

OpenVLC: Software-Defined Open Architecture for Embedded Visible Light Networks

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ABSTRACT

The goal of this demo is to introduce OpenVLC, a flexible software-defined platform for research on Visible Light Communication (VLC) networks. Built around a cost-effective embedded Linux platform with an LED front end, OpenVLC offers a set of essential physical layer (PHY) and medium access control (MAC) primitives, as well as an interface to Internet protocols. OpenVLC makes it possible to easily build PHY and MAC protocols and rapid prototype them in realistic network setups. In this demo, we show that OpenVLC can switch between different MAC protocols and can be employed jointly with standard TCP/IP diagnostic tools.

1. INTRODUCTION

Visible Light Communication (VLC) has the potential to complement radio frequency communication, or even replace it for certain applications. Though there has been a great deal of interest in VLC in recent years, the lack of an open-source reference platform is hindering the progress of research in VLC networks. A general-purpose platform would add momentum to VLC research, open up new avenues of VLC research, and spark the interest of researchers and engineers. The goal of this demo is to showcase the operation of OpenVLC, a flexible software-defined VLC platform for rapid prototyping that runs on a cost-effective yet powerful embedded board. OpenVLC interfaces the LED front-end to an embedded Linux platform and offers key primitives such as signal sampling, symbol detection, coding/decoding, carrier sensing and Internet protocol interoperability. Among its many benefits, OpenVLC provides the basic tools to implement various protocols and prototype them in real-world VLC network setups.

Design OpenVLC is a software-defined platform, built upon a BeagleBone Black (BBB) board [1] and a front-end transceiver that adopts a single LED to both transmit and receive light signals. While photodiodes are normally used as receivers, a reverse-biased LED (rather than a photodiode) may be used as a receiver to implement bidirectional LED-to-LED communication [3]. This principle has been exploited to introduce the con-

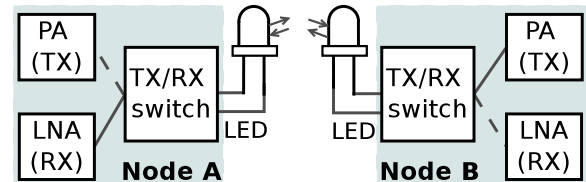


Figure 1: Block diagram of the transceiver.

cept of LED-to-LED communication networks [4]. Among other benefits, it permits to reduce the design complexity and increase the resilience to ambient (e.g. sunlight) noise without additional signal processing. A block diagram of the front-end transceiver is shown in Fig. 1. A software-defined Transmitter (TX)/Receiver (RX) switch allows to control the operation mode of the LED. In **TX mode**, the LED is connected to the Power Amplifier (PA); in **RX mode**, it is connected to the Low-Noise Amplifier (LNA). These approaches enable the implementation of time-division duplex protocols as well as the IEEE 802.15.7 standard [2] for short-range communication. Fig. 2 illustrates a block diagram of the software stack of OpenVLC¹. Primitives are implemented in the Linux operating system, including:

- writing/reading a symbol to/from an LED
- switching an LED between TX and RX mode
- coding/decoding
- preamble detection
- interfacing with TCP/IP

Details of the implementations can be found in [6]. Based on these primitives, various PHY and MAC layer protocols can be implemented as Linux drivers that can communicate directly with LED and the Linux networking stack. These primitives can be further used to implement programmable MAC protocols [5].

2. DEMONSTRATION SETUP

The Linux operating system running on the BBB board is the Angstrom Distribution with kernel version 3.8.13.

¹We have launched a website to share the source code and electronic schematic of OpenVLC: <http://openVLC.com>

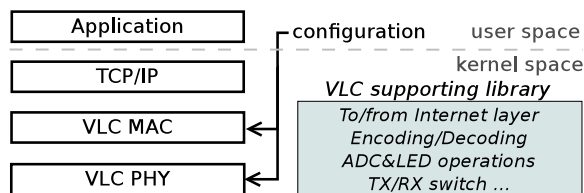


Figure 2: Block diagram of the implementation of the OpenVLC platform in an embedded Linux operating system.

