Enhanced Wireless Data Transmission using LED Modulation

G. Reyes, M. Jilani, A. Nguyen, M. Basharat, J. Farfan, M. Moges
Department of Engineering Technology
University of Houston
gareyes@uh.edu, mujilani@uh.edu, ahnguyen21@uh.edu, mbasharat@uh.edu, jfarfan@uh.edu, mmoges@central.uh.edu

Sai M. Chittajallu, H. Nandagopal
Department of Electrical and Computer Engineering
University of Houston
schittajallu@uh.edu, hnandagopal@uh.edu

Abstract

The explosive growth of wireless systems coupled with the generation of smart phones has propelled the traffic in the available spectrum to reach the channel capacity. This is slowly resulting in congestion, low bandwidth and reduced speed. Hence, there is a call for an alternative, more reliable way to transmit data for communication. This paper demonstrates a technique proposed by Professor Harald Haas, whose research on LiFi helps solve the problem of congestion by alleviating the traditional radio wave workload using visible light communication. The Visible light spectrum operates at a wider bandwidth compared to traditional radio waves, hence allowing for multi-gigabit wireless transfer. In this paper, light from LED bulbs are used to send information using PWM (pulse width modulation) technique and a photodiode is employed to receive and decode the information on the target device. This technique can provide increased packet reliability and increased data transfer speeds for all wireless users. The project was implemented in two phases. In the first phase, the transfer of ASCII codes using the modulation of LED was demonstrated. In the following phase, the transfer of audio file which has a higher bit rate was achieved. By transferring the data from one device to another using light as a medium for communication, this project demonstrates the proficiency of the technology for future developments.

Introduction

“Internet Access is a Human Right” [1], United Nations classifies internet as a necessity for all human. Indeed internet communication is essential for everyone in every field in the modern society. Specifically, wireless communication has become a utility like electricity and water. The rate at which technology innovating, the need for a reliable way to transmit data has become a necessity. To accommodate the need, telecommunication providers are working to resolve the congestion and speed issues with the new technologies like LTE and transforming to more yet smaller base stations such as Picocells [2].

In theory, these smaller cell towers should lead to less users sharing the same amount of spectrum, resulting in more available bandwidth per user [3] [4]. However, multiple small cell sites actually poses significant issues. One of which is inter-cell interference. Multiple small cells with a decent amount of transmission power leads to several areas of signal overlap. This overlap results in signal interference and users will experience dead zones on their mobile devices. Additionally, when people travel, there is handoff from one cell tower to another. In order for the users to move uninterrupted, towers available in that vicinity use small amount of spectrum space to exchange information. With smaller cells this happens much more often and becomes overwhelming. These two major issues lead to an insignificant improvement in capacity and, coupled with the increase in cost, does not prove to be economical in a cost-benefit analysis for carriers.

Literature Review

The increased usage of the modern smartphone as well as quick wireless data technologies such as 3G and now 4G LTE have led to an exponential rise in bandwidth usage. According to Cisco, global mobile data traffic is expected to grow to 15.9 Exabyte's per month by 2018 [5]. This is roughly an increase by a factor of 11 when compared to 2013. Furthermore these numbers are projected to increase 27 fold by year 2020. Although mobile data usage continues to rise, the current allocated spectrum is quickly being exhausted with several bands already considered "full." The year 2013 marked the first year where average mobile data rates dropped. Currently about 1.4 million cellular base stations are deployed to provide this exponential rise in bandwidth to over 5 billion devices. More surprisingly, in 2013 North America only had about 65% of its installed base on smartphones. With about 35% of users still needing to upgrade to smartphones combined with the "internet of things" revolution of placing a network connection on all kinds of devices [6], the already deficit in spectrum poses a legitimate problem for wireless carriers where they are unable to produce more capacity. This issue is already noticeable in densely populated areas such as New York City or Chicago. In crowded areas mobile users have to share cell towers, which results in everyone sharing the same amount of available spectrum, placing them in a queue, which not only lowers the data rate but significantly increases latency. Low latency is critical for real-time applications such as voice-over-IP (VoIP) and video streaming [7].

