Implement Glossy on Visible Light Communication

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UCSC

Declaration

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Abstract

This project about implementing Glossy on Visible Light Communication. As a part of this research we implement a low-cost open source bidirectional communication research platform using off-the-shelf microcontrollers, LEDs and photo transistors. First part of this goal is to implement separate emitter and receiver and evaluate that nodes. We test the emitter and receiver and get the results with different payload sizes and different distances between emitter and receiver.

There are research platforms develop for VLC researches and different protocols are implement on that platforms. Here we review that platforms and get the idea of how that work has done.

Then we develop a bidirectional communication node by combining emitter and receiver functionalities and change the states according to received packet states.

Glossy is an efficient network flooding architecture for wireless networks. In this research, we refer to glossy implementations and study how implementations are done in glossy environment and its functionalities.

Glossy network can be made with many number of nodes and they can be placed in anywhere. But this will affect by the angle covered by the emitting LED and receiving photo transistor. Done the experiment on this angles and referring to the data sheets of those equipment.

Then we set the functionalities of Glossy in VLC node and test the Glossy on VLC. Here we mention how the states are change in glossy node and how it is implemented.

Results and evaluation are discussed in chapter 5 and as an initiation to VLC researches this platform and result can be helpful to conduct future results.

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CA: Collision Avoidance, 24
CD: Collision Detection, 24
CSMA: Carrier Sence Multiple Access, 24
LED: Light Emitting Diode, 44
LWB: Low Power Wireless Bus, 30
VLC: Visible Light Communication, 10, 11, 16, 17, 34

Chapter 1

Introduction

1.1 Overview

Visible light communication is a new era in wireless communications. It's a complement for wireless communication. Researchers found that Li-Fi is faster than Wi-Fi and more spectrum in electromagnetic spectrum compare to radio spectrum. It's faster than radio transmission and it can be use in places where radio signals are not allowed.

There have been research attempts to implement different types of transmitters and receivers that can be used for several purposes such as research platforms, tracking people in a room or a building, VLC communication using flesher and camera in smart phones etc. Also, the researches were aimed at gaining more speed considering the distance of two nodes and cost of the equipment.

Broadcasting is a main activity in wireless communication that uses different broadcasting protocols for different purposes. Flooding can be considered as a method of broadcasting messages in wireless networks. Glossy is another efficient network flooding architecture with implicit time synchronization[1].

By considering these aspects and approaches this research attempts to implement a Glossy network flooding architecture in visible light communication.

1.2 Motivation

Visible Light Communication is new era of Wireless Communication. Currently there are no sufficient platforms for open source visible light communication researches. In order to meet the gap, this research was focused on building an open source VLC platform and implementing Glossy, which is an efficient

network flooding architecture, on it. An open source VLC platform was developed using open hardware platforms, LED bulbs and photo transistors.
No research has been conducted on Visible Light Communication so far in University of Colombo School of Computing (UCSC). Since it's still a new research area in the world many future works can be carried out based on this research as well. VLC can be helpful in developing effective solutions for practical scenarios especially where radio signals are prohibited. For an example, in environments like airplanes and operation theaters VLC is much useful for data transmission[2].

Researchers have found that energy consuming for VLC is less than radio signaling. Hence VLC can be used in wireless sensor networks more effectively. In wireless communication, broadcasting is achieved using network flooding. This Glossy implemented VLC platform can be used in network flooding from VLC and send signals to any direction.

1.3 Research Question

Current researches reveal some implementations of research platforms using different kind of micro controllers, LEDs and Photodiodes. Referring to their results and work they have already carried out this research aimed at building initial functionalities of emitter and receiver and testing them. The implementation included getting the results on the distance used to communicate using the platform, angle that emitter and receiver could be placed and the throughput of the platform according to different payload or data slot sizes in one frame.

Using the aforementioned platform, this research tried to answer the question that "is it possible to implement Glossy on Visible Light Communication"? Considering the emitting and receiving performance of the VLC platform the research was focused on implementing Glossy on them. It was important to ensure that nodes were capable in both emitting and receiving the signals.

1.4 Goals and Objectives

The main goal of this research study was to Implement Glossy on Visible Light Communication. The journey to achieve this ultimate goal comprised of several objectives which has been discussed below

Review OpenVLC and Disney research platforms.

OpenVLC is an open source research platform developed for visible light communication researches which uses Beagle Bone Black board whereas Disney performs their VLC researches with Arduino boards[3][4]. Both platforms have their own functionalities and different data rates. One objective of the research was to conduct a comprehensive study on the functionalities of those research platforms, data rates they have achieved, mechanisms they have used to send and receive data and the frames they have used.

Build an open source Visible Light Communication platform with open hardware platform.

Based on the results obtained from reviewing the research platform next objective was to build an open source research platform for VLC. Since Glossy is tested network cost was a main fact that this research considered. Choosing the micro controller, emitting source, receiving source, frame format, speed that research platform can achieve were also main concerns of the research.

The new research platform was a low-cost approach and could easily build with the off-the shelf emitting and receiving sources.

Review Glossy and its functionalities

The main focus of this research was to implement Glossy on visible light communication. Comprehensive study and review was conducted on the functionalities and requirements needed to implement glossy.

Implement Glossy on Visible Light Communication.

Glossy is a new flooding architecture for wireless networks which guarantees exploit symbol transmission and implicit time synchronization[1]. Implementing the glossy architecture in visible light communication platform was another objective of this project.

1.5 Scope of the project

The main focus of this research is to implement Glossy Network Flooding architecture on Visual Light Communication. Glossy Network Flooding architecture involves a single initiator in the network. Therefore, the networks implemented and evaluated for Visual Light Communication in this research will only have one initiator per network.

Furthermore, communication will involve LEDs for transmitters and Photo Transistors for receivers. There will not be any LED to LED communication. The implementation will also be limited to Manchester Encoding.

Practical applications would require the LEDs to be in ON state throughout the entire operation of the network. However, within the scope of this research LEDs will be in Off state when a node is receiving a signal.

1.6 Overview of the Report

Chapter 2 (Background) reviews what is Visible Light Communication and presents a brief history about it. And a review on the characteristics, applications of visible light communication is presented. Next sub sections review the identification of the modulation methods that can be used to visible light communication, research platforms that have been used to conduct the researches on VLC and different types of current researches on VLC. Discussions on glossy network flooding architecture, low power wireless bus and application of Glossy are presented in later part of the chapter.

Chapter 3 (Design) discusses the designs of the research components including the emitter and receiver and the Glossy node which was made using the emitter along with the receiver functionalities. Design of the data gathering process designs is discussed in later part of the chapter.

Chapter 4 (Implementation) discusses the implementation details of the emitter, receiver and Glossy nodes.

Chapter 5 (Results and Evaluation) present the results of the research platform. Results of Emitter and receiver results according to different distance, payload sizes are presented in the chapter. Results of the Glossy network are presented afterwards. Flooding results to different network topologies that tested are also presented in the chapter.

Chapter 6 (Conclusion and Future Work) discuss the conclusions that can be made from the results obtained from implementing research platform and the Glossy on Visible Light Communication. It further discusses the problems faced during the implementation, data gathering and the evaluation mechanisms for the emitter and receiver and Glossy on VLC in related to speed, throughput, efficiency etc. Future works that emerge from this research are also presented in the chapter along with the bibliography of the research project.

Chapter 2

Background

2.1 Introduction

Visible Light Communication (VLC) is a type of communication which uses light spectrum in electromagnetic spectrum.

There has been number of researchers who conducted researches on VLC and among them. Dr. Harald Hass, who has been working on this area of Li-Fi , since 2004, was finally able to demonstrate the idea of VLC (Visible Light Communication) by sending video in a conference (in 2011) with the speed of 10Mbps.

In this chapter, explanation about VLC and its behavior is clearly explained. The characteristics, importance and applications of VLC are mentioned further. In simple term, communication, can be done with LED (Light Emitting Diodes) by setting the bit 0 as OFF and bit 1 as ON state of LED. But there are other characteristics in light / LED that can be helpful to communicate as well.

There are other modulation methods that can be used to build communication using characteristics of lights / LED and it will be explained later on this chapter. VLC can be applied in areas where radio signals are prohibited and also it can be used to build new applications. Some researchers have been conducted to achieve more speed and distance and some of those researches will be explained later in this chapter.

The main entity of VLC is the emitter and the receiver of the network. Some researches have been built by different kinds of emitters and receivers. Here we discuss about the two main research platforms which has been built for VLC researches and its functionalities.

2.2 Visible Light Communication

Visible Light Communication is a type of communication which uses light spectrum in electromagnetic spectrum. In visible light communication, it communicates from the illumination source (light bulb) other than the illumination.

In Morse code signals were send using ON and OFF states of flash lights. But it done manually. Flash lights were remained in OFF state for a while and ON state for a while. This cannot categorize as VLC because it not gives the main feature of the light illumination.

If we can change the ON and OFF states of the flash light we can send data but we were not able to see the data as in Morse code. Then flash light appear as constant light illumination and then can define it as Visible Light Communication.

But to achieve this challenge we have to good receiver at receiver's end. To effectively detect the signals at receiver's end success the communication.

In here we can define VLC as communication using visible light but cannot catch the data by human eye. But there is no universal definition on Visible Light Communication.

But current implementations of lighting systems are used LED as illumination source. this matter speedup the researches and motivation of the people to move to visible light communication. LEDs can be switch more faster than fluorescent and incandescent lamps. This created a vast opportunity to Visible Light Communication.

There are some other trerms that uses for Visible Light Communication but slight different meanings.

- **Free space optical (FSO) communication** which is similar to VLC but is not constrained to visible light. Ultraviolet and infrared also in FSO category.

And there are laser diodes are used to communication other than to LEDs[5][2].

- **Li-Fi** term is used simply used for define Wi-Fi feature of radio signal giving using light bulbs. Li-Fi means Light Fidelity. This can be consider as complementary for Wi-Fi but not competitor for Wi-Fi. Man, who was in Li-Fi area can be delivered the messages like man who is in Wi-Fi area. This also can be done using both Wi-Fi and Li-Fi[5][2].

- **Optical Wireless communication (OWC)** is a general term which refers to all types of optical communications where cables (optical fibers) are not used. VLC, FSO, Li-Fi and infra-red remote controls are all examples of OWC[5][2].

2.2.1 Characteristics of Visible Light Communication

Capacity: The radio waves used by Wi-Fi to transmit data are limited due to high cost. With the development of 3G and 4G technologies, the amount of available spectrum is running out. The visible light spectrum is 10,000 times wider than the spectrum of radio waves. Additionally, the light sources are already installed. Hence Li-Fi has greater bandwidth and equipment which is already available[2].

Efficiency: There are 1.4 million cellular radio masts worldwide. These masts consume massive amounts of energy, most of which is used for cooling the station rather than transmission of radio waves. In fact, the efficiency of such stations is only 5%. LED lights consume less energy and are highly efficient[6].

Availability: Radio waves cannot be used in all environments, particularly in airplanes, chemical and power plants and in hospitals. Light sources are present in all corners of the world. Hence, availability is not an issue. The billions of light bulbs worldwide need only be replaced by LEDs[6].

Security: Radio waves can penetrate through walls. This leads to many security concerns as they can be easily intercepted. Light of course does not penetrate through walls and thus data transmission using light waves is more secure[2].

Bandwidth: The visible light is unlicensed and free to use and gives a very large bandwidth[2].

Data Density: Li-Fi can achieve about 1000 times the data density of Wi-Fi because visible light can be well contained in the tight illumination area[2].

Low Cost: As it requires very few components the cost of it is comparatively low[2].

2.2.2 Applications of Visible Light Communication

Medical and Healthcare

Due to concerns over radiation, operating rooms do not allow Wi-Fi and even though Wi-Fi is in place in several hospitals, interferences from computers and cell phones can block signals from medical and monitoring equipment. Li-Fi solves these problems[6].

Airlines and Aviation

Wi-Fi is often prohibited in aircrafts. However, since aircrafts already contain multiple lights, thus Li-Fi can be used for data transmission[2].

Power Plants and Hazardous Environments

Li-Fi offers a safe alternative to electromagnetic interference due to radio waves in environments. Also in chemical or petrochemical industries, radio signals will harmful. But since they use light VLC can use to communication purposes[2].

Underwater Explorations and Communications

Radio waves cannot be used in water due to strong signal absorption. Acoustic waves have low bandwidth and disrupt marine life. Li-Fi offers a solution for conducting short-range underwater communications[2].

GigaSpeed Technology

The Li-Fi Consortium provides the fastest wireless data transfer technology presently available. Our current solutions offer effective transmission rates of up to 10Gbps, allowing a 2-hour HDTV film to be transferred in less than 30 seconds[2].

Smart Lighting

Street lamps can be used in the future to provide Li-Fi hotspots and can also be used to control and monitor lighting and data[2].

