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VISIBLE LIGHT COMMUNICATION PHYSICAL LAYER DESIGN FOR JIST SIMULATION

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ABSTRACT

Current advances in computer networking consider using visible light spectrum to encode and decode digital data. This approach is relatively non expensive. However, designing appropriate MAC or any other upper layer protocol for Visible Light Communication (VLC) requires appropriate hardware. This paper proposes and implements such hardware simulation (physical layer) that is compatible with existing network stack.

KEY WORDS

VLC, Visible light communication, simulation, JIST

INTRODUCTION

VLC is a novel technology that utilizes latest emerging technologies like LED[1] which are versatile, resilient, and durable light emitting elements, especially latest OLED[1][2]. LED are to be used widely in EU homes, according to (3). Today, LED can be found everywhere: in living spaces, streets as street lights, advertisement panels, vehicle head and tail lights,...
With LED market penetration growth there is also new room for research, so VLC conveniently comes in place to utilize high efficiency and flexibility of LED. VLC is a new communication technology that needs to be compatible with existing communication infrastructure. Having this in mind, scientific community requires appropriate testbed and working environment for researchers to develop and design various protocols and applications using VLC. Existing wireless communication protocol has many simulation environments but none has the support for VLC specific characteristics.

STATE OF THE ART

VLC
History of VLC starts back to 1880 when Alexander G. Bell invented something he called photophone that used sun light to transmit sound information to distant receiver, it is notable

[1] Organic LED

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that visible light, to transmit sound, was used before radio waves (like described by Guglielmo Marconi). During the past Infrared data transfer has been used to transfer data from various devices, later on IrDA[2] technology lost its market share to novel technologies like WiFi or Bluetooth. There are many research groups that conduct research on VLC, notable one is OMEGA[3] project that has the goal to provide gigabit access to homes; one technology to help with this goal is the optical-wireless technologies, more specifically VLC. Latest VLC research efforts result in VLC transmission speed up to 875Mb/s (4).

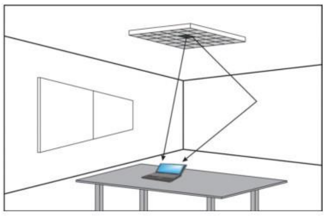

Fig. 1 *Typical VLC use case scenario [5]*

VLC infrastructure:
Figure 1 shows typical VLC use case scenario where source of data represents ceiling light hardware with programmable LED light array sources. On the other side there is a consumer (PC-laptop device) that consumes data being provided by the ceiling light.

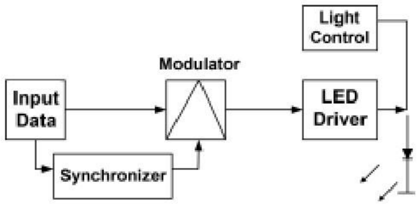

Fig. 2 *VLC transmitter system (1)*

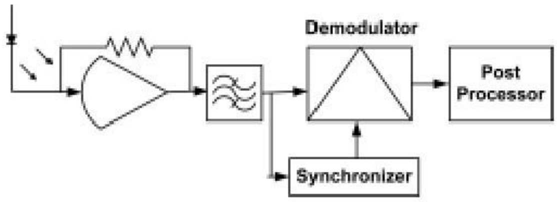

Fig. 3 *VLC receiver system (1)*

Figure 2 shows typical VLC transmit equipment containing all the necessary components. Modulator is key component that receives input data and modulates output light to represent input data. Figure 3 shows typical VLC receive equipment containing all the necessary components. Demodulator is key component that interprets incoming data and decodes it into a digital format ready for post processing.

VLC modulation:
To encode data into light spectrum several methods of modulation can be used[6]. Changing frequency (colour) is one of techniques but it requires RGB LED array. Frequency modulation requires filtering and special photodiode to distinguish different frequencies. Prism may come in handy with separating visible light frequencies. On-Off-Keying (OOK) (7) where logical true is represented as existence of light and logical false is nonexistence of light. Of course, this turning light on and off is not noticeable to human eye, however to distinguish 0 and 1 there has to be preamble that will indicate start of transmission, other technique would be to modify intensity instead of turning LED completely off.

