits (Texas ***Instruments TMS320C6711****). The D/A converters of the boards have a precision of 16 bits and operate at a frequency of 8kHz – offering a maximum system bandwidth of 4kHz and a sampling interval of 125µs. The on-board DSP is capable of floating point operations. With a 64-point IFFT (inversefast Fourier transform) the duration of an OFDM symbol is (64 × 125µs =) 0.008s. With QPSK (quadrature phase shift keying) modulation, the maximum number of bits transferable by each OFDM symbol is then (64 × 2 =) 128. The ideal system is then capable of a maximum raw (assuming no guard or pilot, and all subcarriers are modulated by independent data streams) data rate of a 128 0.008 = 16kbps. However, with the IFFT framing structure chosen for the implementation, the maximum achievable data rate (assuming no guard or pilot) is approximately 8kbps.*

III. TRANSMITTER

The transmitter consists of a file processor, QPSK modulator, and an OFDM modulator. The file processor accepts an ASCII data file consisting of the binary data stream. The data read from the file is encoded using the QPSK modulation scheme by means of a lookup table:

00 ⇒ 1+j **10 ⇒ -1 + j**

01 ⇒ 1-j **11 ⇒ -1 – j**

The symbols then undergo a serial to parallel conversion in preparation for the IFFT operation. The parallel data stream is then used to design the data frame for the IFFT. The first element of the data frame represents the DC value and hence is chosen to be zero. If the number of subcarriers is M, and the IFFT size is N, then elements 2 to M + 1 of the frame consist of the parallel data and elements N − M + 1 to N consist of the conjugate complex and mirrored version of the data. If N > 2M + 1, the intermediate elements are zero. N < 2M + 1 is not feasible and hence the condition N ≥ 2M + 1 must be strictly enforced. When N = 2M + 1, there are no intermediate zero elements. The transpose of a sample frame is shown in Fig. 2. For the simple one LED transmitter, this is necessary to ensure

0	a	b	c	d	· · ·	0	· · ·	d*	c*	b*	a*

Fig. 2. Sample IFFT input frame (transposed)

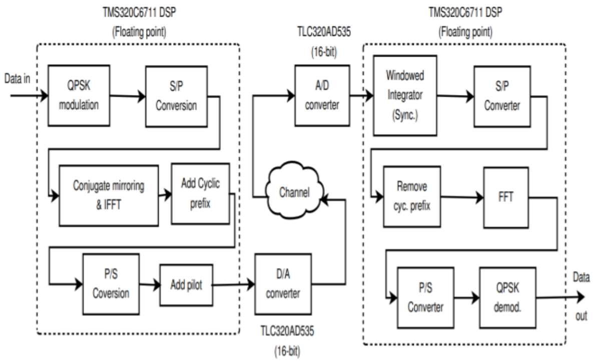


Fig. 1. Block diagram of the OFDM communication chain

that the output from the IFFT operation is real valued. In favour of simplicity, the resulting reduction in the spectral efficiency by a factor of two is accepted – again, this setup should primarily provide a proofof-concept. Many white LEDs are in effect a combination of red, green and blue LEDs and hence, it is also possible to use the regular data frame structure (no complex conjugate mirroring) and modulate two of the three LEDs to transmit the real and imaginary parts of the resulting complex OFDM symbols separately. The third LED can be left active but unmodulated to maintain ”whiteness”. Of course the two LEDs can also be used with the modified IFFT frame structure to provide full-duplex communication. The receiver would then also have to employ two photo-diodes – each filtered to be sensitive to the wavelength of one of the LEDs. Once the IFFT operation is carried out, the output is processed to append a 5μs cyclic prefix for protection against multipath effects. The guard length was chosen such that any such effects can be safely ignored. Once the prefix has been added, the parallel data stream is converted back into a serial stream. Before the OFDM symbols are transmitted via the D/A converter, a pilot sequence is transmitted. The sequence is one OFDM symbol long and consists of two complete sinusoids separated by zeros (Fig. 4). The peak-to-peak amplitude of these ”guard sinusoids” is approximately 2.5V and hence they are as strong as the strongest data signal in the time domain waveform. This special structure is needed for successful synchronization at the receiver. The synchronization procedure is detailed in Section II-B. The transmitter then stops processing further data and repeatedly transmits the sequence of OFDM symbols and the pilot until a feedback from the receiver is obtained via a wired return channel. Once the transmitter reaches the end of the ASCII data file, it transmits a predefined bit pattern to signal the end of file to the receiver and stops. An OFDM time domain signal depicting the typically high peak-to-average ratio is shown in Fig. 3