Mobile Connectivity

Laptops, tablets, smart phones and various other mobile devices can interconnect with each other using Li-Fi, much like they interconnect today using Wi-Fi[2].

Toys

Several toys consist of LED lights and these can be utilized to implement low-cost communication in order to build interactive toys[2].

RF Spectrum Relief

Li-Fi networks can be used to relieve the radio spectrum off of excessive capacity demands of cellular networks[2].

RF Avoidance

Li-Fi can be used as a solution to any situation in which hypersensitivity to radio frequencies is a problem and radio waves cannot be used for communication or data transfer[2].

Indoor Wireless Communication

Li-Fi is very well suited for indoor wireless communication and data transmission. Li-Fi makes use of a free, unlicensed spectrum and is not affected by RF noise. Moreover, most indoor locations would have a sufficient number of light sources and provide additional security since Li-Fi as previously discussed cannot penetrate through walls[2].

Hidden Communications

Li-Fi is extremely useful for applications in which the communications must be hidden. This involve various military and defense based communications as well as communications in hospitals[2].

2.3 Modulations methods used for Visible Light Communication

There are number of modulations which are used for visible light Communication (VLC) and are;

On-Off Keying (OOK): The 802.15.7 standard is used Manchester coding so that the period of positive pulses is same as the period of negative ones, however this doubles the bandwidth required for transmission. For higher bit rates, run length limited (RLL) coding is used which is spectrally more efficient. Dimming is supported by adding an OOK extension which adjusts the aggregate output to the correct level[2].

Variable Pulse Position Modulation (VPPM): PPM encodes the data using the position of the pulse within a set of time period. The duration of the period containing the pulse must be long enough to allow different positions to be identified. VPPM is similar to PPM but it allows the pulse width to be controlled to support light dimming[2].

Color Shift Keying (CSK): This is used where the illumination system uses RGB-type LEDs. By combining different colors of lights, the output data can be carried by the color itself and hence the intensity of the output can be near constant. Mixing of RGB primary sources produces different colors which are coded as information bits. The disadvantage is that it increases the complexity of the transceivers[2].

Sub-Carrier Inverse PPM (SCIPPM): This method is divided into two parts (1) sub-carrier part and (2) DC part. The DC part is used only for lighting or indicating. When there is no requirement for lighting or indicating, SCPPM (Sub-Carrier PPM) is used in order to save energy[2].

Frequency Shift Keying (FSK): In this method, data is represented by varying the frequencies of the carrier signal. Before transmitting two distinct values (0 and 1), there needs to be two distinct frequencies[2].

SIM-OFDM (Sub-Carrier Index Modulation OFDM): This is a new approach to transmission in which an additional dimension is added to conventional 2D amplitude/phase modulation (APM) techniques such as quadrature amplitude modulation (QAM) and amplitude shift keying (ASK). The key idea is to use the sub-carrier index to convey information to the receiver[2].

2.4 Researches on Visible Light Communication

There are number of researches which have been gone through for gaining Gigabyte speed from visible light communication. Due to limitations of radio spectrum and speed of the radio signals, researchers have tried to achieve this through visible light.[7][8].

Visible light communication can be used for tracking people in a room or floor. In a room or floor of a building there is always light bulbs on the roof. There are some researches on how to track people in a room using light in the room.
Human sensing using visible light communication. by capturing the light and the shadow there are researches try to figure out the actions taken by human[9][10].

Visible light communication can be used for traffic signaling and sending alerts via vehicle lights. Nowadays LEDs are used for headlights and backlights in the vehicles. So collection all the traffic on the roads makes big network. Using this lights in the vehicles can use effectively send messages about road traffics and traffic signals on the road and also can use for driver assistant services using the data that sends from LEDs in the vehicles[9]. Traffic signals are also use LEDs. So they also can be used to send more informative signals other than traditional signals on the road[12].

Secure Barcode-based Visible Light communication for smartphones. Smart phones have flash lights and cameras. They also can be used for communication between two phones[13]. Camera can detect the light signals and also flash lights can be used as transmitters. Then we can transfer data within smart phones effectively and efficiently using visible light communication[14].

2.5 OpenVLC

Open VLC is an open source research platform developed to researches on visible light communication. This platform build with Beagle Bone Black board. They use high power LED and low power LED to transmit the data. Also, they use low power LED and a photodiode to receive the data. This platform will capable of bidirectional communication. They define a protocol for bidirectional communication and define separate frame structure for packets.

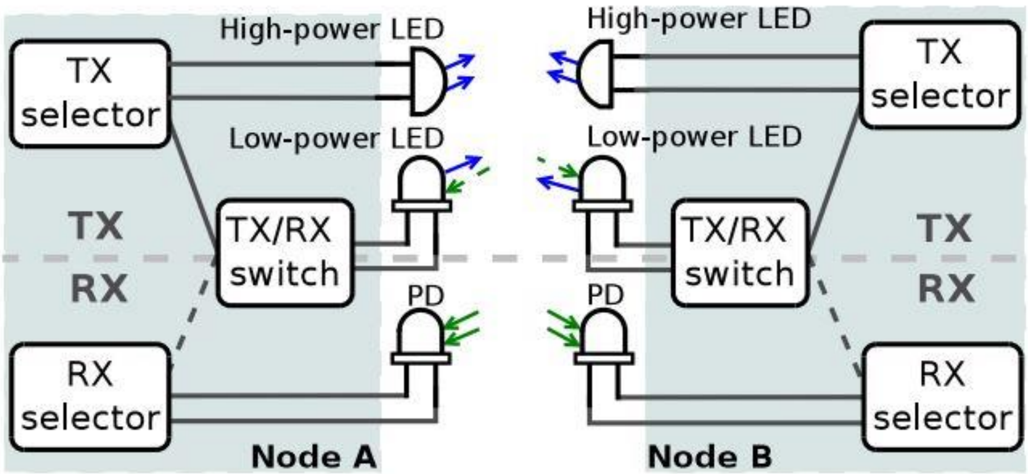

Figure 2.1 - OpenVLC transmitters and receivers[3]

Packet of OpenVLC [15] denote in the following table 2.1.

Table 2.1 - frame structure of OpenVLC

Preamble	SFD	Length	Dst.	Src.	Protocol	Payload	CRC
3B	1B	2B	2B	2B	2B	Data	2B

Preamble is like an synchronization bit slot to sync with the receiver and SFD for indicate the start of the packet. Length denote the length of the payload and Dst denote the destination. Src is the id of sending node and they mention the choose protocol for transmit and CRC denote the cyclic redundancy check[3].

They use this frame structure use for achieve bidirectional communication and implement CSMA/CD protocols in OpenVLC[3].

2.6 Disney Researches on Visible Light Communication

Disney research group also do the experiments on visible light communication[16]. Mainly focus their researches on communicate remotely with the toys using VLC. They also try to build a low cost embedded visible light communication platform[17].

Disney researches done researches to build an VLC platform with ATmega microprocessor and off-the-shelf 5mm Red color LEDs. They Position pulse modulation method as their encoding mechanism.

They conduct the researches on LED-to-LED communication in VLC. They propose that solution because the power consumption and the cost will lower in LED compare to photodiodes.

A Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol is used to coordinate how VLC devices access the optical medium.

2.6.1 Frame Structure used in Disney VLC

The frame structure used in Disney research group is shown in table 2.2 below. They use CSMA/CA protocol for transmit data[18].

Table 2.2 frame structure of Disney VLC platform

SFD	Header					DATA/ ACK	FCS
	Frame body size	Frame control	Destination address	Source address	Sequence number		
1B	1B	1B	1B	1B	1B	0-255B/ 0B	2B

2.7 Transmitter (Emitter)

OpenVLC and Disney research groups are use LEDs as illumination source in their research platforms. Because LEDs have some specific characteristics with compare to incandescent bulbs such as capacity of LEDs to produce more light per watt than incandescent bulbs, ON-OFF time, capability of LEDs to light up quickly. Unlike fluorescent lamps, LEDs do not contain mercury. With power and signal enhance devices can achieve high speed. Simply it does with using high power or low power LEDs and microcontrollers. Speed depends on power of the LEDs and speed that can gain from microcontroller.

To transmit data using LEDs there are several modulation methods use as mention before in this chapter. Both OpenVLC and Disney research groups use ON-OFF keying as their modulation method in transmitter. After that it has to be use suitable encoding mechanism to transmit the signal. Encoding mechanism will helpful to identify the signals correctly at receiver's end.

OpenVLC use Manchester encoding as their encoding mechanism. In Disney research paper mention that it uses 2-Pulse Position Modulation as encoding mechanism. The purpose of using a encoding mechanism is send consecutive 0s or 1s without flickering to the receiver and correctly identify the bits at receiver end. Both of the encoding mechanisms mention above are use ON and OFF states of LED to send bit 0 or 1. It gives continuous illumination to the user and solve the flickering problem when data transmit regardless sending bit is a 0 or 1.

In present some applications are using LEDs other than incandescent. Including smart phone flash lights[17], vehicles headlights and backlights[12], LED light bulbs for home and office use[10][19][20] etc. Researches try to apply VLC in these areas for communication. There are more opportunity to use these LEDs as emitters to build traffic light base communication, build networks with vehicles, track people within a building, smart phone base VLC applications, communicate with toys etc.

2.8 Receiver

When Receiving signal, we have to capture the light signal using On-Off-keying modulation which goes with a speed that cannot be detected from a human eye. In order to capture the signal in effective way we can use photodiodes for receiving the signal and low power LEDs.

After receiving signals at the receivers end it's responsible to decode the received message and show the original message.

2.9 Glossy

Glossy is a new flooding architecture for wireless sensor networks. It exploits constructive interference of IEEE 802.15.4 symbols for fast network flooding and implicit time synchronization and it derives a timing requirement to make concurrent transmissions of the same packet interfere constructively, allowing a receiver to decode the packet even in the absence of capture effects.

To satisfy this requirement, their design temporally decouples flooding from other network activities and then analyze Glossy using a mixture of statistical and worst-case models, and evaluate it through experiments under controlled settings and on three wireless sensor test-beds.

The evaluation shows that Glossy floods packet within a few milliseconds and achieve an average time synchronization error below one microsecond. In most cases, a node receives a flooding packet with a probability higher than 99.99 %, while having its radio turned on only for few milliseconds during a flood. Moreover, unlike the existing flooding schemes, Glossy's performance exhibits no noticeable dependency on node density, which facilitates its application in diverse real-world settings[1].

2.7.1 Flooding Mechanism of Glossy

All nodes have three states as Emitting, Receiving, and Idle. During a flood a node will change their state to one of the above.

First initiator in emitting mode sends signals. In the meantime, the first hop nodes are in receiving state and then receive the signal. During the next time period initiator and the second hop change their states to receiving mode and first hop nodes transmit the data while others are in the state of idle. Again, the initiator and second hop nodes will transmit the data as shown in figures below.

This retransmission will be done until N number of times. The retransmission time will be defined as N in glossy network. After transmitting the data N times go for idle for the rest of the network time period and then give the time for the application layer to execute their functionalities.

If one node will detect a collision on receiving data, then it goes for idle at that time until the start of the next transmission. Then it changes its state to receiving mode instead of emitting mode. One transmission time can be identified by all the nodes and relay counter in the network packet which will increase in each transmission.

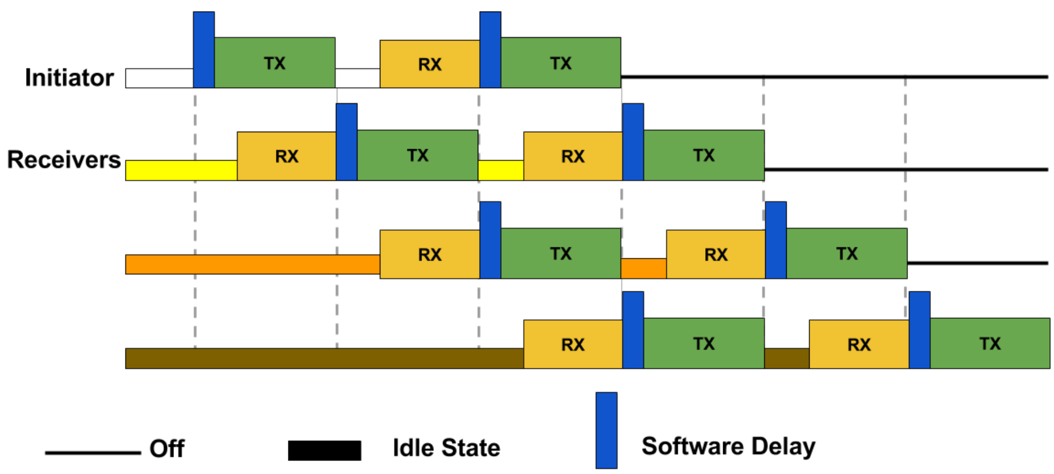

Figure 2.2 - Glossy States in network flooding

Using this relay counter, the node will know how far it is placed from initiator. That's how glossy achieves the implicit time synchronization[19]. Node states transmission and glossy steps are shown in figure 2.3 - figure 2.6.