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2 Infrared DataAssociation
3 omega

JiST

JiST[4] is a high-performance discrete event simulation engine that runs over a standard Java virtual machine; that is a Javabased simulation system that executes discrete event simulations both efficiently and transparently by embedding simulation semantics directly into the Java execution model (8). According to authors, JiST performance outperforms popular network simulators like ns2, Parsec or GloMoSim. Performance was questionable mainly because use of Java technology against fast and robust C/C++.

Performance results, along with the fact that JiST is opensource solution are the main reason why JiST was selected platform to simulate VLC MAC protocol.

PHYSICAL DESIGN

Modifying existing JiST simulator to be able to simulate VLC communication requires intervention on several elements (classes) inside simulator source code.

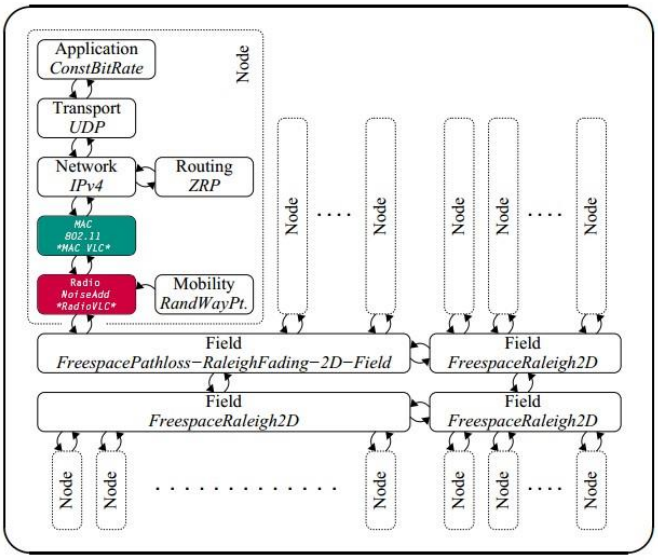

Fig. 5 *JiST simulator architecture related to network stack (8)*

As shown on Figure 5. most modifications are done on green and red elements. It was necessary to implement complete MAC protocol that is compatible with upper layers and with lower layers of protocol like WiFi radio to maintain transparency. Also, to maintain transparency modification to the Radio class (red element on Figure 5.) were necessary. Thus being vehicle simulator and according to (9) each vehicle can have multiple head and tail lights, each is able to transmit different data. In practice this means that each node (vehicle) can have several distinct transmit and receive devices.

Sensors

Sensor, in the context of software code is a device (class) that is able to transmit or receive data. To maintain compatibility with the rest of the code, VLC radio device is a single object with multiple sensors. Sensor implementation is not visible outside of RadioVLC class, this means that every other MAC protocol e.g. 802.11 can use RadioVLC to transmit or receive data.

[4] more info at jist.ece.cornell.edu

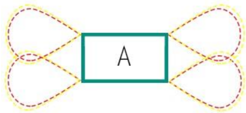

Fig. 6 *Vehicle Tx/Rx device(sensors) layout*

Figure 6 shows typical sensor allocation on vehicle node A. Red displays Transmit sensor coverage area and yellow is Receive coverage area. It can be noticed that shape of Tx/Rx segment is circle slice. According to [9] slice radius should be 30m and angle is 70. There are many variations of sensor layout and the number of sensors.

Listing 1: VLC sensor constructor signature

```
/**
 *  @param sensorID sensor unique ID for device.
 *  @param node Radio device (VLC)/vehicle this sensor belongs to.
 *  @param distancelimit desired distance limit, line of sight, radius of circle slice.
 *  @param visionAngle circle slice angle.
 *  @param originalLoc node starting location.
 *  @param offsetX offset in x axis of sensor location regarding to center of vehicle (originalLoc)
 *  @param offsetY offset in x axis of sensor location regarding to center of vehicle (originalLoc)
 *  @param bearing bearing of sensor. 0 faces forward and 180 faces backward * @param mode sensor mode: Rx or Tx.
 */ public VLCsensor(int sensorID, RadioVLC node, float distancelimit, float visionAngle, Location originalLoc, float
offsetX, float offsetY, float bearing, SensorModes mode);
```