This paper aims to solve the congestion issue by alleviating the traditional radio wave workload using visible light communication, work based on Professor Harald Haas's research on LiFi [8]. Data transmission using light is a relatively new technology that uses visible light rather than radio waves to achieve wireless communications [9]. It can provide reliable and high-speed data transfer by using simple light source, namely LEDs. This will assist in reducing the congestion of radio waves, along with a low power yet catering an efficient solution to the wireless data problem. The visible light spectrum consists of 10,000x more space compared traditional radio waves allowing multi-gigabit wireless transfer a reality.

The project was broken down into four. The first phase is the Test Phase where simple ASCII code was transmitted through a modulating LED. For this, two Arduino microcontrollers are used as transmitter and receiver. The success of the transmission of data can be verified using serial display screen [10]. Once the transmission of data was achieved, the second phase involving the transfer of data from one device to another device with a higher bit rate was tested. In this phase, a low bit rate MP3 audio data was transferred. Finally, the last phase would modulate internet connectivity in a duplex environment [11]. The web server was connected to a transmitter. The transmitter would transmit packets of information to the receiver. The receiver will translate it and send it to the PC. We look at our transmission rate and improve on it, because this system is supposed to be faster than radio frequency. We want to make sure we meet these conditions. During the length of the project, information will be collected and used as data to complete the project.

Design description

In the initial test phase, the design was focused on two Arduino Microcontrollers and providing connectivity to send and receive ASCII codes using visible light for transmission and a photodiode as a receiver. This also includes the circuit needed to successfully modulate and transfer those ASCII codes. The Arduino Microcontroller has an in-built analog to digital converter and multiple digital/analog outputs. This would greatly reduce the requirement for excess hardware and power consumption. Moreover it is programmed using C++ which uses Object-Oriented methods. The operation of the system in the test phase is shown in Figure 1.

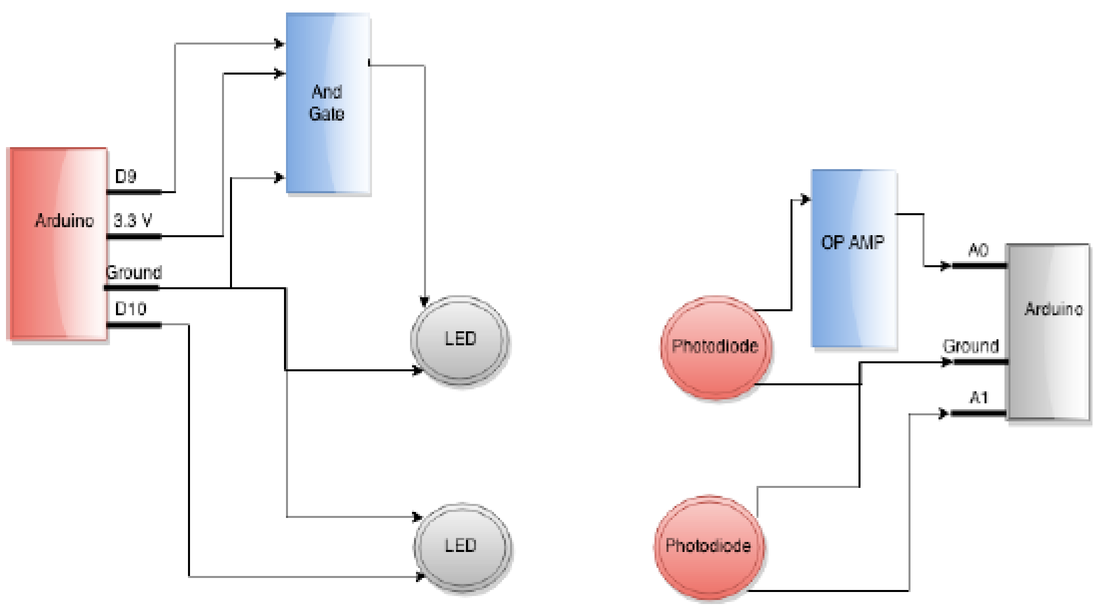

Figure 1. OPERATIONAL FLOW DIAGRAM FOR THE TEST PHASE

Arduino base Transmitter circuit:

The circuit in Figure 2 sends ASCII codes using On-off keying (OOK). In this circuit an AND gate MC74HC08AN was use to have a clean emitter signal. Two 570-ohm resistors were used to limit the current to the LEDs. One of the LEDs is used to send the actual ASCII code bits, and the other to enable the reading of the photodiode receiving the ASCII bits. This was done to prevent the continuous reading from the first photodiode [12].

