

Visible light communication: implementation and analysis

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Abstract

Major research in Visible Light Communication is at simulation level and researcher needs a test system for the physical implementation of VLC. LEDs are predominantly used everywhere due to greater development in technology of light sources. LED sources are used in Visible Light Communication for an eco-friendly world due to its advantages over conventional wireless communication systems like Radio Frequency. Communication between two personal computers using Visible Light Communication system is implemented and tested for various distances between transmitter and receiver. The neutral white LED array of 12W and PIN photodiode for visible light range is used for downlink purpose and uplink is implemented using simple IR LED and photodiode. The system is implemented using ATmega328 board. Maximum communication distance is achieved up to 2.1 m.

Keywords: Frequency Shift Keying (FSK); on-Off Key (OOK); Visible Light Communication (VLC).

1. Introduction

In the history, light signals are used for communication purpose over long distance like smoke signals were used to convey information. The ancient Greeks used polished shields to transmit messages by reflecting sunlight. The world's first wireless telephone message successfully transmitted over a distance of 213m on 3rd June 1880 by the father of telephone system Alexander Graham Bell and his assistant Charles Tainter and the device is called as Photophone [1-3]. VLC is a branch of Optical Wireless Communication (OWC). In VLC for data transmission visible light is used as the wireless communication medium. Light Emitting Diode (LED) is the ultimate component of VLC system as its having numerous advantages over conventional light sources like sodium lamp, fluorescent lamp. LED is a semiconductor device due to which it's having inherent fast switching capability. The LED is having advantages like larger lifetime, high energy conversion efficiency, and overall low maintenance cost and humidity tolerance [3, 4]. The wavelength range of 750nm to 1mm belongs to Infra-Red (IR) frequency spectrum. For data communication purpose the near-IR wavelengths from 780nm to 950nm are used. Due to which most of the advantages of wireless IR systems are present in VLC systems with light behavior. Therefore, the research for techniques and models of wireless communication systems using the visible range of the electromagnetic spectrum appears as a viable alternative [5].

In today's world the importance of wireless communication systems is hardly needed to be accentuated. Recent wireless communications systems have been conquered by Radio Frequency (RF) based technologies. It becomes highly necessary to find alternatives to RF wireless systems due to their disadvantages [6]. IR technologies were presented as an alternative for the RF based systems and which offering several benefits in bandwidth, implementation simplicity and data security. However, they never became a mainstream technology due to IR rays are harmful to the

human being. Fiber optics technology plays main important role in guided communication channel. In VLC, data is transmitted by the modulating intensity of the LED and information is recovered back by using the photodiode as receiver. Different modulation techniques are used for modulating the intensity of LED source like On-OFF Key (OOK), Frequency Shift Key (FSK) [7], [8]. VLC is mainly implemented to reduce the bottleneck of RF communication during the downlink. So for full duplex communication VLC link is mainly used for downlink and alternative link is designed using IR. In recent years, many research works are carried out in VLC and most of the research work is in simulation or mostly in an initial stage. In this paper, a full duplex VLC system is designed and implemented using ATmega328 board. For downlink, 12W cool white LED array is used as the source and a special PIN photodiode as receiver. Additional IR LED-photodiode pair is used for uplink. The system is successfully implemented in indoor environments and maximum distance between the LED array source and photodiode 2.1m. We have achieved the maximum speed 128 Kbps up to distance 2.1m. Which quite a great achievement as compared to MPU H8/3096F based system [9] and OpenVLC protocol [10].

2. System design

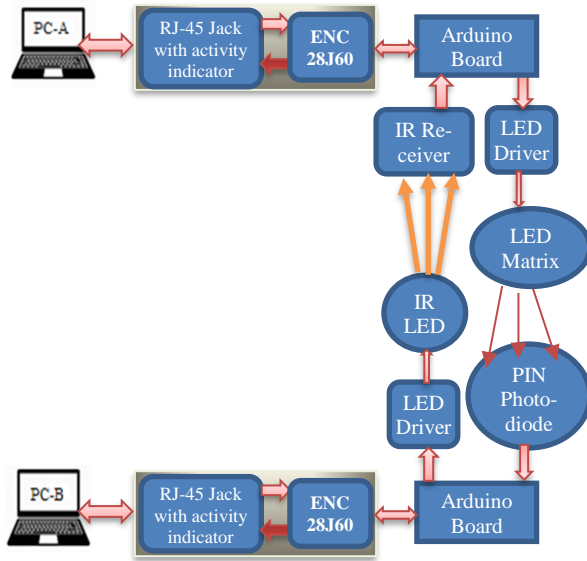


Fig. 1: VLC Block Diagram.