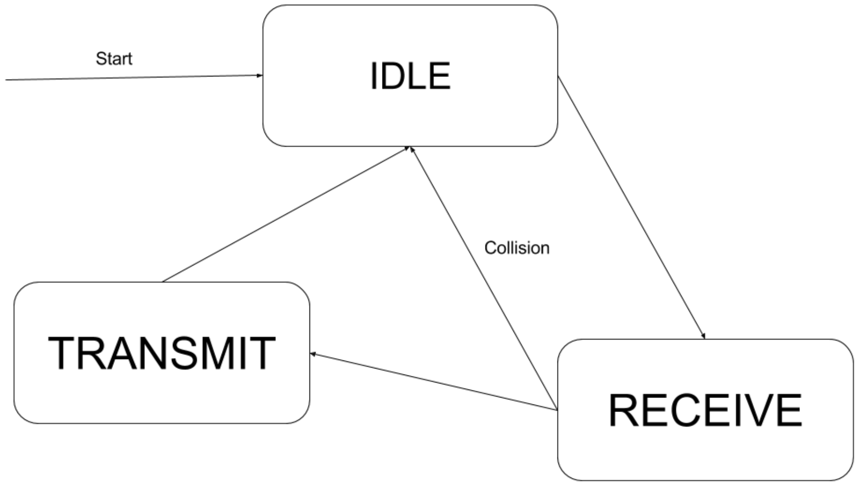

Figure 2.3 - States of a Glossy node

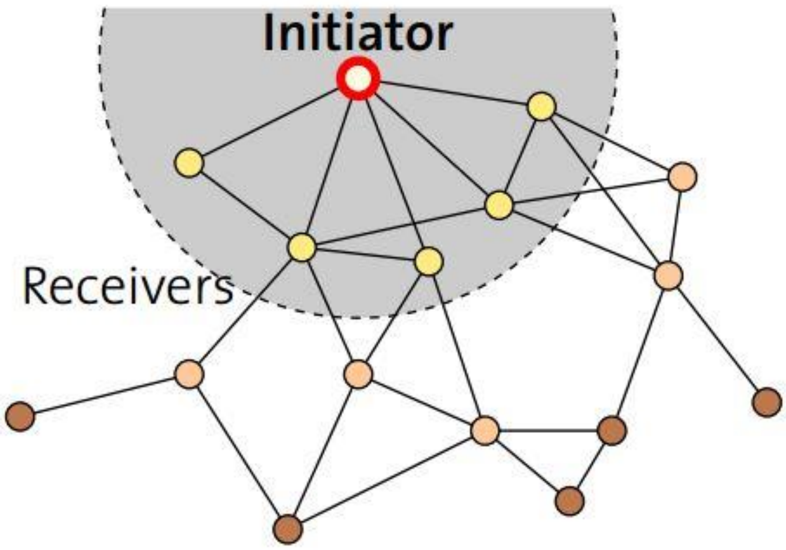

Figure 2.4 - First step of Glossy

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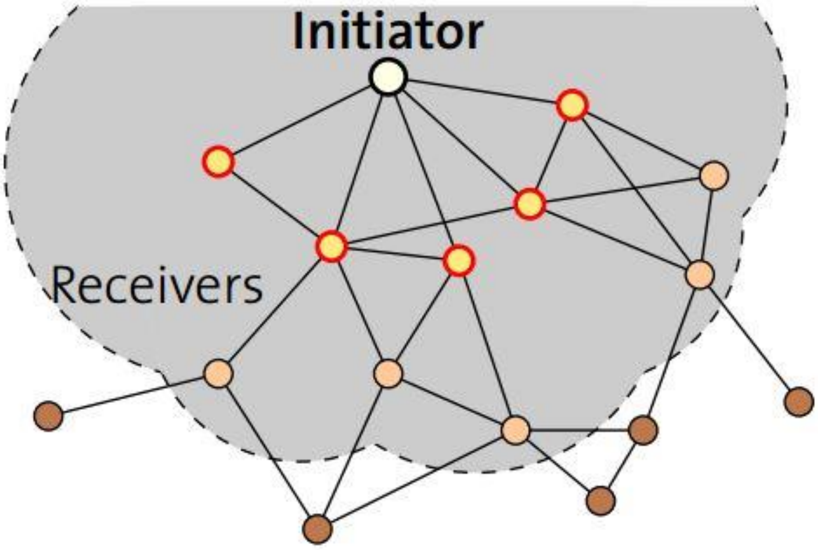


Figure 2.4 - Second step of Glossy

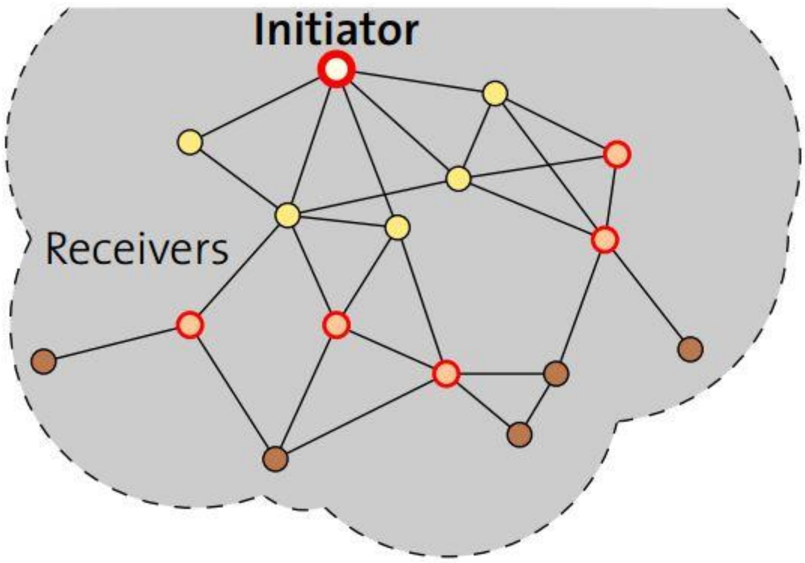


Figure 2.6 - Final state of Glossy

LWB uses Glossy as underlying communication and time-synchronization primitive. Glossy provides two services that are fundamental to LWB's operation: one-to-all network flooding and network-wide time synchronization. That is, in multi-hop wireless networks Glossy can send a packet from one node to all others within a few milliseconds and at a reliability close to 100%, while synchronizing all nodes to within sub-microsecond accuracy. Unlike most wireless protocols, Glossy takes advantage of packet collisions rather than fighting against them. It deliberately forces multiple nodes to send the same packet at nearly the same time, thereby taking advantage of the capture effect and constructive interference to harness different forms of diversity.

2.10 Low Power Wireless Bus (LWB)

Low-Power Wireless Bus (LWB) is a communication protocol for low-power wireless embedded systems. LWB lets nodes communicate as if they were connected to a shared bus, where all nodes can receive all packets, although the underlying multi-hop wireless topology may be very complex and continuously changing. LWB provides an API through which an application can dynamically adjust its traffic demands at runtime. To serve the current traffic demands in the network, a scheduler computes online a global communication schedule. All nodes follow this schedule and communicate in a time-triggered fashion. Thus, LWB's operation is conceptually similar to that of wired busses used in the avionics and automotive industries, such as CAN, FlexRay, or TTP[21].

LWB supports multiple communication patterns, including one-to-many, many-to-one, and many-to-many. It quickly adapts to changes in the application's traffic demands and is highly resilient to network dynamics. This entails in particular that LWB's performance and reliability are remarkably unaffected by, for example, the presence of mobile nodes and wireless interference. Experiments on large multi-hop networks with more than 100 nodes show that LWB's end-to-end packet reliability typically ranges above 99.9%, with energy consumption on par or below state-of-the-art solutions.

As the main application of glossy low power wireless bus has use in many different researches to give an efficient network communication[22][23][24][25].

Chapter 3

Design

3.1 Transmitter (Emitter)

In this research, it's a main goal that build an open source transmitter and receiver. To build an emitter we use Arduino UNO as microcontroller. Red and White LEDs were used as illumination source.

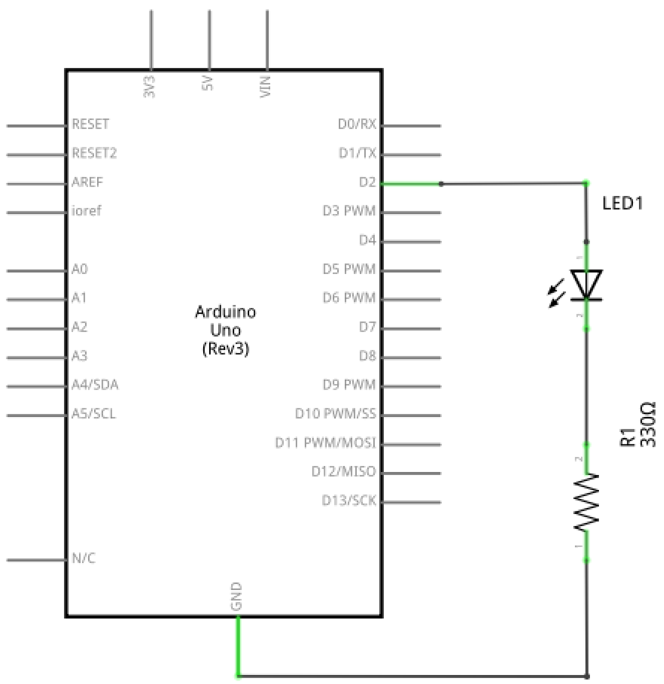


Figure 3.1 - Emitter Design

If we use only the functionalities of Arduino UNO we can ON LED for 1ms and OFF for 1ms. Then without any encoding method we can gain 1000bits/s. But there are more problems occurs when we try to receive the signal in receiver's end. At receivers end we are unable to identify number of consecutive 1s or number of consecutive 0s or there is no signal emitting at transmitter. Choosing OFF state of LED to send bit 0 will off the LED for certain time period when sending consecutive 0s in signal. That will cause flickering to the user. we use Manchester encoding to solve this problem as encoding method. With 1ms ON or OFF setting we can gain 500bps speed.

Using TimerOne library we can operate ON and OFF states in lower than 100microseconds time period. Receiver must able to capture this speed and convert the analog signal read to digital and identify the data received. Then the speed of this platform depends on the receivers ends performance like ADC conversion speed, light detection accuracy, etc.

3.2 Receiver

First without using any libraries we have to append 15ms to read a bit using analogRead() function. With analogRead() function read the analog value where photodiode or LED connected. It reduced the speed to 66bps without any encoding method. If we use Manchester encoding, then speed is around 33bps.

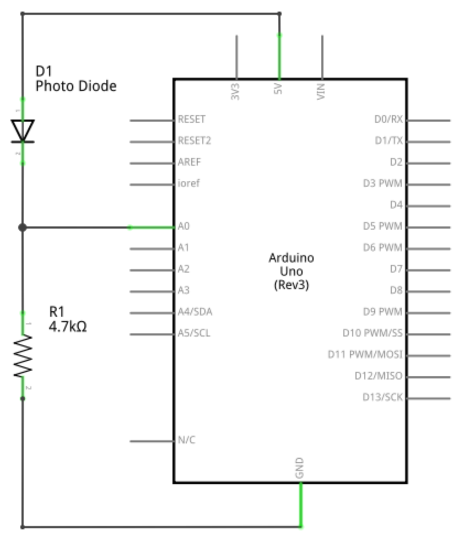


Figure 3.2 - Receiver Design

Arduino returns different sampling rates according to prescale values in ADC conversion. Timer one library use to execute the analog read function in time periods. using TimerOne library we able to reduce the analog read time gaps and efficiently detect ON and OFF states of LED and emitter.

3.3 Glossy Node

The VLC nodes used for implement and test glossy flooding architecture are here called as Glossy nodes. Glossy node is different from separate emitter and receiver node. Glossy nodes must have both emitting and receiving functionalities. Other than receiving and emitting glossy nodes increment the relay counter C in receiving frame and transmit it again.