Receiver circuit:

For the receiver side of the system, two photodiodes are used to detect the light from the LEDs and input that analog signal into the analog pins of the second microcontroller. Photodiode 1 will start reading as soon as GPIO A1 receives a signal from photodiode 2. In this case, resistor R2 is being used as feedback and the 39-pF capacitor as feedback loop. A simple voltage divider circuit was made in order to measure the changes in voltage to receive the signal from Led 2. Figure 3 shows the circuit construction of the receiver circuit.

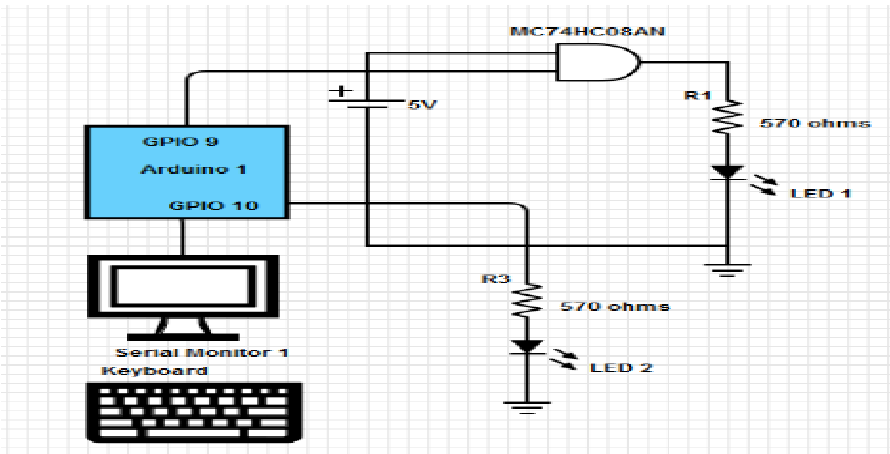

Figure 2. TEST PHASE ARDUINO TRANSMITTER CIRCUIT

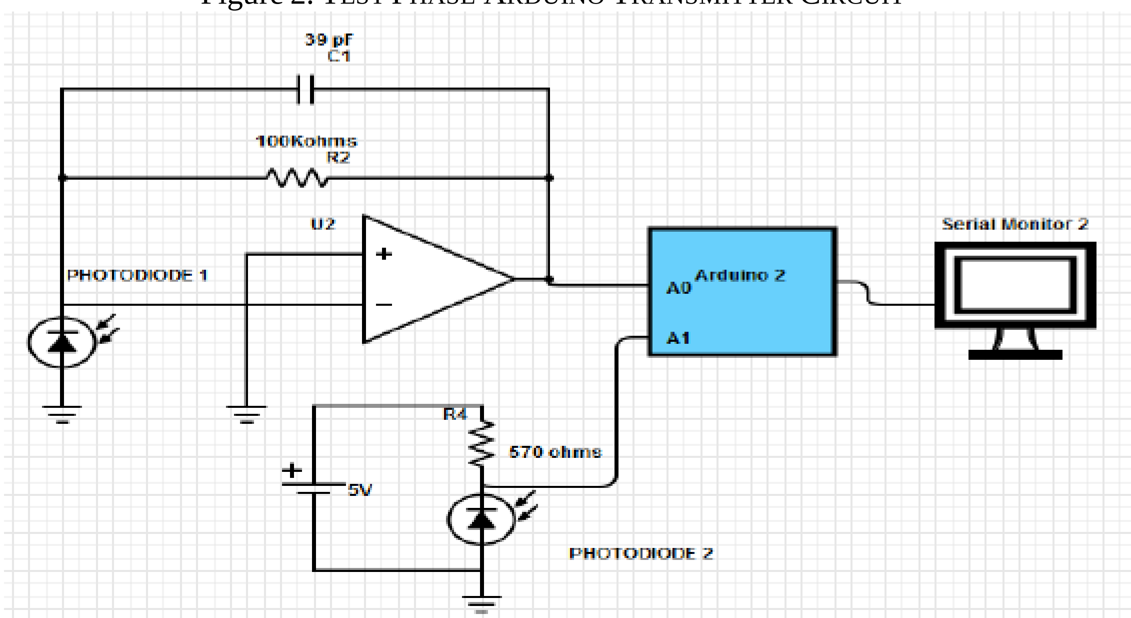

Figure 3. TEST PHASE: ARDUINO RECEIVER CIRCUIT

Use of Raspberry Pi in Audio Transmission Phase:

For the transfer of audio, Raspberry pi was used. In order to transmit audio data, it needs to be converted into binary information. Arduino can transmit a maximum of 17 characters at a time with a delay of 50 milliseconds [13]. As such Raspberry Pi was chosen, since it has memory storage. Aiding to this, processing power on the Pi is much stronger than the Arduino. Although the Raspberry Pi has an agile CPU, the B+ model used in this project only has a single core. The new