This system is a low cost test system for researchers. The communication between two computers, Personal Computer (PC)-A as a server and PC-B as a client is carried out using VLC. Two add-ons are designed and implemented separately, which is shown in Figure 1. One add-on is designed with a visible light transmitter for down link and photo diode for uplink receiver. Another add-on is designed with photodiode as visible light receiver for downlink and IR LED as a transmitter for uplink. The data from the PC-A through Ethernet is sent to the Ethernet controller ENC28J60 which connected to ATmega328 board using Serial Peripheral Interface (SPI) protocol. This data from ATmega328 controllers is given to switching control and transmitted serially to the LED driver circuit. This LED driver circuit actually converts electrical energy into optical energy. The Switching of LED from ON state to OFF state and OFF state to ON state is at very high speed which is above the rate of persistence of vision due to which flickering of light intensity is not observed by a human being. So the illumination and data transfer can be achieved simultaneously. Proportional output current is generated by the PIN photodiode when light falls on it at the receiver end. PIN photodiode converts Optical signals back into electronic form. This low power signal pass through signal conditioning block and then filter to recover back original signal. Now the signal which transmitted by the LED array has been recovered back at the receiver end. These signals are fetched with ATmega328 and given to PC-B through Ethernet controller ENC28J60. The primary goal of the system is to convert persistent light sources into VLC transmitters. These VLC transmitters must be connected to the main network from where it'll access the requested data and transmit it. Ethernet lines already present in most of the offices and homes. Local Area Network (LAN) networks which make them as persistent light sources. So in order to bring a light source on the grid just connect it to the LAN through developed hardware.

For interfacing of a PC with VLC hardware serial communication is a simpler way to implement than Ethernet. And the most important thing is that it will make any microprocessor and microcontroller based VLC transceiver system redundant. It will drastically bring down the cost of the system. A router can also be used in between the computer and VLC transmitter. A router will allow multiple VLC transmitter connections and will also support dynamic IP address assignment using techniques like Dynamic Host Configuration Protocol (DHCP). In order to use DHCP without router (to save system cost) we can use software like DHCP Server on a computer. This setup consists of an RJ45 Ethernet jack with on board network activity indicators and ENC28J60 module.

An Arduino board simplifies and reduces the required hardware and software cost of the development system which need to get the system running. Arduino uses ATmega8U2 on board for programming and debugging tool which makes it so much simpler for the system development. From the system development point of view Arduino provides a number of libraries to make programming the microcontrollers easier than the other. The channel used in this scheme is free space Industrial, Scientific and Medical (ISM) frequency band. Different intensity modulation technics can be implemented for the ranging purpose like On-Off Keying (OOK), Frequency Shift Key (FSK), Orthogonal Frequency Modulation and Phase Shift Key (PSK).

Arduino development board (Arduino UNO) consists of ATmega8U2 and ATmega328 on-board, out of which ATmega8U2 is preprogrammed to work as programmer for ATmega328. It can be used for debugging of the same. Arduino is connected to the LED matrix via LED driver circuit. Arduino drives this circuit through its Serial TX pin. The LED driver circuit is powered by a 45V, 350 mA DC power supply. This LED driver circuit is driven by Darlington pair. Darlington pair has advantages that it increases the current sinking capability of circuit without changing its bandwidth.

A specialized PIN photodiode is used in Photovoltaic mode. Without biasing this photodiode we can minimize the noise in the output of the output driver circuit. Due to low output current of a PIN photodiode in photovoltaic mode, the gain of the amplifier circuit needs to be higher. The rest of the receiver hardware is identical to that of the transmitter system. The photodiode is connected to a trans-impedance amplifier for current to voltage converter. The output of the trans-impedance amplifier is given to the Arduino board. PC-B and Arduino board is connected using ENC28J60 module. The visible light is used for the downlink communication purpose. IR LED and photodiode pair is used for the uplink communication purpose so that it will not disturb the operation of the downlink. Both IR LED and photodiode are matched to each other and work in spectrum away from that of visible light.