Listing 1 shows signature for constructor that is used while creating single node (vehicle) that is to create object of RadioVLC class. Implementation is modular in aspect that single node can have virtually unlimited number of sensors attached on outer edge of node. To enable versatility of VLC multiple sensors - multiple duplex channels, MAC protocol can assign sensor to each message. Using methods defined in VLCSensor class: `setSensorIDTx(int sensorID)` and `setSensorIDRx(int sensorID)` MAC protocol can assign sensor by unique sensor ID given at create time (Listing 1). To secure transparency, if no sensor is set then all sensors are used to transmit message, and if sensor is busy then message is dropped. This extra information is not stored in the message itself, more precisely: it will not be transmitted over the field.

Message being sent from MAC layer is tested against intersection of sender and receiver sensors circle slices. *Sending* sensor must be in the circle slice of *receiving* sensor for the message to be sent and received. Transmission power, pathloss, and fading still affect message delivery, but slice filtering is executed before, and message is dropped before pathloss calculations, this way code executes faster.

Control channel

Having control channel provides extra helpful service to possible MAC protocol implementations. There can be several methods to implement control channel: time division (10) or frequency division (11). Frequency and time division reserve time or frequency band at the cost of bandwidth. This implementation uses virtual division. Designing MAC protocol, bandwidth itself is not the most relevant metric, Package Delivery Rate (PDR) is more relevant to define good MAC implementation. Impact of having control channel on bandwidth can be ignored. Because of that, control channel is implemented as an independent feature not related to message transport or field characteristics. Control signal can only have two values, existence or not, that is 0 or 1. This implementation does provide multiple control channels identifiers: 0-

127. Virtual, MAC implementation can have 125 different control channels. Having large number of control channels will have significant effect on bandwidth in real case scenarios.

Pathloss and fading

According to some authors VLC systems do not experience fading[9]. However, VLC does experience rather specific pathloss, unlike omnidirectional antennas in common wireless systems, VLC has directional ”antennas”, which means that it is not irrelevant at which angle light ray enters or exists VLC transmitter or receiver.

Listing 2: Calculation of receive power for VLC pathloss

```
ReceivePower = TransmitPower * (((m+1)*A)/(2*Math.PI*Dd*Dd)) * (Math.pow(Math.cos(fiAngle),m) * Ts(psiAngle) *
g(psiAngle, psiC, n)* Math.cos(psiAngle));
```

Listing 2 is implemented using equation (6) from (7). Real issue is calculating exit and entry angle of light ray between nodes that can be randomly placed and randomly oriented.

Two nodes form virtual line, slope of this line can be expressed as an angle using the formula:

$$\theta_0 = \tanh(\frac{y_2 - y_1}{x_2 - x_1}) \quad [1]$$

where x_n and y_n are corresponding coordinates of nodes 1 and 2.

$$\psi = |(360^{\circ} - \theta_0 - B_d)| \quad [2]$$

where ψ is the enter angle between light ray and normal to the photodiode sensor surface; B_d is the bearing of destination node. Bearing is an angle between orientation vector and *X* axis.

$$\varphi = |\theta_0 + B_s| \quad [3]$$

where φ is the exit angle between light ray and normal to the LED ray surface toward the receiving node; B_s is the bearing of source node.

As noted in previous sections pathloss calculation is only executed when nodes are near each other and when one is inside the circle slice of the other.

CONCLUSION

VLC does have a great potential to enable fast and environment friendly communication. Visible light does not harm human beings as it is the case with other spectrum of electromagnetic radiation (12). VLC technology is relatively new and it still has many issues, like light noise from the Sun and environment lightning.

Advances being made are relatively specific, to encode and transmit data as fast as possible. To use VLC in existing Internet infrastructure still requires some research in the areas of MAC protocol or routing layers.

This hardware simulation design is both transparent which means it can accept any input from upper or lower layers and it can provide expected output as defined in ISO OSI standard (13). Being transparent, VLC radio simulation can work with 802.11; however, this MAC protocol, in essence, is designed for single omni-directional transceiver, and there are obvious flaws with 802.11 on VLC link. For researcher to develop and measure MAC implementations this hardware simulator is essential because implementing and testing one protocol on a real hardware will be expensive and slow.

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