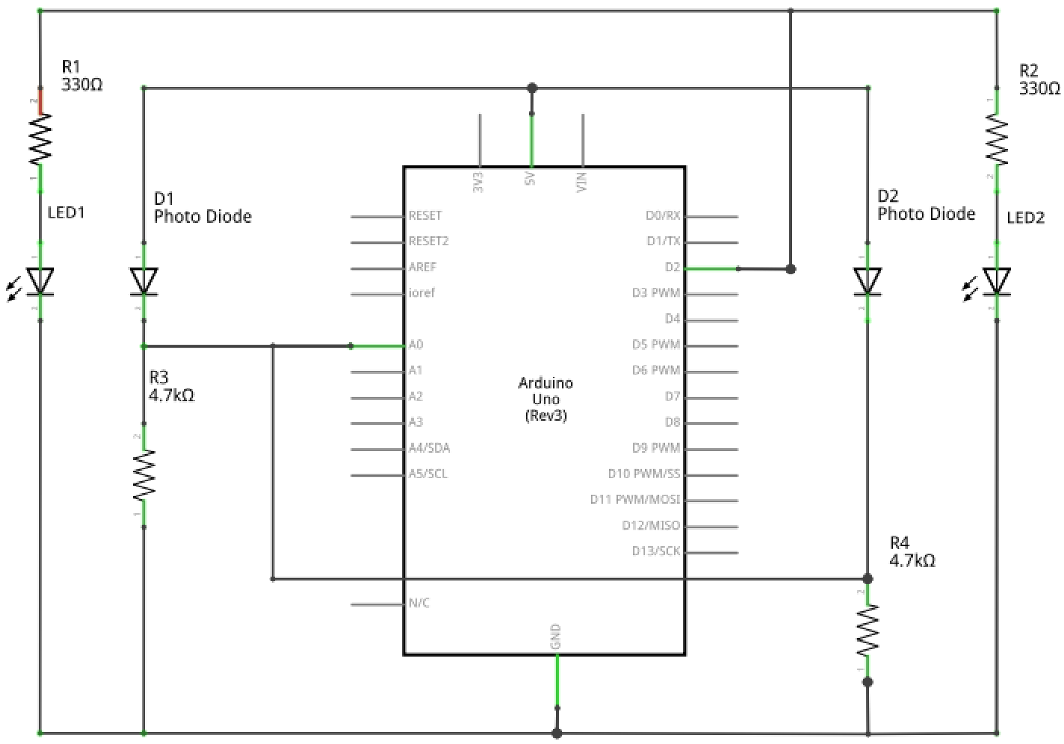


Figure 3.3 - VLC Glossy node

In glossy node, we use one Arduino UNO board and two LEDs and two photo transistors. Here we use two LEDs for transmit the signals for both directions and two photo diodes to receive signals from both directions.

There is a problem with sending and receiving signals in one node because of emitting is done with digital writing and receiving signals were capture using analog readings. As Arduino UNO is single threaded microcontroller we use separate time slots for emitting and receiving signals.

Also, the initial states of receiving and emitting is change according to role of the node in network topology. If the selected glossy node is the initiator, then start state is Emitting. If the glossy node is a receiver, then start state is receiving.

In after first time slot initiator change its state to receiving and receivers who receive the signals change their states to emitting. Those who didn't receive the signals remain in receiving state till they receive a signal.

3.4 Sample Frame – Normal Frame

Sync 3x	Break Sync	STX	Data	ETX
0xAA	0xD5	0x02	<Data>	0x03

Table 3.1 - Sample frame use for normal emitter and receiver testing

This frame will use to send data from emitter to receiver. its consists with Synchronization symbol, Synchronization break symbol, start of the frame symbol, data or the payload and the end of the frame signal.

Synchronization symbol

Synchronization symbol is the first section of the frame. we use 0xAA as the synchronization symbol. Hexadecimal AA (0xAA) will convert to binary as 10101010. Three times this symbol will send. This part will helpful to synchronize the signal and detect ON and OFF states of the emitter.

Break synchronization

Synchronization break symbol will use to notify the end of synchronization to the receiver. There is another usage of this symbol. This will helpful to receiver to identify the consecutive ON and OFF states at the emitter. Because with Manchester encoding there will be consecutive ON and OFF states in signal.

STX

STX symbol is the start symbol of the data or payload. Here after receiver knows that next will be the payload of the frame.

Data

Frame include its data in this section. Data or payload size can be define in the system and each data item will convert into 8bit binary value. Then Manchester encoded data will be send via LEDs.

ETX

Here is the end of the frame. This section will notify the end of the frame. this section will insert at the end of the data set unless it's fill the full size of data section. If data is more than the define size then this section will insert after defined data size at the frame buffer.

3.5 Sample Frame – Glossy Frame

There is slight different between normal emitter and receiver sample frame and the frame used for Glossy. In glossy they suggest that include a relay counter to get the idea about how many times that each frame relay on the network and get the idea to each receiver in network how far they placed from the initiator. Also, this relay counter can be used to synchronizing purposes. If we know the time to send one packet from one node to the other node with multiply that value from relay counter will return the start time of the network flooding at the initiator.

Sync 3x	Break Sync	STX	Data	Checksum	Relay Counter	ETX
0xAA	0xD5	0x02	<Data>	1byte	1byte	0x03

Table 3.2 - Sample frame of Glossy

Checksum

In network frame, we use hash value of the message in 1 byte slot. In Glossy all nodes are retransmit the received packet. If there are any corruption in receiving frame, then node goes to again to receiver mode instead of transmitting mode. Checksum help to detect corruptions received packet. After calculating the checksum of received at received node and compare with the checksum in the received packet. If both of them are equal, then node will retransmit the frame. otherwise change its state to receiving mode.

Relay Counter

Relay counter is the counter that increment from one transmission to another. All the nodes that receive the frame will increment this relay counter by one and retransmit the frame. this will change all the time in network flooding of that frame.

3.6 Manchester Encoding

In this research, we use Manchester encoding as encoding method. At Disney research, they also use ON and OFF states for encode each bit. Here each character or symbol that need to communicate convert in to 8bit data set and add start and end bit to both ends in 8bit data set. Then convert this whole 10bit encode with Manchester encoding and prepare for transmit. This added start and end data bit are use as mask to filter the received from the series of bits at the receiver’s end.

bit	First symbol	Second symbol
0	ON	OFF
1	OFF	ON

Table 3.3 - Manchester Encoding

Character A encoded as follows.

Character:	A
Hexadecimal:	0x65
Binary:	0110 0101
Manchester encoding:	0110011010010110
Word to be send:	10011001101001011001

Above 1s and 0s shown in Manchester encoding value will be the corresponding ON and OFF sates of the LED.

Chapter 4

Implementation

4.1 Emitter

4.1.1 Microcontroller

One main goal of this research is build an open source research platform for visible light communication. OpenVLC is already built open source research platform. Beagle Bone Black board was used for OpenVLC. They use High power LED and a low power LED for transmit data. Since beagle bone black

But Disney research group done their VLC researches with Arduino boards. They use 500 microsecond symbol period for send half of a bit. Compare to Arduino UNO Beagle Bone Black board is 10 times expensive. Since Glossy is a network flooding architecture we need to test it on network of VLC nodes. First, try to test it on 10 VLC nodes. This will be an expensive start for VLC researches.

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O pins	14
Analog Input Pins	6
DC Current per I/O Pin	40mA
DC current for 3.3V Pin	50mA
Flash Memory	32KB (0.5 KB used by bootloader)

SRAM	2KB
EEPROM	1KB
Clock Speed	16MHz

However, the performance such as speed will higher in Beagle Bone Black board than Arduino UNO. But Arduino UNO also can achieve 1kpbs speed. Then we choose to use Arduino UNO board to build emitter as microcontroller. We use publicly available source code implement for VLC in Arduino.

We include TimerOne library and atomic library at emitter end. We use TimerOne library functions to change the ON and OFF states of LED in microseconds. Also, we gain the emitting speed of the LED using interrupts. For this interrupts we use TimerOne Library. Hence, we were used interrupts to emit the LED there will be interrupts at any point of the code. But some assignments have to be done without interruptions. So, we use atomic library functions to overcome this problem.

4.1.2 Illumination Source

OpenVLC uses high power white color LED and low power white color LED. In Disney researches they use red color LEDs. Most of the off the shelf red color LEDs are focus LEDs. They were not illuminate wide area. But the White LEDs are we use different from Red LEDs.

4.2 Receiver

4.2.1 Sampling speed

ADCSRA register of Arduino UNO use to ADC conversion enable and set prescale values. ADPS2, ADPS1, ADPS0 bits use to set the prescale values. Arduino system clock has higher rates. For ADC circuitry to work at its maximum resolution needs to be supplied with 50 kHz to 200 kHz frequency as per the datasheet. According to Arduino UNO technical specification it has 16MHz sampling rate. we use prescale value as 128. Then sampling rate is 16000000/128 = 125kHz. Then 125KHz is between 50 - 200KHz.

We collect 4 samples per ON and OFF states at emitter. 125*4 = 500. In this research platform, this is the key factor to limit the speed.

4.2.2 Receiver

To capture the light signals use ST-1KLA photo transistor. Photodiodes and low power LEDs used as receivers in OpenVLC and Disney research groups.

4.3 Glossy Node

Glossy nodes will capable in both transmitting and receiving the signals. We have to combine both transmitter and receiver's functionalities to build the Glossy VLC node.

Since Arduino UNO is a single threaded microcontroller switch the receiving and emitting modes linearly. Board change its state to receiving mode or emitting mode once at a time.

We use the LEDs used for build emitter node mention above. Red and white LEDs use in glossy nodes. Two LEDs used for Glossy node to send the signals both forward and backward directions in network. This was done because of network setup in linearly and signals sends to both next and previous nodes in glossy network.

First initiator node start with the its state in emitting mode. After the initial signal sent initiator change its state to receiving mode.

Other receivers start their execution in receiving mode. Receivers check the received data while receiving and change the receiving packet's state according to received data. For an example after receiving the STX data slot receiver change the state of the receiving packet to Data state. After receive the packet receiver get the ETX slot data receiver compare the two checksums calculated and received and change the node's state. If two checksums are equal, then change the node's state to emitting mode or else remain it on receiving mode.

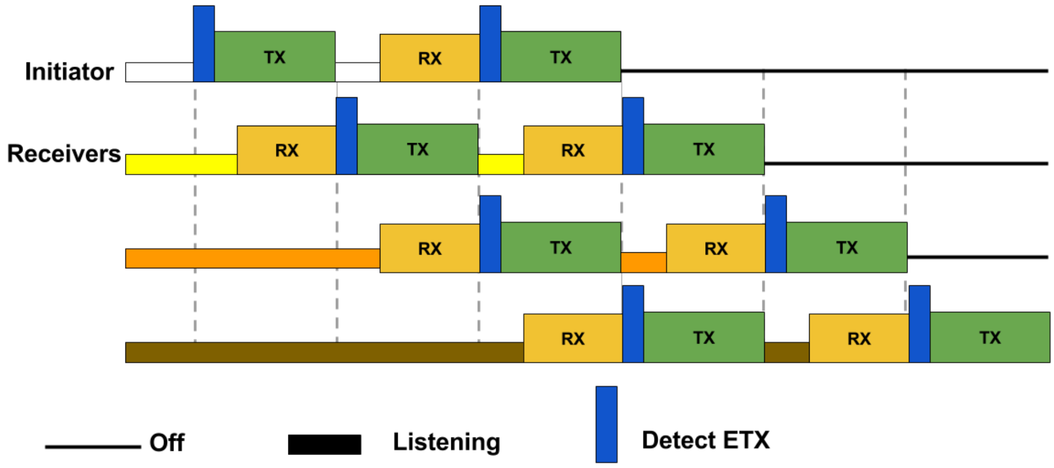


Figure 5.1 Glossy states of VLC nodes

Both initiator and receivers after sending the signals for defined N time goes to idle mode. Idle time depend on hops distance from the initiator. Initiator has the idlest time while Glossy network flooding and the nodes in the last hop has the least idle time.

For an example defined retransmitting number N is 3 after each node goes idle after transmit the same signal 3 times. First transmission done by initiator. Then 1st hop will receive the signal. Then initiator change its state to receiving mode and nodes in the first hop will transmit the received frame. according to that order initiator completes its transmitting time first. Then go to idle till the end of the first packet flood. Then initiator got more idle time compare to other nodes. next most idle time will get by nodes in first hop and continues.

4.4 Time Synchronization

Glossy network flooding architecture has implicit time synchronization. After receiving the signals nodes can decide whether it change its state to transmitting mode or remain in receiving mode using checksum. Then all the nodes are synchronized in glossy network.

Chapter 5

Results and Evaluation

5.1 Emitter and Receiver Testing Methodology

Then we have to test and note the results of emitter and receiver. in a network topology nodes, can be any direction from emitter and from difference distances. It's important to get the results according difference distances from emitter and from different angles. According to Disney research they were able to send signals up to 2-2.5m. so here we plan to test the distance up to 3m and get the results from different angles. Record the results for every 20cm and 5 degrees from nodes.

Also the size of payload or data section in one frame will cause to the efficiency of the platform. It is important to get the results with relevant to each payload size. Disney researches have reported the results up to 100bytes payloads and at OpenVLC they were report the results up to 1MB payload size. Our emitter and receiver more significant to Disney research than OpenVLC platform. Considering these factors, we select payload as 10, 25, 50, 75 and 100bytes sizes.

