Demo: Streaming Video over 360 Degrees Visible Light Communication

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Abstract

In this paper we present the demo of a 360 degrees visible light communication (VLC) transmitter built over the low-cost OpenVLC platform. We present how we can stream a video broadcasted from a VLC transmitter providing large angular coverage, and displaying it seamlessly in the receiver. We show how the setup is implemented and evaluate its performance. This work shows the feasibility of low-cost 360 degrees VLC transmitters complying with real-world requirements of distance, coverage angle, mobility, data rate and robustness against background light.

CCS Concepts

• **Hardware** → **Networking hardware**; **Wireless devices**; • **Computer systems organization** → *Sensor networks.*

Keywords

Visible Light Communication (VLC), embedded systems, video streaming, 360 degrees

1 Introduction

Visible Light Communication (VLC) has received great attention in the last years as wireless technology to provide access to the Internet leveraging the optical spectrum. It has been originally proposed as an alternative to radio frequency (RF) technologies affected by the spectrum crunch [8, 9] providing both illumination and communication. It has then found applications also in the low-data rate regime, such as indoor localization [1], and simultaneous data and energy transfer [7].

The research and innovation in VLC originated with the invention of Light Emitting Diodes (LEDs). LEDs transmit photons following the Lambertian model, meaning that the radiant intensity is proportional to $\cos^m(\theta)$ where θ is the angle with respect to the normal direction and m is the Lambertian order. As such, they are naturally more secure than RF-based systems, that instead broadcast their signals. For instance, the higher is the order of m, the more directional is the link. Furthermore, collimators are often used in VLC to narrow down the optical beam and increase the communication range. As a result, disrupting VLC is challenging for attacker, thanks to its resilience to jamming. For instance, it can be used to communicate when the RF infrastructure is compromised. On the other hand, achieving the same directionality with RF technology would result in computationally expensive and power-hungry beamforming techniques.

However, the natural directionality of VLC can be also a drawback. For instance, in those scenarios where one or both ends of the link require mobility or change their direction, directionality causes frequent disruption of the communication link. In order for these applications to benefit from VLC, this problem must be overcome. In prior attempts to provide larger coverage, Shine used low-power LED indicators consuming only a few mW each, which resulted in limited communication range of less than 50 cm [6]. An additional layer added to this challenge is to address the problem without using complex or expensive optical equipment, which is prone to not be suitable to deploy in mobile users.

This demo shows VLC with 360 degrees capabilities using low-cost hardware such as OpenVLC [4]. This platform has been previously used to show its data rate capabilities are sufficient to stream video over it [3]. In this paper, we show how this can be extended to 360 degrees video transmission and its challenges.

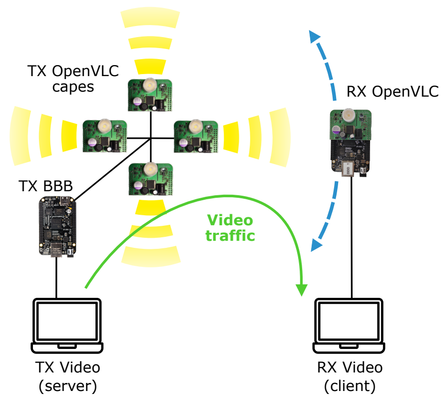

Figure 1: Experimental scenario of the 360 degrees VLC system. The transmitter, composed of a set of LEDs and their driving circuits (TX OpenVLC capes), provides large angular coverage. The video traffic is streamed from all LEDs in a broadcast manner, and the receiver is moved around the transmitter. The demo shows that video streaming at the receiver is maintained despite of mobility.

2 System view

The system overview is shown in Fig.1. A video server (TX) is connected to the OpenVLC-based 360 degrees VLC transmitter and sends the video through it. Another OpenVLC unit is used as a VLC receiver (RX), being able to rotate around the transmitter. The video stream it receives is displayed on the video client side.

2.1 VLC link

OpenVLC is comprised by an embedded board (BeagleBone Black, BBB) that runs Linux Operating System, with the OpenVLC Linux driver and firmware that interface the TCP/IP stack to a low-cost

VLC front-end, called cape. Both Linux driver and firmware, as well as the hardware are open source, and available in the project website[1]. OpenVLC was designed to have a single cape attached to a single BBB.

A simple extension to provide coverage over 360 degrees would be to send the same data stream over multiple BBBs, each connected to a single OpenVLC cape. However, this approach would result in out-of-phase optical signals.

We instead leverage the fact that we could control in software several OpenVLC capes with a single BBB. In particular, the BBB provides the data signal while each OpenVLC cape drives its LED with a separated circuit and power supply. The limit on the number of capes a single BBB can control is not limited by the current drained by the capes; the BBB pin can provide an output of 6 mA, while the MOSFET gate driver of the cape requires less than 10 μA. However, to protect both components and facilitate the connections, we use a line driver [5] to interface the BBB with the capes. As all the capes are driven with the same electrical (baseband) signal, they simultaneously broadcast the same data with in-phase optical signals in all the covered angles.

The VLC link is established between the TX BBB and BBB with one OpenVLC cape as a receiver. A by-product result of having optical signals in phase is that the communication range performance increases in those angular regions covered by more than one LED.

