Demo: OpenVLC1.0 Platform for Research in Visible Light Communication Networks

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ABSTRACT

Built around a cost-effective embedded Linux platform, OpenVLC is an open source project (`www.openvlc.org`) for research in Visible Light Communication (VLC) Networks. In this work, we introduce and demonstrate the OpenVLC1.0 platform, a flexible, software-defined, and low-cost research platform. OpenVLC1.0 consists of a simple electronic design, and a new driver of the Linux operating system that implements the MAC, part of the PHY layers and it offers an interface to Internet protocols. The electronics of OpenVLC implement a flexible optical front-end consisting of commodity low- and high-power Light Emitting Diodes (LEDs), photodiodes (PDs), and ancillary electronic circuitry. In order to quickly start playing with VLC Networks, we have designed and developed a printed circuit board (OpenVLC1.0 cape). The cape can be plugged into the main embedded Beaglebone board. Researchers can then swiftly build PHY and MAC protocols using the software implementation (OpenVLC1.0 driver), and prototype innovative solutions in realistic network setups. In this demo, we show that OpenVLC1.0 can switch between different MAC protocols, it can choose different optical channel for data transmission and reception, and it can be employed jointly with standard TCP/IP diagnostic tools.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless Communication*

Keywords

Visible light communication networks; OpenVLC; Open-source; Low-cost; Research platform

MobiCom'15, September 07–11, 2015, Paris, France.
ACM 978-1-4503-3619-2/15/09.
DOI: http://dx.doi.org/10.1145/2789168.2789173.

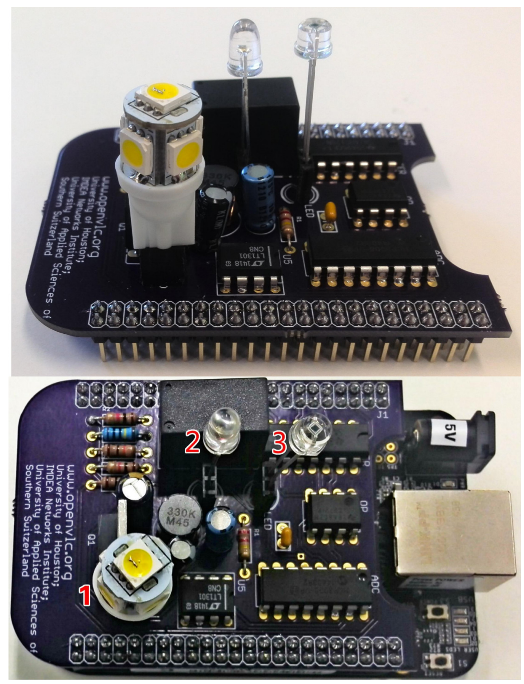

Figure 1: On the top: The OpenVLC1.0 cape. On the bottom: the cape plugged into an embedded board, that runs a Debian Linux and the OpenVLC1.0 driver to interface the OpenVLC1.0 cape to the Internet. The optical components are: (1) high-power LED; (2) low-power LED; (3) Photodiode (PD).

1. INTRODUCTION

Visible Light Communication (VLC) is emerging as a complementary technology to traditional Radio Frequency (RF) technologies. VLC is believed to be a proper candidate for the next-generation cellular networks [11, 3], accurate indoor localization [8, 2] and the Internet of Things [7, 14, 9]. Recent attempts for "softwarization" of VLC networks [14, 10, 4] show the need to speed up the research progress in this new field. Among these former works, only our low-cost OpenVLC project is open-source from the very beginning and it is designed to provide real-time functionalities for rapid prototyping of networked VLC systems [13].

In this demo, we introduce the OpenVLC1.0 platform, that interfaces an optical front-end consisting of a high-power LED, a low-power LED and a Photodiode (PD) to a cost-effective and powerful embedded board. In order to ease the exploration of the optical front-end, we have designed and implemented a printed circuit board (OpenVLC1.0 cape) that can be easily attached to the main embedded board. This plug-and-play approach allows researchers to focus on the software design of communication network protocols, without the hassle of wiring the optical components and the electronics in a breadboard. The cape is controlled using the OpenVLC1.0 driver, that implements key primitives at MAC and PHY layer such as signal sampling, symbol detection, coding/decoding, channel contention, carrier sensing and Internet protocol interoperability [14]. Among its many benefits, OpenVLC1.0 provides the basic tools to implement various protocols and prototype them in real-world VLC network setups.

2. SYSTEM DESIGN

OpenVLC1.0 is a software-defined platform built upon a BeagleBone Black (BBB) board [1] and a front-end transceiver that adopts a high-power LED, a low-power LED and a PD to transmit and receive light signals. A block diagram of the front-end transceiver and the software stack of the implementation are shown in Fig. 2 and Fig. 3, respectively. Several communication links are possible: OpenVLC1.0 can choose between high- and low-power LEDs as the optical transmitter, and between low-power LED and PD as the optical receiver. Each configuration comes with its own unique features in terms of channel propagation, receiver sensitivity, Field-of-View (FoV), etc. Flexible protocols can be designed that can dynamically choose the most desired configuration based on the current circumstance.