IV. RECEIVER

The receiver starts by capturing a data stream two frames long. This ensures that the captured data contains at least one

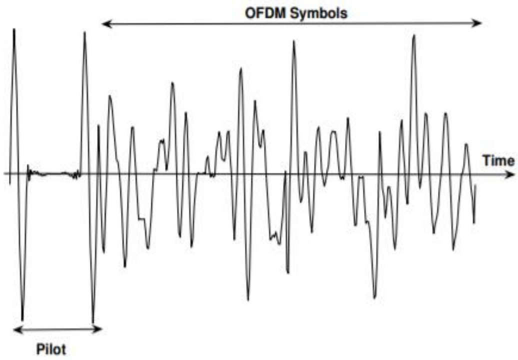


Fig. 3. A Typical Time Domain Signal

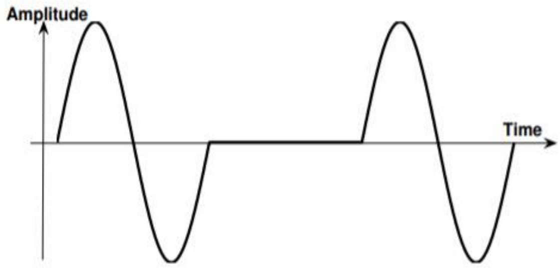


Fig. 4. The Pilot Symbol

contiguous frame (one pilot symbol and OFDM symbols). Once the symbols have been captured, the receiver signals the transmitter to continue processing the next set of data. The captured symbols are then run through a synchronization detection subroutine. The detector is essentially a running integrator with a window size equal to the length of the silent period (zeros) in the pilot symbol. The integrator scans through the absolute value of the captured data stream one sample at a time and records the index of the position where the minimum value of the integral was observed. As the integrator only considers absolute values, the integral over a sinusoid is a non-zero number. At this point the advantage of the special pilot structure becomes clear – the guard sinusoids provide an effective contrast between themselves and the silent period and hence make it easier for the detector to reach the correct decision. Eventually, the integrator window will come into alignment with the silent portion of a pilot symbol and it is here that the lowest integral will be recorded. Thus the index to the start of the OFDM symbols is determined. Then, using this index, the OFDM symbols are extracted and run through the serial to parallel converter. Once the data is parallelized, the cyclic prefix is removed and the frame is passed to the FFT operator. The FFT operation reproduces the mirrored frame structure designed in the transmitter. The upper half (elements 2 to M + 1) of this frame is retained as the valid result. The complex data is then passed through the QPSK demodulator to recover the binary data.

A. OPTICS CHANNEL

For the theoretical analysis a suitable channel model is required. The channel model used is that proposed by Barry et al. [3]. For the line of sight (LOS) case with no reflections and assuming that the source and receiver separation squared (R2) is much greater than the receiver area (AR), the channel impulse response can be approximated by a scaled and delayed Dirac delta function

h (t; S, R) ≈ n + 1/ 2π cos^n(φ) dΩ rect (θ /FOV) δ (t – R/ c) ……….. (1)

where S is the source and R is the receiver. The simple source is defined as S = {rS, nˆS, n}; rS is the position, nˆS is the orientation, and n is the mode number associated with the directivity of the source and can be calculated from the source half-angle, αH, using (2) [4]. The simple detector is defined as R = {rR, nˆR, AR, FOV }; rR is the position, nˆR is the orientation, AR the receiver area, and FOV the field of vision.

αH = cos−1 (0.5)^ 1/ n …..(2)

dΩ is defined as the solid angle subtended by the receiver's differential area

dΩ ≈ cos (θ) AR/ R^2……. (3)

θ is the angle between nˆR and (rS − rR)

cos (θ) = nˆR · (rS − rR) R ………(4)

φ is the angle between nˆS and (rR − rS)

cos (φ) = nˆS · (rR − rS)/ R ……(5)

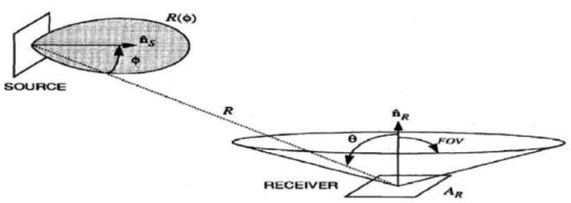


Fig. 5. Source and Detector Geometry [3]

The function rect (x) is defined as:

rect (x) ={1 for |x| ≤ 1
{ 0 for |x| > 1 (6)

c is the speed of light. The approximation to the impulse response approaches equality as the ratio AR R2 approaches zero. The source and detector geometry is best explained by Fig. 5. Although an algorithm to derive the channel impulse response

for multiple reflections is provided in [3], the influence of multiple reflections was neglected; as the 5µs guard in the OFDM symbols is more than enough to mitigate any multipath effects encountered.