Raspberry Pi 2 contains multi core architecture and the program can be threaded to allow simultaneous processes including reading file, parsing data and writing to PWM pin. A multithreaded program will allow several fold increase in transfer speed only to be bounded by the PWM maximum rate of 19 megabits per second [14]. The circuit from figure 4 is used to send audio through the LED. In order for this to work, the audio file should be converted to a raw HEX file (see construction detail for information on converting Mp3 file). The program is predefined to read Hex data from numbers.txt'. Then, the LED would send such bits using Pulse Width Modulation (PWM). Again, a current limiter resistor was used to limit the current to the LED. On the other hand, the photodiode receives the bits, then that signal is sent to an amplifier, and finally to the speaker.

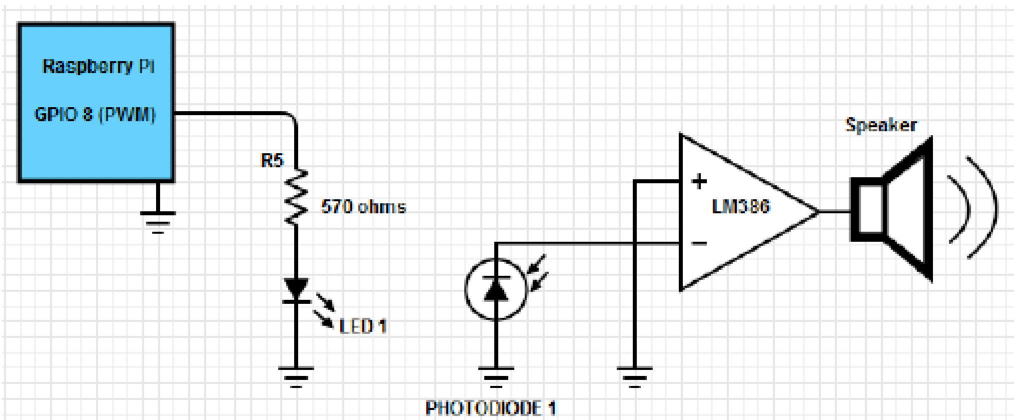

Figure 4. AUDIO TRANSMISSION PHASE RECEIVER AND TRANSMITTER CIRCUIT

Transmission circuit using Raspberry Pi:

LED bulbs and photodiode with same wavelength was used as transmitter and receiver respectively. LM386 with a gain of 50 was used an audio amplifier to increase the signal strength. NPN epitaxial Darlington transistor was used to provide modulation for the LED bulbs. The operating voltage of the bulb will vary depending on the specifications of the bulb to be used [15]. A 1-Ohm resistor is used at the base which contains the modulating signal coming from the Raspberry Pi. Finally, it is also important to use the LED without the rectifier circuit embedded in the bulb. Figure 5 shows the circuit developed for transmitting audio data from the raspberry pi using LED's.