For instance, the high-power LED can be used to emulate the scenarios of communication under typical indoor illumination from the ceiling, while low-power LED can be enabled for those applications where the primary goal is communication, and the illumination is used as visual feedback. The LED as a receiver can be used to increase the resilience to ambient noise (e.g., sunlight and indoor illumination [7]) with no need for additional optical filters [5]. However, it comes with a smaller FoV than PDs. In our design, a software-defined optical selector allows to choose either the low-power or the high-power LED as the transmitter. Similarly, we can choose the low-power LED or the PD as the receiver.

Low-/high-power LED-to-PD communication: OpenVLC supports the communications between a low-/high-power LED and a PD. Low-power LED-to-PD can be used in scenarios where a more directional communication (e.g. secure communication) is perceived of interest, while a high-power LED can be used as an access point that serves a number of users.

Low-power LED-to-LED communication: 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 [6]. This principle has been exploited to introduce the concept of LED-to-LED communication networks [7] and to design an open-source platform for VLC research [13, 14]. In our design, a software-defined Transmitter/Receiver switch allows to control the operation mode of the low-power LED. This approach enables the implementation of time-division duplex protocols in the visible light spectrum [12].

High-power LED to low-power LED communication: the communications between high- and low-power LEDs are also supported by OpenVLC1.0. Under this case, a pair of high-power LED and a PD can form a transceiver that acts as an access point with wide FoV; while a single LED can be a transceiver residing into embedded size-limited devices.

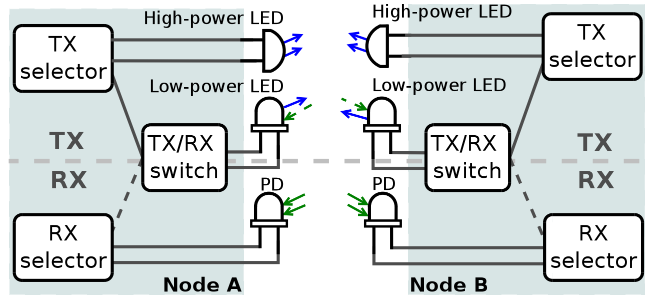

Figure 2: Block diagram of the OpenVLC1.0 cape.

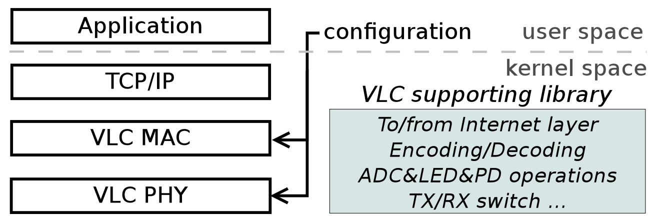

Figure 3: OpenVLC1.0 driver implementation in the software stack of an embedded Linux operating system.

3. DEMONSTRATION SETUP

The Linux operating system running on the BBB board is the Debian Linux Distribution (with kernel version 3.8.13) with the Xenomai patch. Off-the-shelf electronic components are used in the OpenVLC1.0 cape. To ensure fair channel access among nodes and reduce collisions, we implement three contention-based MAC protocols in the OpenVLC1.0 driver:

- listen-before-talk CSMA/CA (Carrier Sensing Multiple Access with Collision Avoidance) protocol for any configuration of the transceiver;
- listen-before&while-talk CSMA/CD (CSMA with Collision Detection) protocol for the low-power LED-to-LED communication [7];
- listen-before&while-talk CSMA/CD-HA (CSMA with Collision Detection&Hidden Avoidance) for the low-power LED-to-LED communication networks [12].

We implement the On-Off-Keying (OOK) with Manchester run-length line code and Reed-Solomon correction code as part of the PHY layer of the OpenVLC1.0 driver.

We demonstrate some functionality of OpenVLC1.0 through the following scenarios:

Scenario 1: Optical transceivers. We select on the fly the optical components for communication, such as choosing low-/high-power LED as the transmitter, and selecting the PD or low-power LED as the receiver.

Scenario 2: MAC protocols. We demonstrate the MAC protocols CSMA/CD, CSMA/CA, and CSMA/CD-HA using two to three OpenVLC1.0 nodes. We first show the interaction between two communicating nodes with a focus on the backoff mechanism. After that, we demonstrate the collision and hidden-node detection mechanism, i.e., as a node detects a collision, it interrupts the ongoing frame transmission or will not start a transmission. Since visible light is the communication medium, the attendees will be able to observe visually how the protocols are affected by collisions and hidden-nodes.

Scenario 3: Networking diagnostic tools. We demonstrate the network layer performance through the well-known networking diagnostic tools `ping` and `iperf` using two OpenVLC1.0 nodes. We demonstrate the results in a terminal when one node pings the other, and in another experiment where we test the UDP performance with `iperf`.

Demo setup. We need a table to hold one to two laptop(s) and two to three VLC nodes (a normal office table is enough) and a power socket extension. Additionally, we need a poster holder to introduce the demonstrator.

4. CONCLUSION

The goal of this demonstration is to introduce the OpenVLC1.0 platform, prove its flexibility for selecting different optical components for the communication, and showcase several prototyped network protocols. OpenVLC1.0 adopts a plug-and-play electronic approach, it relies on a customizable software implementation and it aims to be a starter kit for VLC networks research.

Acknowledgement

This research work has been partially supported by the Madrid Regional Government through the TIGRE5-CM program (S2013/ICE-2919), and partially supported by the National Science Foundation of the United States under grant no. IIS-1111507.

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