3. System working

Client computer (PC-B) requests for an HTML page of website by requesting its URL to the server via uplink. Server (PC-A) processes this URL request and transmits respective website HTML pages to the client's browser using downlink. The requested website is then displayed in client (PC-B) web browser. Functional overview of the system is shown in the Figure 2. To implement a mechanism described above the types of protocol to be used in the Transport layer along with the Internet Protocol (IP) in the Network layer of the OSI model for communication has to be selected. There are three possible protocols for Network layer and they are Transmission Control Protocol / Internet Protocol (TCP/IP), User Datagram Protocol (UDP) and Real time Transmission Control Protocol (RTCP). Implementation of TCP/IP was avoided due to its error correction and continuous alive client requirement. No Arduino libraries are available for RTCP protocol. So UDP is implemented in this system. Socket address is a combination of IP address and Port number. Separate socket addresses are required

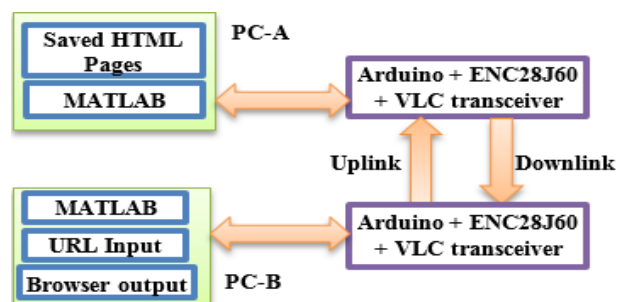


Fig. 2: Functional Overview.

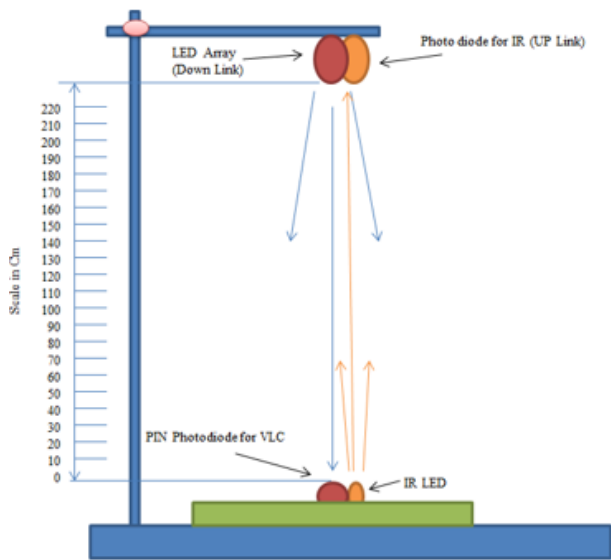


Fig. 3: Experimental Setup.

For data transmission and reception. Due to which four different socket addresses are assigned in this system two for PC-A and PC-B and two for Arduino on TX and RX. As automatic addressing like DHCP is not used in this system so IP addresses assigned to the computers and Arduinos are static addresses, these IP addresses remains unchanged throughout the operation. Static addresses make debugging easier using software like UDP test tool.

a) Uplink Working:

Uplink starts from the MATLAB program on the client side where it asks for the URL to the user. The user enters the required URL in MATLAB browser. This is nothing but a simple text string which is stored on the server. This string or data are first filled in UDP packet and Sent to RX Arduino. The first packet is received by ENC28J60 and it verifies whether this packet is intended for its host controller i.e. Arduino. Then it passes whole data, including header to the Arduino board. Error checking for this packet is also handled by ENC28J60. Then Arduino handles parsing of this packet. It extracts URL form this packet and uploads it to the TX Arduino via IR uplink. This IR uplink is implemented through a custom made protocol similar to Serial communication with a start bit and stop bit for each byte. This uplink of data takes place at 10 Kbps. Then the TX Arduino receives this URL, and creates a UDP packet with the URL in it. Then it sends this packet to the server for further processing.

b) Downlink working:

Server continuously listens to the client request when it receives one, then, according to received URL it selects the saved HTML pages in PC-A and generates UDP packet that contains the textual data of this html page. This packet is sent to the TX Arduino via

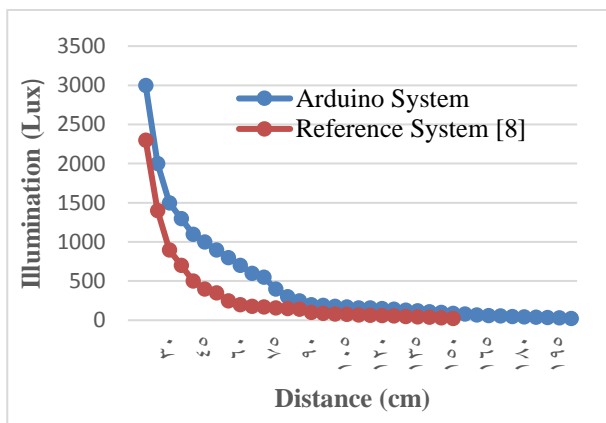


Fig. 4: Relation between Illumination and Distance between LED Array and Photodiode.