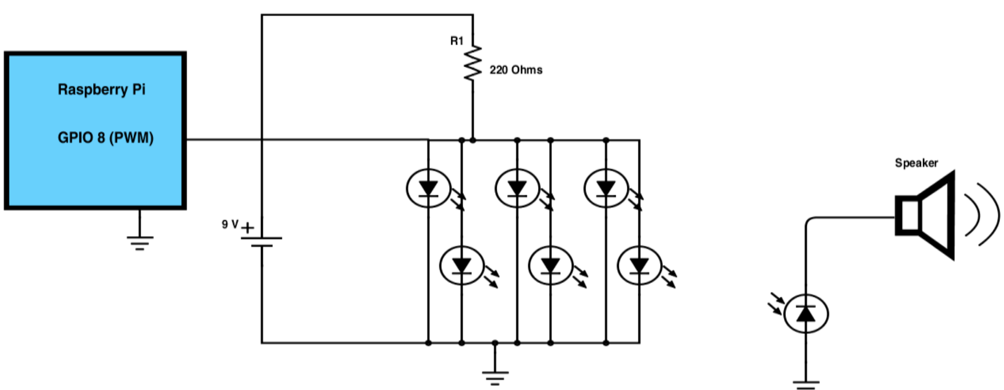

Figure 5. AUDIO TRANSMISSION PHASE: LED BULB CIRCUIT

Experimental procedure on the design

A. Test Phase

The test phase consisted of 2 Arduino Microcontrollers, where one acts as a transmitter and the other as a receiver. Each microcontroller has a separate circuit associated with it. The transmitting circuit consisted of using 2 digital pins from the Arduino, ground, the 3.3V pin, 2 LEDs and an AND gate. Digital pin 9 and the 3.3V were fed into an AND gate for smoother signal from which the output was linked to the transmitting LED. Digital pin 10 was wired to the status LED which turns on to indicate transfer of data. On the receiver end, the circuit consists of 2 photodiodes; one for each LED from the transmitter side, an operational amplifier, and the receiving Arduino. The photodiode facing the status LED is wired to analog pin 1; the other photodiode is wired to the OP AMP for signal processing which is then wired to analog pin 0. The transmitting Arduino uses the program written to send data ("textSend.ino") which contains proper interfacing with the LEDs wired according to Figure 5. Similarly, the receiving Arduino uses the program to read data ("BC_Read.ino") that consists of preset threshold values for the photodiodes. Both programs will not need modification, interfacing can send them across with the serial monitor.

B. Audio Transmission Phase

In the audio transmission phase, a single LED was required which needs to be attached to GPIO pin 8 on the Raspberry Pi. The receiver end simply had the photodiode attached to a pair of speakers via a stripped 3.5mm auxiliary cable. The figure below describes the hardware wiring for the audio phase. On the software end, the Raspberry Pi was flashed with Raspbian distribution which ships as an installer with a raspberry pi kit or can be simply downloaded from the official website. The program is coded in C++ and the Wiring Pi library is required to properly interface with the GPIO pins.