We test this platform using Red color LED as well as White color LED at emitter. So here we try to fill the below table corresponding to Red color LED and White color LED as well as different payload sizes (10, 25, 50, 75, 100).

Table 5.1 - Sample test results record sheet

Color of LED: <Red, White> Distance from emitter: <20, 40, 60, 80, 100>						
Bytes	Angle between two nodes					
	0 degree	5 degree	10 degree	15 degree	20 degree	...
10 bytes						
25 bytes						
50 bytes						
75 bytes						
100 bytes						

5.1 Emitter and Receiver Distance Testing

The testing was done by keep the emitter at one point and get collect the data from receiver. record the data according to some time periods. Execute the emitter for 100s and collect the data receiver in that time slot. We use different payload sizes 10, 25, 50, 75, 100. For each payload size emit the signal for 100s and repeat that test for 5 times in each time slot.

We were planning to place the nodes in Glossy network 100cm distance between two nodes. here we record the results up to 140cm distance from emitter and in each 20cm period.

Following table 5.2 to table 5.11 represent the gathered results relevant to each distance for both Red and White LEDs.

5.1.1 10bytes Payload Testing

White color LED

Table 5.2 represent the White LED results with 10bytes packet relevant distance.

Table 5.2 - 10bytes payload results with White LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput(b/s)
10	2943	2925	99.3883792	468
20	2943	2933	99.66021067	469.2
40	2943	2940	99.8980632	470
60	2943	2941	99.93204213	470.56
80	2943	2943	100	470.88
100	2943	2943	100	470.88
120	2943	2942	99.96602107	470.72
140	2943	2943	100	470.88

Red color LED

Table 5.3 represent the Red LED results with 10bytes packet relevant distance.

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	2943	2931	99.5922528	468.96
20	2943	2940	99.8980632	470.4
40	2943	2942	99.96602107	470.72
60	2943	2940	99.8980632	470.4
80	2943	2941	99.93204213	470.56
100	2943	2943	100	470.88
120	2943	2942	99.96602107	470.72

140	2943	2943	100	470.88

Table 5.3 - 10bytes payload results with Red LED

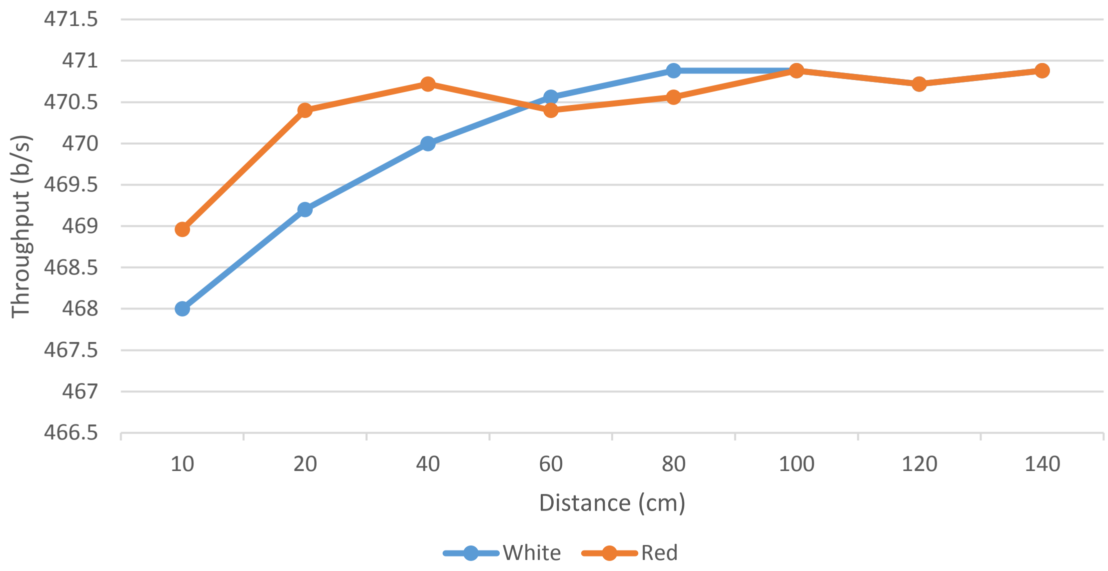


Figure 5.1 - 10bytes payload results

5.1.2 25bytes Payload Testing

White color LED

Table 5.4 represent the White LED results with 25bytes packet relevant distance.

Table 5.4 - 25bytes payload results with White LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	1565	1511	96.54952077	604.4
20	1565	1525	97.44408946	610
40	1565	1478	94.44089457	591.2
60	1565	1551	99.10543131	620.4
80	1565	1506	96.23003195	602.4
100	1565	1490	95.20766773	596
120	1565	1427	91.18210863	570.8

140	1565	1556	99.42492013	622.4

Red color LED

Table 5.5 represent the Red LED results with 25bytes packet relevant distance.

Table 5.5 - 25bytes payload results with Red LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	1565	1476	94.31309904	590.4
20	1565	1506	94.31309904	602.4
40	1565	1560	99.68051118	624
60	1565	1559	99.61661342	623.6
80	1565	1560	99.68051118	624
100	1565	1547	98.84984026	618.8
120	1565	1558	99.55271565	623.2
140	1565	1562	99.80830671	624.8

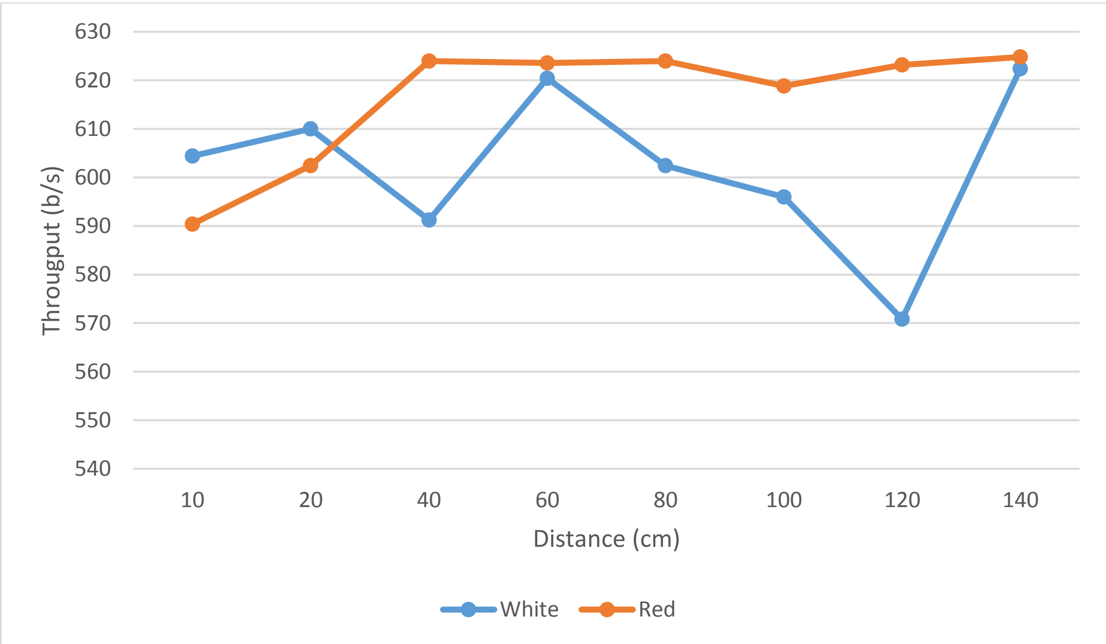


Figure 5.2 - 25bytes payload results

5.1.3 50bytes Payload Testing

White color LED

Table 5.6 represent the White LED results with 50bytes packet relevant distance.

Table 5.6 - 50bytes payload results with White LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	880	668	75.90909091	534.4
20	880	844	95.90909091	675.2
40	880	880	100	704
60	880	876	99.54545455	700.8
80	880	876	99.54545455	700.8
100	880	875	99.43181818	700
120	880	875	99.43181818	700
140	880	875	99.43181818	700

Red color LED

Table 5.7 represent the Red LED results with 50bytes packet relevant distance.

Table 5.7 - 50bytes payload results with Red LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	880	813	92.38636364	650.4
20	880	876	99.54545455	700.8
40	880	876	99.54545455	700.8
60	880	880	100	704
80	880	873	99.20454545	698.4
100	880	875	99.43181818	700
120	880	875	99.43181818	700

140	880	870	98.86363636	696

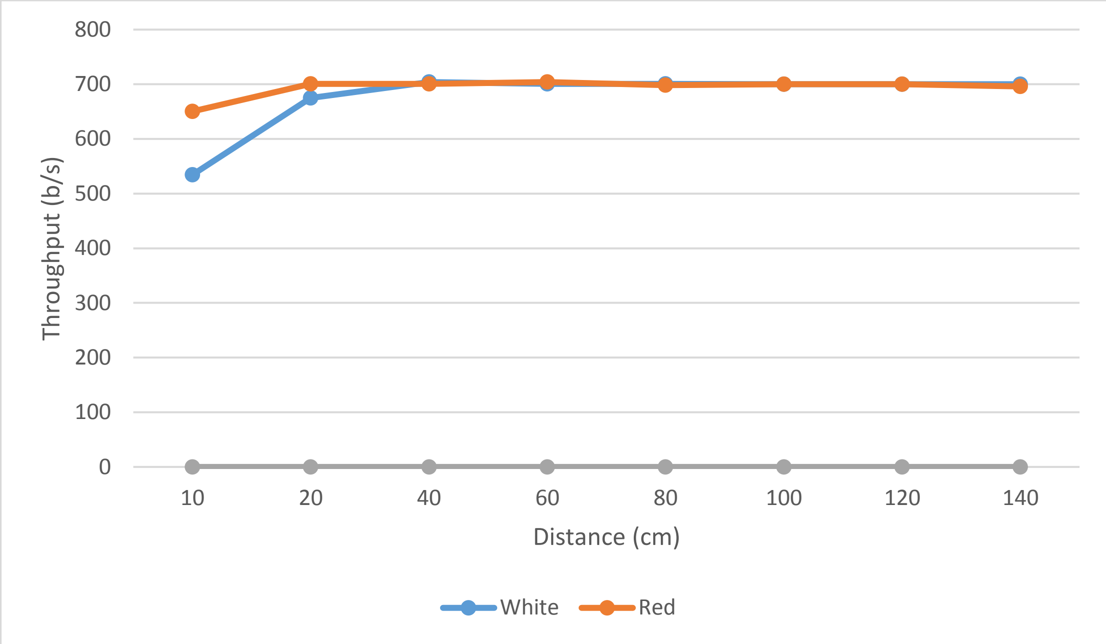


Figure 5.3 - 50bytes payload results

5.1.4 75bytes Payload Testing

White color LED

Table 5.8 represent the White LED results with 75bytes packet relevant distance.

Table 5.8 - 75bytes payload results with White LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	612	608	99.34640523	729.6
20	612	609	99.50980392	730.8
40	612	608	99.34640523	729.6
60	612	609	99.50980392	730.8
80	612	608	99.34640523	729.6
100	612	608	99.34640523	715.2
120	612	610	99.67320261	732
140	612	600	98.03921569	720

Red color LED

Table 5.9 represent the Red LED results with 75bytes packet relevant distance.

Table 5.9 - 75bytes payload results with Red LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	612	609	99.50980392	730.8
20	612	610	99.67320261	732
40	612	611	99.83660131	733.2
60	612	607	99.18300654	728.4
80	612	609	99.50980392	730.8
100	612	596	97.38562092	729.6
120	612	610	99.67320261	732
140	612	605	98.85620915	720

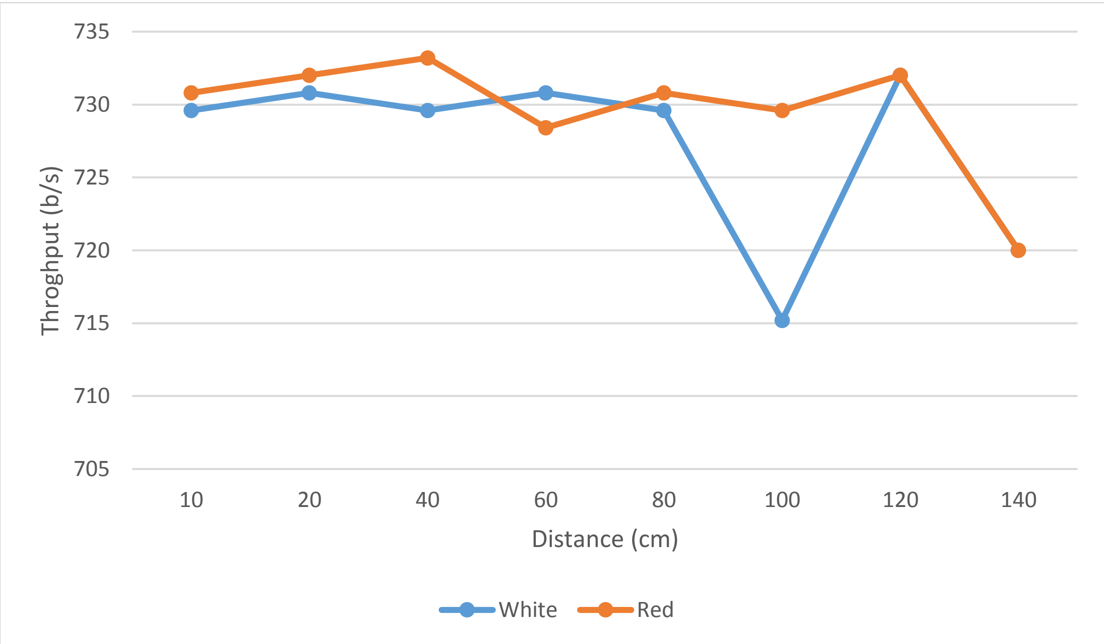


Figure 5.4 - 75bytes payload results

5.1.5 100bytes Payload Testing

White color LED

Table 5.10 represent the White LED results with 100bytes packet relevant distance.