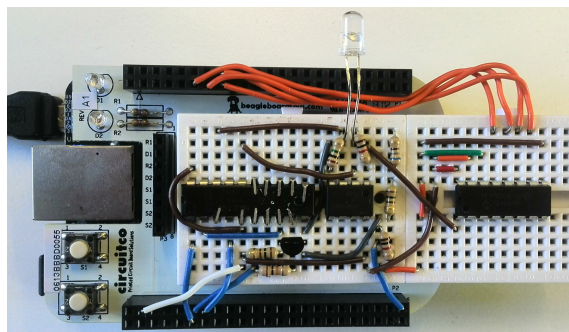


Figure 3: The current prototype of OpenVLC.

Off-the-shelf electronic components are used in the VLC transceiver. To ensure fair channel access among nodes and reduce collisions, we implement the contention-based CSMA/CA (Carrier Sensing Multiple Access/Collision Avoidance) and the CSMA/CD (Carrier Sensing Multiple Access/Collision Detection) MAC protocols [4]. Both protocols are implemented in software as part of a dedicated VLC Linux driver and are connected to the Internet Protocol layer. The current prototype is shown in Fig. 3 but may quickly evolve in the next months (e.g., a cape plug-in board may be designed to connect the circuitry to the BBB²). We demonstrate some functionality of OpenVLC through the following scenarios:

Scenario 1: modulated light. We demonstrate the PHY flexibility of OpenVLC with one node. First we demonstrate an On-Off-Keying (OOK) with Manchester run-length limited (RLL) line code, and then we switch the modulation on the fly to OOK without Manchester RLL line code. The difference between these two modulations can be observed easily from a remote host.

Scenario 2: MAC protocol. We demonstrate the MAC protocols CSMA/CA and CSMA/CD using two OpenVLC nodes. In CSMA/CA, we show the interaction between two communicating nodes with a focus on the backoff mechanism. In CSMA/CD, we demonstrate the collision detection mechanism, i.e., as a node detects a collision, it interrupts the ongoing frame transmission. Since visible light is the communication medium, the attendees will be able to observe visually how CSMA/CA

²http://elinux.org/Beagleboard:BeagleBone_Capes

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root@beaglebone:~/net_vlc# ./tx.sh
PING 192.168.0.2 (192.168.0.2) 10(38) bytes of data.
18 bytes from 192.168.0.2: icmp_req=1 ttl=64 time=415 ms
18 bytes from 192.168.0.2: icmp_req=2 ttl=64 time=410 ms
18 bytes from 192.168.0.2: icmp_req=3 ttl=64 time=419 ms
18 bytes from 192.168.0.2: icmp_req=4 ttl=64 time=405 ms
18 bytes from 192.168.0.2: icmp_req=5 ttl=64 time=408 ms

--- 192.168.0.2 ping statistics ---
5 packets transmitted, 5 received, 0% packet loss, time 2000ms
rtt min/avg/max/mdev = 405.672/411.790/419.220/4.867 ms

```

Figure 4: Snapshot of the ping results.

and CSMA/CD are affected by collisions.

Scenario 3: networking diagnostic tools. We demonstrate the network layer performance through the well-known networking diagnostic tools `ping` and `iperf` using two OpenVLC nodes. We demonstrate the results in a terminal when one node pings the other, as shown in Fig. 4, and other TCP/UDP test results from `iperf`.

3. CONCLUSION

The goal of this demonstration is to introduce the OpenVLC platform, demonstrate its functionalities, and highlight its potential as a research tool for the VLC community. It should be noted that a handful of commercial off-the-shelf components can suffice as a starter kit for VLC research. Going forward, we envision that research groups in embedded systems with no prior VLC experience can use OpenVLC to explore the realm of visible light, while research groups with a solid VLC background can easily expand OpenVLC and enrich its set of functionalities.

4. REFERENCES

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