At this point, it is necessary to note that the channel equation

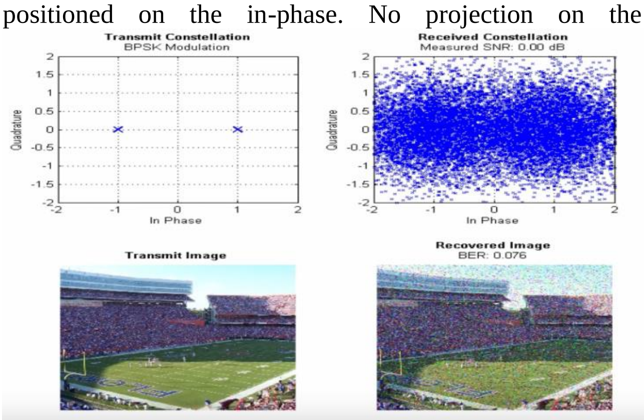
y = r · (x ∗ h) + n (7)

relates the transmitted power to the received current. The input signal x is a power signal, the channel transfer function

h is dimensionless, and the receiver responsivity factor r represent ts the conversion ratio between received optical power and photodiode current at the receiver. Consequently, the received signal y and the additive white Gaussian noise ˜n are currents. In optical channels the quality of the transmission is dominated by shot noise; the ambient light striking the detector leads to a steady shot noise that can be considered as a Gaussian noise process

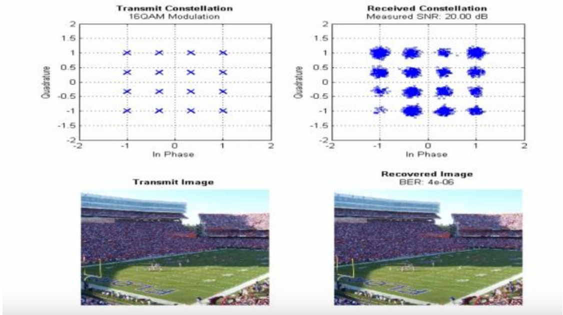
B. type of modulation schemes

Binary phase shifting key: -BPSK is also usually referred to as Phase reversal keying, or 2PSK.BPSK is the best form of Phase-Shift Keying. BPSK uses two phases are separated by 180° which is called as 2-PSK. The signal state can change from 0 to 1 or 1 to 0, then the phase of the wave changes by 180 degrees. It is capable to modulate at 1 bit /symbol and it is more robust. The constellation diagram for BPSK is two constellation points wholly positioned on the in-phase. No projection on the



- **M-quadrature amplitude modulation**

QAM is a modulation technique where its amplitude is allowed to vary with the phase. The modulation of the amplitudes of two carrier waves conveys two digital bit streams which is called QAM. The two carrier waves are the identical frequency unit of phase with one another by 90 degrees is called as orthogonality quadrature . The main advantage of QAM is blend of two amplitude modulated signals in the identical channel. In QAM, amount of the bandwidth is doubles, thus construction it more efficient . In, QAM there are many various points which will be used, they are a definitive value of phase and amplitude. This is often referred as a constellation diagram. The constellation points are generally organized in an exceedingly square grid. The constellation will have a square with the number of points adequate to an influence of two i.e. 4,16,64 i.e. 4 QAM,16QAM.64QAM, etc.,



Modulation scheme of OFDM			
Schemes	***Data rate***	***SNR***	***BER***
BPSK	*1bit/1 symbol*	*0 dB*	*76*
16QAM	*4bit/1 symbol*	*20 dB*	*4.06e^-6*

ACKNOWLEDGMENT

The experimental results validate the claim that intensity modulation using OFDM is indeed feasible; the high crest factor that plagues OFDM RF equipment is no longer a disadvantage. We have presented Li-Fi and its modulation techniques which is essential for communication. Li-Fi is the upcoming technology of data communication. Since it is simple to generate light waves, it is appallingly advantageous and simply implementable in varied fields. Li-Fi technology is very advanced to the LAN. It has wider bandwidth, fast response time and quicker than Wi-Fi. Each light in the world will be replaced by the LEDs and would act as data hotspot. As it is very low-cost, each and every one can afford it.

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