Table 5.10 - 100bytes payload results with White LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	470	468	99.57446809	748.8
20	470	470	100	752
40	470	469	99.78723404	750.4
60	470	468	99.57446809	748.8
80	470	470	100	752
100	470	468	99.57446809	748.8
120	470	469	99.78723404	750.4
140	470	460	97.87234043	736

Red color LED

Table 5.11 represent the Red LED results with 100bytes packet relevant distance.

Table 5.11 - 100bytes payload results with Red LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
10	470	467	99.36170213	747.2
20	470	469	99.78723404	750.4
40	470	470	100	752
60	470	469	99.78723404	750.4
80	470	468	99.57446809	748.8
100	470	468	99.57446809	748.8

120	470	459	97.65957447	750.4
140	470	460	97.87234043	747.2

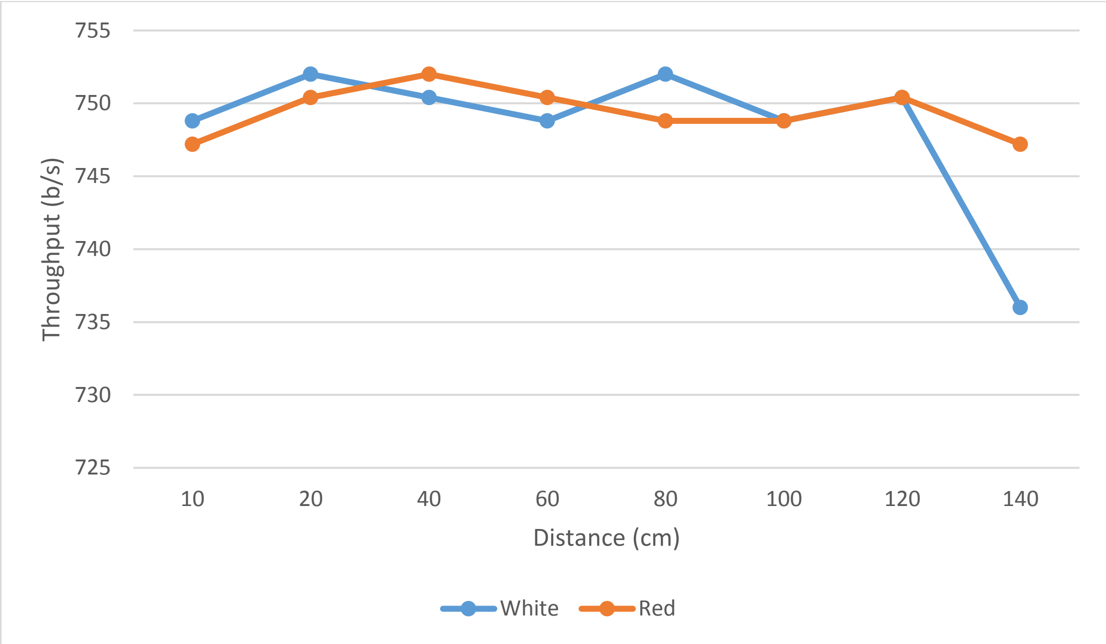


Figure 5.5 - 100bytes payload results

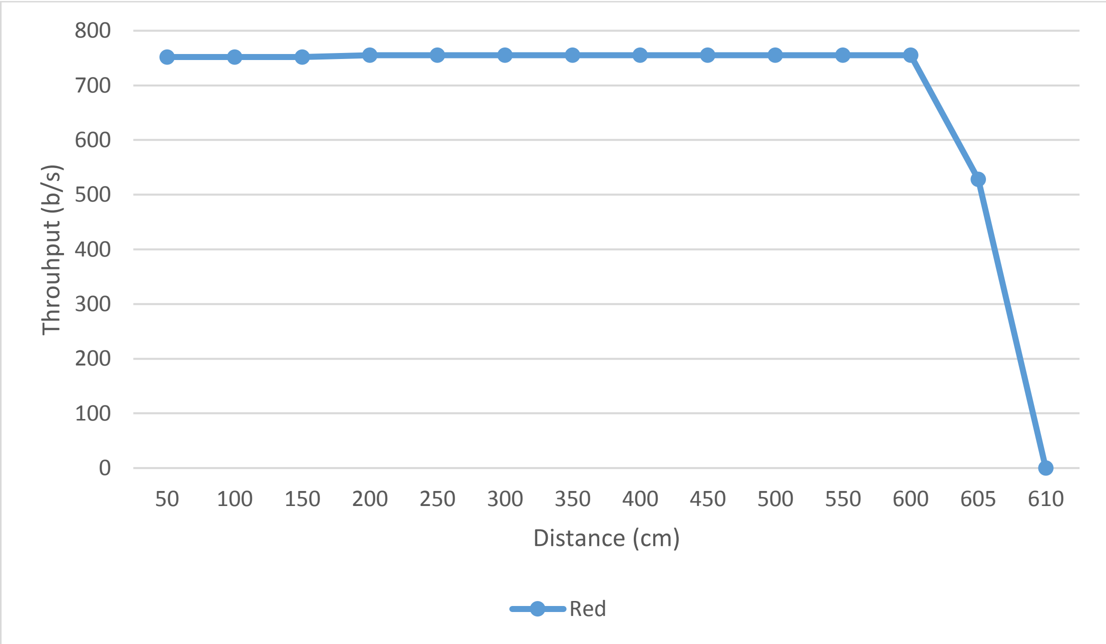
5.1.6 More distance test with Red color LED

Since 5mm off-the-shelf red color LEDs focused and the light beam goes far. So this experiment done in indoor where all the lights are off in the room in the evening. Since there are no other light bulbs and the sunlight the light of the Red color can detect efficiently at the receiver. the results of this experiment is shown in the table below. The results shown in the table collect in 250 seconds.

Table 5.12 -Test results for longer distance with Red LED

Distance(cm)	No. of Packets Sent	No. of Packets Received	Percentage	Throughput (b/s)
50	236	235	99.57627119	752
100	236	235	99.57627119	752
150	236	235	99.57627119	752
200	236	236	100	755.2
250	236	236	100	755.2

300	236	236	100	755.2
350	236	236	100	755.2
400	236	236	100	755.2
450	236	236	100	755.2
500	236	236	100	755.2
550	236	236	100	755.2
600	236	236	100	755.2
605	236	165	69.91525424	528
610	236	0	0	0



According to the results shown in table 5.11 receiver received all the frames that sent by emitter. Most of the time the drop the first packet. After that all the packets were successfully received by the receiver. in this experiment, it can be proved that this platform can send data more than 600cm (6m). Sunlight and other lights can cause for a successful transmission on VLC. According to the graphs of Disney research and this results[18] when accuracy starts to go down it is get to the zero very quickly.

5.1.7 Throughput of VLC platform with White color LED

Figure 5.6 shows the throughput results of White color LED and photo transistor. The Throughput will increase with the payload size of the frame.

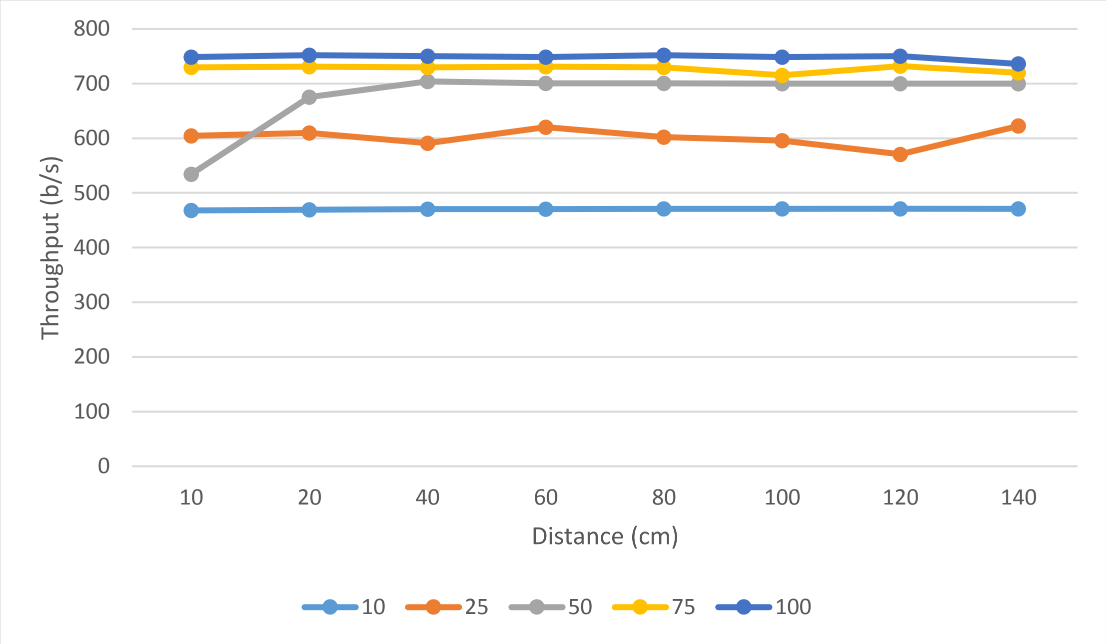


Figure 5.6 - Throughput of VLC research platform with white LED

5.1.8 Throughput of VLC platform with Red color LED

Figure 5.7 shows the Throughput results of research platform emitter and receiver with Red color LED. In here also throughput is increment with the payload size of the frame.

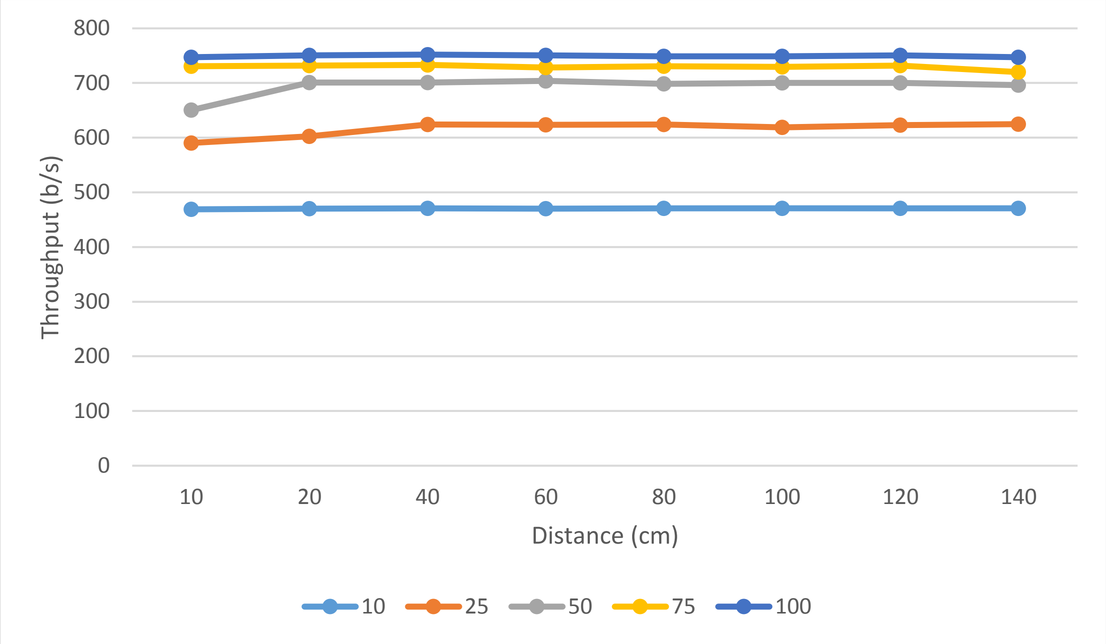


Figure 5.7 Throughput of VLC research platform with Red LED

5.2 Area Test of Emitter

In a network topology, emitters can be place in anywhere and any angle to each other. Then receivers must able to receive the signals correctly. This angle will depend on the LED use. In this section present the results of angle between emitter and receiver using 5mm straw hat cool White color LED. As shown in the figure below we place the node and emitter in each 10 degrees right and left side. Then it can reduce the errors that can be occurred with the faced direction of the LED. We cannot draw line that exactly where LED had focused. The X value in the figure denote the angle between emitter and the receiver

We were plan to place nodes up to 100cm distance starting from 20cm distance for initial experiment on VLC Glossy. So, record the results from each 10 degrees to left and right side up until not receive the frames and find the max degree from left and right directions. This was repeated for each 20cm distance up to 100cm.