2.2 Video streaming setup

In the demo, we arrange adequately the OpenVLC capes at the transmitter side with the help of a 3D-printed case providing the desired 360 degrees VLC coverage.

Several tools can be used for streaming the video. Given the unidirectional nature of the VLC in this setup, we decide to use a technology that does not require communication from the receiver to the transmitter i.e. for requesting back missing packets. For that reason we configure the server to just send an RTP video stream to a known IP where the client is listening to. Each one of the nodes in the system is configured to route video traffic in this direction.

It is important to consider the limitation in terms of data rate of the VLC link. We use OpenVLC1.3, which has a limitation of 400kb/s on the transport layer. The bitrate of the video must respect this limit to avoid congestion in the VLC link. As we cannot benefit from the control messages provided by the RTCP protocol, we dismiss its use to save the available bandwidth for video traffic.

We measure the one-way delay from the server to the client, by synchronizing both nodes using Network Time Protocol (NTP) and sending packets including a timestamp. We conclude a one-way delay of 24 ms. This is negligible compared to the delay of few seconds required by the video decoder on the client side.

3 Results

Once the system has been setup and the IP routes configured, the client starts listening for RTP traffic in a known port and the server starts sending to it using the VLC link. The video stream is received and displayed by the client.

We move the receiver OpenVLC around the 360 degrees transmitter without disruption in the video streaming. The receiver is served by a different TX cape when this one has a better alignment than the receiver.

We note that in this demo, we can provide 360 degrees covering only the azimuth angle, as the cape is not physically designed to pack several units over all the zenith angles.

4 Conclusions

In this demo, we show the design and implementation of a 360 degrees VLC transmitter based on a low-cost platform as OpenVLC. We show that the system supports video streaming across the full angular range. This opens the possibilities for VLC communications to high mobility scenarios without requiring complex or expensive hardware, but just with open source hardware and software.

5 Requirements

For the demo, we use two NUC units [2] with Ubuntu as a video server and client. They are connected to the Beaglebone Black boards through their USB interfaces, leveraging the Ethernet-over-USB feature of the board. In the demo, the transmitter and the receiver are attached to one tripod each for showing the mobility of the system. Each OpenVLC cape is powered individually, using its 5 V input.

The organization should provide a table at least 2 meters long for deploying the material, monitors and keyboards for both the server and client, and a power supply connection.

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References

[1] Mohamed Amine Arfaoui, Mohammad Dehghani Soltani, Iman Tavakkolnia, Ali Ghrayeb, Chadi M. Assi, Majid Safari, and Harald Haas. 2021. Invoking Deep Learning for Joint Estimation of Indoor LiFi User Position and Orientation. *IEEE Journal on Selected Areas in Communications* 39, 9 (2021), 2890–2905. https://doi.org/10.1109/JSAC.2021.3064637

[2] Intel Corporation. 2024. Intel® NUC 12 Pro Mini PCs. https://www.intel.la/content/www/xl/es/products/docs/boards-kits/nuc/mini-pcs/nuc-12-pro.html. Accessed: 2024-10-15.

[3] Ander Galisteo, Diego Juara, Hector Cordobes, and Domenico Giustiniano. 2019. Video Transmission Using Low-Cost Visible Light Communication. In *Proceedings of the Twentieth ACM International Symposium on Mobile Ad Hoc Networking and Computing* (Catania, Italy) *(Mobihoc '19)*. Association for Computing Machinery, New York, NY, USA, 401–402. https://doi.org/10.1145/3323679.3326617

[4] Borja Genoves Guzman, Muhammad Sarmad Mir, Dayrene Frometa Fonseca, Ander Galisteo, Qing Wang, and Domenico Giustiniano. 2023. Prototyping Visible Light Communication for the Internet of Things Using OpenVLC. *IEEE Communications Magazine* 61, 5 (2023), 122–128. https://doi.org/10.1109/MCOM.001.2200642

[5] Texas Instruments. 2022. SN74HC244. https://www.ti.com/lit/ds/symlink/sn74hc244.pdf. Accessed: 2024-10-15.

[6] Lennart Klaver and Marco Zuniga. 2015. Shine: A Step Towards Distributed Multi-Hop Visible Light Communication. In *2015 IEEE 12th International Conference on Mobile Ad Hoc and Sensor Systems*. 235–243. https://doi.org/10.1109/MASS.2015.78

[7] Muhammad Sarmad Mir, Borja Genoves Guzman, Ambuj Varshney, and Domenico Giustiniano. 2021. PassiveLiFi: Rethinking LiFi for Low-Power and Long Range RF Backscatter. In *Proceedings of the 27th Annual International Conference on Mobile Computing and Networking* (New Orleans, Louisiana) *(MobiCom '21)*. Association for Computing Machinery, New York, NY, USA, 697–709. https://doi.org/10.1145/3447993.3483262

[8] Oledcomm. 2024. LiFi Technology by Oledcomm. https://www.oledcomm.net/.

[9] PureLiFi. 2024. PureLiFi. https://www.purelifi.com/.

[1] www.openvlc.org/