ENC28J60. Similar to the receiver, this ENC28J60 also performs filtering packets this filtering will be useful if there are multiple VLC transmitters in the network. TX Arduino parses this packet to extract the HTML text and passes it serially to LED driver which then transmits it to VLC receiver. Why serial communication is used between LED array and PIN photodiode? The reason is here as it can use up to speed of 2Mbps and it remains in the HIGH state, even when there is no data to send so that its servers dual purpose of data transfer and illumination. RX Arduino receives this packet byte by byte through photodiode driver. RX Arduino again generates a UDP packet with header addressed to PC-B that is client. This transfer of packet again takes place using ENC28J60 like the transmitter side. When the client receives the packet, it is handled by MATLAB. It uses inbuilt browser present in the MATLAB to display the HTML page.

4. Result and discussion

One test page of 131,072 bytes size is created using HTML. PC transmitter is set to transmit data with 8 bits (byte) binary. Arduino studio is used to change the data rate by changing the value of baud rate set for UART. In this setup we use baud rate 128 Kbps. The average indoor illumination is 40 lx for the experiment. Experimental setup is shown in Figure 3. The LED light array is vertically movable on scalable track. The distance between the LED array and

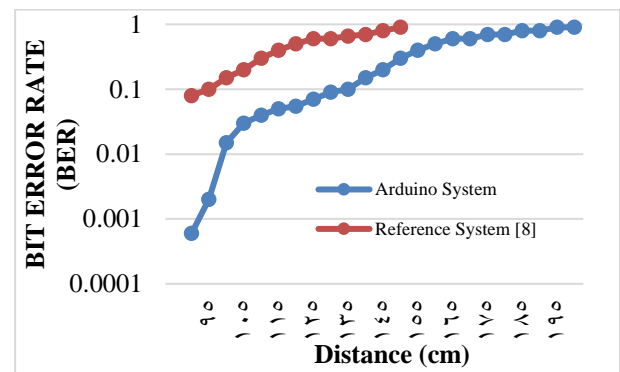


Fig. 5: BER vs Communication Distance.

Photodiode is gradually changed from 25, 35, until 210cm. Initially minimum distance kept between transmitter and receiver that is 25

cm. For which successful communication going to be start and below this range no communication going to take place. Then we started increasing distance between receiver and transmitter to get smooth communication between transmitter and receiver. We found that with increase in distance between transmitter and receiver after 105cm illumination is sharply reduced at photodiode. After the 210 cm distance between a photodiode and the LED array, output data are absent. The system is testified for maximum bitrate of 128 Kbps. Figure 4 shows the relation between illumination and the distance between the LED array and photodiode also output is compared with the reference system [8] and the results are quite satisfied with reference system. Figure 5 shows Bit Error Rate (BER) versus communication distance. For baud rate 128 Kbps system has best performance in the first 135cm. And above 135cm BER increases to limit the communication distance. Hence VLC has a large space to improve.

5. Conclusion

The VLC system possesses tremendous potential and promise over conventional systems like RF. VLC can be used to replace the conventional communication schemes in many walks of daily life. This will prove to be a life saver in the present scenario where constant, earnest efforts are being employed in full force so as to find cleaner, more efficient and environment friendly substitutes

in every trait of technology. The scheme can be used in conjunction with the existing network infrastructure. And this is not all. In this paper VLC system based on a white LED array has been implemented. The system is implemented using ATmega328 Arduino boards for modulation and demodulation purpose. MATLAB software is used for interfacing purpose of Arduino boards with computers. For best performance, maximum distance between LED array source and the photodiode is 2.1m and with a maximum bitrate up to 128 Kbps is achieved. Higher bitrate can be achieved using further improvement in system design. System design using raspberry pi is under development.

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