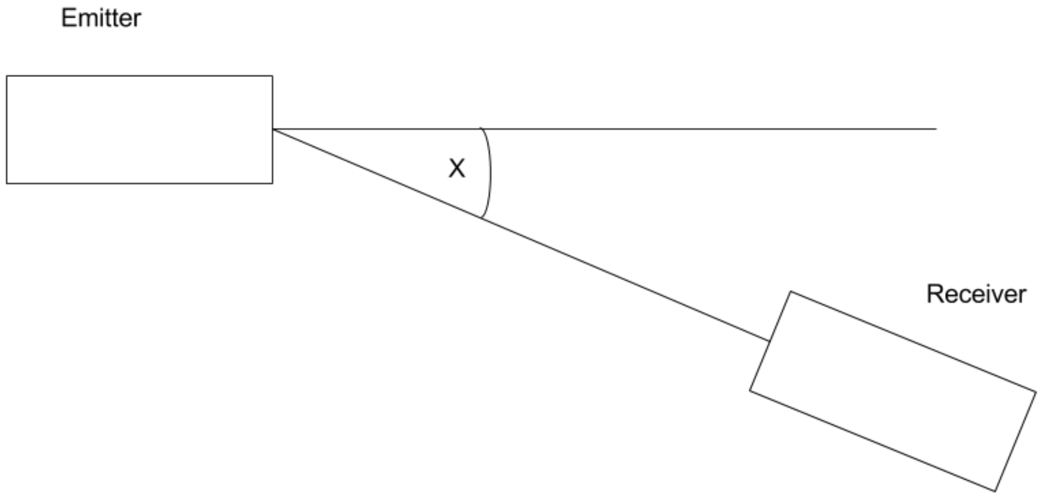


Figure 5.8 Area Test for Emitter

To collect the data, we transmit 100bytes payload size frames. There are 283 frames send within 300 seconds. The values of following table are shows the number of frames received out of 283 frames. Frames with number of received packets to each distance are shown in table 5.13 to table 5.17
When angle test results gain 0 we test again between two degrees by 1 degree difference. then able to find the highest degree from left and right directions. In following tables, they contained a row with numbering 1-9. Those are the values of each degree that contain the threshold values.

Table 5.13 - Angle test results for 20cm distance

	10	20	30	40	50	60	70	80	90
Right	282	282	283	280	282	281	282	0	0
Left	280	283	281	282	283	282	2	0	0
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Right	283	282	278	280	281	281	5	0	0
Left	282	282	280	281	279	278	278	282	4

According to this results threshold degree values are 76 degrees right and 68 degrees left. If receiver place within 20cm distance that should be place within this area.

Table 5.14 - Angle test results for 40cm distance

	10	20	30	40	50	60	70	80	90
Right	281	281	283	283	282	281	2	0	0
Left	283	281	282	279	282	282	0	0	0
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Right	282	281	278	280	281	282	278	0	0
Left	282	280	274	0	0	0	0	0	0

Above table shows that threshold value for 40cm distance are 67 degrees right and 63 degrees left direction.

Table 5.15 - Angle test results for 60cm distance

	10	20	30	40	50	60	70	80	90
Right	282	282	280	280	281	0	0	0	0
Left	278	281	279	281	282	0	0	0	0
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Right	278	281	282	282	0	0	0	0	0
Left	281	281	282	5	0	0	0	0	0

According to results in table 6.14 threshold values for the emitter is 54 degrees right direction and 53 degrees to the left direction.

Table 5.16 - Angle test results for 80cm distance

	10	20	30	40	50	60	70	80	90
Right	280	280	282	281	1	0	0	0	0
Left	282	278	281	282	0	0	0	0	0
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Right	283	282	281	282	281	278	281	0	0

Left	282	275	281	278	281	278	278	278	0

Threshold values for 80cm distance is 47 degrees to right and 48 degrees to the left direction.

Table 5.17 - Angle test results for 100cm distance

	10	20	30	40	50	60	70	80	90
Right	281	281	283	2	0	0	0	0	0
Left	283	282	283	1	0	0	0	0	0
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Right	283	281	281	278	281	281	282	278	5
Left	282	278	281	283	278	280	5	0	0

Above table 6.16 represent results for angle of the emitter and receiver placed 100cm distance. for that threshold values are 38 degrees right and 36 degrees to left direction.

These obtained results for each distance are more similar to datasheet results for the straw hat cool White LED[26].

5mm Red LED has lesser angle than compare to straw hat cool White LED[27]. But this Red LEDs are focus to one point and that feature will use to send signals more distance.

5.3 Area Test of Receiver

Also, the receiver angle with the emitter will matter for receiving the light signal. In here we test the receivers angle with the emitting light from different angles. The Figure 5.7 shows how the emitter and the receiver placed to collect data.

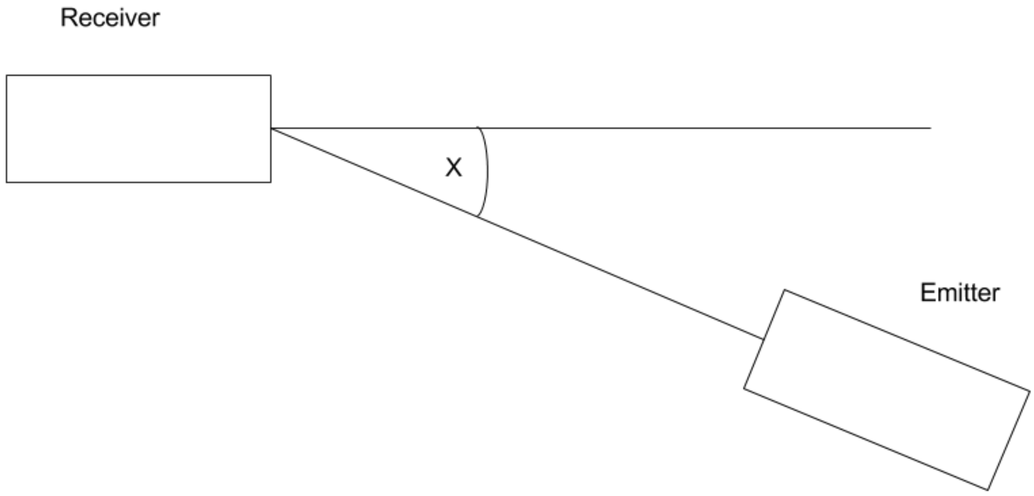


Figure 5.9 - Area Test of Receiver

In this test, it gets only successful reading at receiver for 10 degrees left and right side for each distance. The resistor values that we add to the Photo transistor had caused that result[28].

When try to test Glossy it depends on the angle between receiver and the emitter. According to results on Area testing on receiver and emitter if two nodes placed 60 degrees' angle one node will not able to receive the signals. So here we try to place node within 10 degrees' angle in the experiments.

5.4 Glossy Network Testing

5.4.1 Glossy Environment Setup Methodology

Glossy environment consists of several glossy nodes. A hop has many nodes that receive the signal at same time. In one hop, there can be one or more nodes. After receive the frame to one hop, nodes within that hop will retransmit the frame incrementing the relay counter C.
Since there are more nodes in one hop they cannot place straight. They will place in different positions. Then they will have different angles from the initiator. They the results we take from different angles will be use full to build this network topology.

First, we know that these nodes were able to send and receive signals from more than 1m distance. Most of the nodes that can detect the light signal within 1m distance will receive the signal at very first time. then there will be a problem in testing the behavior of a hops and if they place at the edge of the light signal detecting area then more space needed to test these hops. So here we test with covering the one hop from another.

Glossy tested on different network topologies. Nodes can be place from different distances and different angles to each other. In this research, Glossy on VLC tested up to 4 nodes.

Before execute each test on Glossy place the nodes and test their emitter and receivers with others that they will able to send and receive the signals from others.

5.4.2 VLC Glossy Data Gathering Methodology

In glossy nodes, will retransmit the received frame several times. That retransmission counter or the number of retransmission defined as N. Suppose that retransmission counter N is 3 and the 3 nodes were in the test, data will gather as the table describe below.

Table 5.18 - Data sheet for VLC Glossy tests

Number of frames sent: m **Retransmission counter N**			
Node	**No. of received frames**	**No. of Transmissions**	**Success**
Node 1	X		
Node 2	XX		
Node 3			

First every table will fill the number of packets sent and N. Then all the nodes will receive and transmit the data frames exactly N*m times other than the initiator. The column Number of received frames denote the number of received packets in particular node. the initiator will receive only N-1 times each packet. Then X value will receive m*(N-1) total frames and N*m transmissions. The exact value of X will lesser than XX value in table above. Other node will receive N times each packet. But sometimes there will be collisions and not received exactly N times same frame. Success column denote the exactly N times received total number of frames from each frame. Frame will count as successfully received if it received N times. No. of transmission field will denote the number of transmissions done totally when sending set of packets in the test run.

5.4.3 VLC Glossy Test 1

In this test try to test with two nodes. purpose of this test is test the code and the functionalities of the setup. Figure 5.8 shows that how the nodes are placed in this test. Before run all the run Glossy network 2 and higher do this test for all participating nodes. to identify nodes are correctly work with each other and not interfere by nodes that place from two hops.

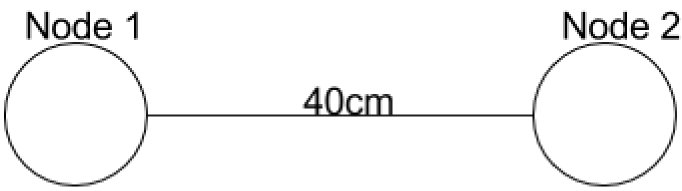


Figure 5.10 - VLC Glossy Test 1

Test results for this test presented in table 5.19.

Table 5.19 - Test results for VLC Glossy test 1

Number of frames sent: 50 Retransmission counter N = 3			
Node	**No. of received frames**	**No. of Transmissions**	**Success**
Node 1	100	150	50
Node 2	150	150	50

5.4.4 VLC Glossy Test 2

This test is done with 3 VLC nodes. Placement of nodes are shown in Figure. In this test middle node get receive the signals from both directions. To avoid to signals sent by Node 1 that received by Node 3 is reduce by increasing the resistor value that set to the LEDs. In this research retransmission number is set to 3.

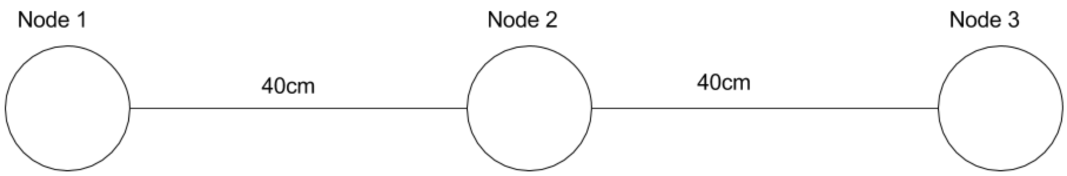


Figure 5.11 - VLC Glossy Test 2

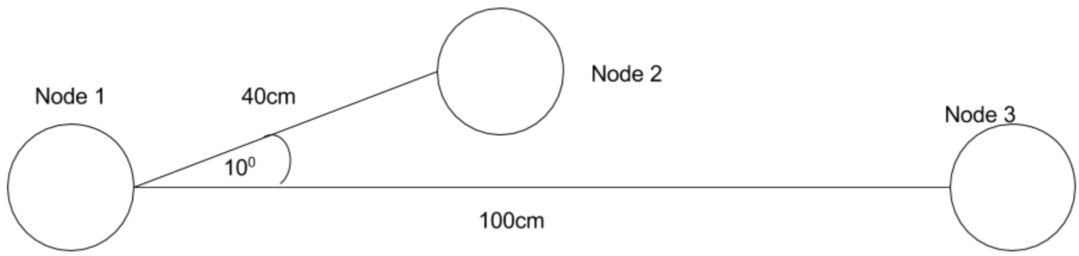
Test results of the VLC Glossy network test are shown in table 5.20.