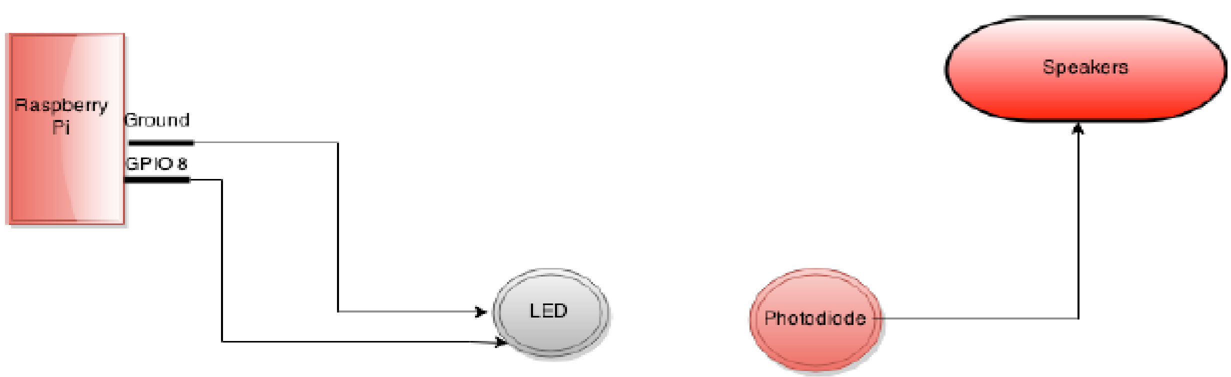

Figure 6. CIRCUIT DIAGRAM FOR AUDIO TRANSMISSION PHASE

The audio must be uncompressed and as hex characters. Once the MP3 audio file is sampled at a rate of 44100 Hz, it will be loaded on to audio editing program "Audacity" and exported as raw 8-bit PCM unsigned file. Using the Unix program to convert the uncompressed audio to hex bytes, the transmission file is loaded to Raspberry Pi SD card for transmission.

Conclusions

Data transmission using visible light was successfully demonstrated using the proposed LED based wireless communication design. Dividing the ultimate project into phases yielded the results needed to prove, data transmission through light is possible. ASCII codes were being transferred through a modulating light but the limitation of the microcontrollers were visible for the next phase. In the initial stages of testing, Arduino was able to transmit a maximum of 17 characters across at a time at a delay of 50 milliseconds. Because of the buffer limitations of the Arduino, the Raspberry Pi was included in the design. The use of Raspberry Pi provided the option of saving the audio files as HEX codes on an SD card. Although the design was not tested on video transmission, the proof of concept can make it easy for future developments to be made on the project.

References

[1] A Human Right. (2015). Retrieved January 7, 2016, from http://ahumanright.org/

[2] Bloom, Scott H. "Hybrid picocell communication system." U.S. Patent No. 6,323,980. 27 Nov. 2001.

[3] Liberti, Joseph C., and Theodore S. Rappaport. Smart antennas for wireless communications: IS-95 and third generation CDMA applications. Prentice Hall PTR, 1999.

[4] Spectrum of Issues. (2010, October 27). Retrieved from http://www.technologyreview.com/graphiti/421421/spectrum-of-issues/

[5] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018. (2014, February 5). Retrieved from Http://sistemas.anatel.gov.br/sacp/Parametros/ArquivosAnexos/11032015_163324_20140603_Contribuição CISCO (2).pdf2014

[6] Weber, Rolf H., and Romana Weber. Internet of Things. New York: Springer, 2010.

[7] Sharma, Srikant, Ningning Zhu, and Tzi-cker Chiueh. "Low-latency mobile IP handoff for infrastructure-mode wireless LANs." Selected Areas in Communications, IEEE Journal on 22.4 (2004): 643-652.

[8] Harald Haas. "Harald Haas: Wireless data from every light bulb". ted.com.

[9] Anthony Cuthbertson (23 November 2015). "LiFi internet: First real-world usage boasts speed 100 times faster than WiFi".

[10] Chen, Wei, et al. "Wireless transmission design for health monitoring at neonatal intensive care units." Applied Sciences in Biomedical and Communication Technologies, 2009. ISABEL 2009. 2nd International Symposium on. IEEE, 2009.

[11] Komine, Toshihiko, and Masao Nakagawa. "Fundamental analysis for visible-light communication system using LED lights." Consumer Electronics, IEEE Transactions on 50.1 (2004): 100-107.

[12] Teikari, Petteri, et al. "An inexpensive Arduino-based LED stimulator system for vision research." Journal of neuroscience methods 211.2 (2012): 227-236.

[13] Margolis, Michael. Arduino cookbook. " O'Reilly Media, Inc.", 2011.

[14] Vujovic, Vladimir, and Milan Maksimovic. "Raspberry Pi as a Wireless Sensor node: Performances and constraints." Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2014 37th International Convention on. IEEE, 2014.

[15] Hunter, Keith B., James M. Conrad, and Andrew R. Willis. "Visible light communication using a digital camera and an LED flashlight." SOUTHEASTCON 2014, IEEE. IEEE, 2014.