Table 5.20 - Test results for VLC Glossy test 2

Number of frames sent: 50 **Retransmission counter N = 3**			
Node	**No. of received frames**	**No. of Transmissions**	**Success**
Node 1	100	150	50
Node 2	147	147	48
Node 3	144	144	47

5.4.5 VLC Glossy Test 3

Test 2 run on the nodes that were placed linearly. in here we test the nodes placed in different angles and different distances. Node 2 will have placed 10 degrees left



to the Node 1 and 40cm distance and Node 3 placed 100cm distance linear to Node 1.

Figure 5.12 - VLC Glossy test 3

Results of VLC Glossy test 3 as follows shown in table 5.21.

Table 5.21 - Test results of VLC Glossy test 3

Number of frames sent: 50 **Retransmission counter N = 3**			
Node	**No. of received frames**	**No. of Transmissions**	**Success**
Node 1	94	150	47
Node 2	134	134	42
Node 3	138	138	44

5.4.6 VLC Glossy Test 4

This experiment also done to test how the implementation will work with the nodes that placed in different angles and receive signals from both forward and backward directions. Nodes placement of this experiment will show in figure 5.13.

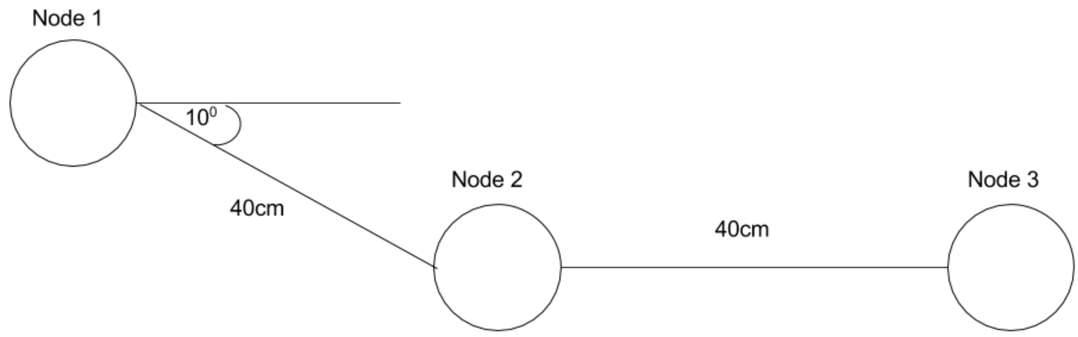


Figure 5.13 - VLC Glossy test 4

Table 5.22 - Test results of VLC Glossy test 4

Number of frames sent: 50 **Retransmission counter N = 3**			
Node	**No. of received frames**	**No. of Transmissions**	**Success**
Node 1	98	148	49
Node 2	148	148	49
Node 3	145	145	48

5.4.7 VLC Glossy Test 5

This test done to evaluate how the Glossy work on nodes that arrange like a tree. Following figure shows ow the 3 nodes are placed in experiment. Placed two receiving nodes from 5 degrees left and right from the initiator.

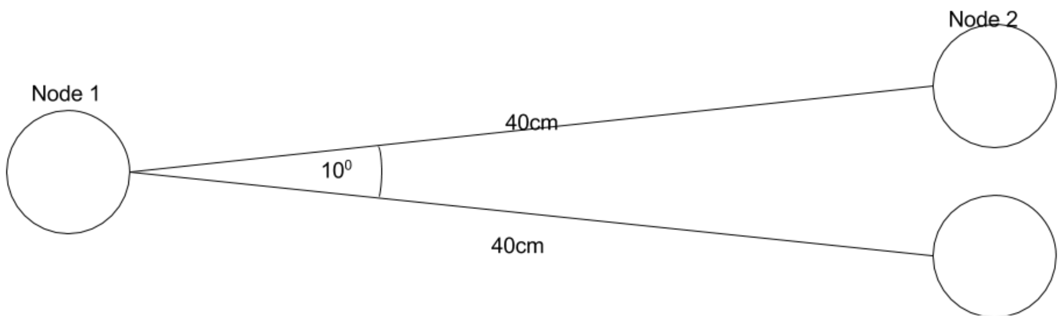


Figure 5.14 - VLC Glossy test 5

Table 5.23 - Test results of VLC Glossy test 5

Number of frames sent: 50 **Retransmission counter N = 3**			
Node	**No. of received frames**	**No. of Transmissions**	**Success**
Node 1	98	149	49
Node 2	148	148	49
Node 3	145	145	48

5.4.8 VLC Glossy Test 6

This experiment done with four nodes. these four nodes are placed linearly. the figure shows how the nodes are placed in this test.

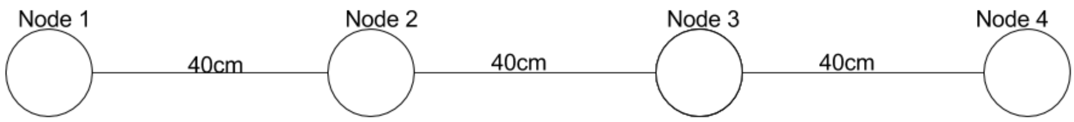


Figure 5.15 - VLC Glossy test 6

Test results for the VLC glossy test 6 had presented in table 5.24

Table 5.24 - Test results of VLC Glossy test 6

Number of frames sent: 50 **Retransmission counter N = 3**			
Node	**No. of received frames**	**No. of Transmissions**	**Success**
Node 1	82	132	30
Node 2	106	106	28
Node 3	98	98	24

Node 4	94	94	22

5.4.9 VLC Glossy Test 7

This test done with 4 nodes placing like a graph. Node 1 as the initiator and Node 4 as the final destination of the frame. Node placement of the test shown in figure

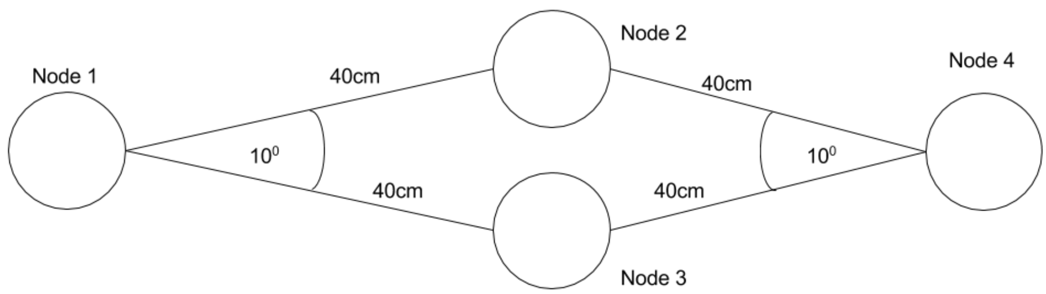


Figure 5.16 - VLC Glossy test 7

Test results are shown in table 5.25.

Table 5.25 - Test results of VLC Glossy test 7

Number of frames sent: 50 **Retransmission counter N = 3**			
Node	**No. of received frames**	**No. of Transmissions**	**Success**
Node 1	86	136	35
Node 2	112	116	31
Node 3	108	108	28
Node 4	120	120	34

This experiment shows that number of received frames at the Node 4 is more than Node 2 and Node 3. This shows that network topology cause for successful message transmission from initiator to a particular destination.

5.5 Problems Faced

The OpenVLC source code is publicly available. But OpenVLC platform is more expensive than the Arduino Platforms. That platform was developed by Disney research group but their source code is not accessible in public. So, we have to build the platform by referring to their findings mention in their research papers.

Lack of knowledge on how to work with the registry level of Arduino microcontroller. Sometimes it takes time to study and understand the source codes, its functionalities and importance of that features.

Lack of Knowledge about glossy and since its new flooding architecture lack of resources to study about Glossy and low power wireless bus.

Using Arduino functionalities, it cannot be achieved this speed. normal analogRead() function takes about 15ms seconds to detect the ON or OFF state at the emitter in initial stages. This speed 1Kbps was achieved using direct executions on registry level in Arduino board.

Since Arduino microcontroller is a single threaded it's become harder to program the Glossy in sequential way. Using interruptions cause to unknown errors in the system. But this has to be use because of multi-threaded micro controllers are expensive.

Sometimes it node read the signals correctly. That was cause by the charger of the laptop. But in some machines, that will not affect. Arduino board reads the analogRead() relative to its ground value. If charger is connected to the laptop this ground values will change and it will cause for the fault analog readings.

When there is more sunlight data transmission will interfere by the sunlight. Receiver cannot read the analogRead values correctly. But there is no solution to detect and reduce the interference cause by the sunlight.

Chapter 6

Conclusion and Future Work

This research focus on Implementing Glossy on VLC. The main problem we encounter was research platform that was not available to start VLC researches. So first benchmark mark of this project was implement a research platform for VLC researches.

First experiment was to implement separate emitter and receiver using off-the-shelf LEDs Microcontrollers and photo transistors. and final outcome will use for implement and test Glossy on VLC. So, implement low-cost research platform is a limitation of this project. Because glossy needs more nodes, low cost research platform is cost effective.

We build and test the results of emitting node and the receiving node. throughputs are more similar to the Disney researches[18]. Throughputs are increased when payload size increase. And 5mm straw hat cool white LED is more suitable for send signals in wide area and 5mm Red LED is suitable for send data to more distance. most of the time when testing the emitter and receiver fist frame will lose due to synchronization between two participating nodes. after synchronize both nodes packet lost rate or collision at receiver node reduced.

Glossy nodes must able to execute both functionalities of emitting and receiving. Next goal is to made a node that capable of sending and receiving signals. Combining the functionalities of emitter and receiver we were able to build a node that capable of sending and receiving signals. Since receiving was achieved by analog mode and emitting was achieved by digital mode we use the mechanism to change between these two mode sequentially. This was cause by Arduino UNO is a single threaded microcontroller.

In Glossy environment signals are send both forward and backward directions. Then we use two LEDs and two photo transistors that focus to forward and backward direction.

In Glossy environment, we placed the nodes in arbitrary positions. But we have to keep nodes within range of photo transistor. With the Glossy, we had achieved the time synchronization with the ETX of the receiving frame. after that all the nodes are change their state to transmission mode. With 3 and 4 nodes, able to test glossy functionality implemented on VLC and it gives accurate results. But the efficiency will reduce when the number of are increased. But to send a message to a particular destination network topology will cause. In tree type node placement experiment (VLC Glossy Test 7), has receive the more frames at the destination than the nodes between initiator and the destination.

6.1 Future Work

6.1.1 Implement the Emitter at Higher Speeds

In the current implementation, the emitter is transmitting at a low speed around 1kbps. The reason behind this low speed is the low sampling rate of the transmission caused by higher free-scale values. If the implementation is improved to support a higher sampling rate through the use of lower free-scale values, then the emitter would support transmissions at higher speeds.

6.1.2 Implement Farther Communication

Communication in the implementation is limited to the maximum distance to which the LEDs and Photo Transistors extend. If the magnitude of the LEDs are amplified or if more powerful LEDs are used, then Glossy communication can be implemented across longer distances.

6.1.3 Extend to Multi-Threaded Functionality

The current implementation of Glossy operates in a single thread since the microcontroller of the Arduino Uno board used for the implementation is single-threaded. Therefore, communication at one node is limited to either transmitting or receiving at a given time. However, if a multi-threaded microcontroller is used instead, the implementation can be extended to support multi-threaded functionality. This implies the possibility of simultaneous transmission and reception at nodes.

6.1.4 Implement Other Protocols on the Platform of the Research

The platform of this research includes design concepts, implementations and evaluation techniques which are independent of Glossy. Therefore, these can be applied to the implementations of other protocols for visible light communication. By reusing the same platform, a significant effort can be saved which would otherwise be repeated.

6.1.5 Implement LED to LED communication

The setup of the current implementation is based on the communication between LEDs and Photo Transistors where an LED sends and a Photo Transistor receives. However, LEDs can be used for reception as well. The setup can be reimplemented for communication between LEDs and the same evaluations can be repeated to assess LED to LED communication against LED to Photo Transistor communication.

6.1.6 Evaluate the Avenues to Improve Collision Tolerance in Glossy

The number of collisions increase as the number of nodes are increased in the network. This research evaluated a network of up to four nodes. The research can be extended to evaluate networks of larger number of nodes and the effect of the additional nodes on the collision tolerance of Glossy.

6.1.7 Extend the Evaluation for Other Encoding Methods

The current implementation uses Manchester Encoding to encode the signals. The evaluation can be carried out using other encoding methods. The results can be used to compare the suitability of each encoding method for Glossy.

6.1.8 Extend the Evaluation for Other Modulation Methods

The current implementation uses On-Off-keying for modulation of signals. The suitability of other modulation methods for Glossy can be assessed by redoing the implementation using other modulation methods.

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