

OpenVLC, an Open-Source Platform for the Internet of Light

Domenico Giustiniano
IMDEA Networks Institute
Madrid, Spain

Qing Wang
IMDEA Networks Institute & UC3M
Madrid, Spain

Abstract—OpenVLC is an open-source, low-cost research platform for Visible Light Communications Networks. We discuss the challenges to use OpenVLC as a part of the Internet of Light.

I. INTRODUCTION

As a spectrum-rich alternative to Radio Frequency (RF), Visible Light Communications (VLC) is attracting the interests of both research and industry [1]–[3]. VLC has been indicated as one of the driving technologies to solve the wireless spectrum crunch problem of RF communication and has the potential to enable the creation of a new generation of ubiquitous networking systems. This is expected to create the foundation of a new generation of Internet of Things, called *Internet of Light* (IoL), where the light will play a central role. IoL will integrate communication, sensors and light towards the creation of smart environments for connected devices and objects. The exploration of light-based technologies is timeliness: facts are that 2015 has been proclaimed by the United Nations as the International Year of Light and Light-based Technologies (IYL 2015) and the 2014 Nobel Prize in Physics has been awarded to the invention of blue LED just two decades ago.

The cross-disciplinary know-how needed to entry in networked VLC could be a barrier to start performing research in this new field. In order to bring light to communication networks, a general-purpose, low-cost, and open VLC platform would pave the way to novel networking research directions and provide the underpinning technology to create novel networks and services. As a first step in this direction, we have built the OpenVLC, an open-source networking platform for Visible Light Communication. We apply a software-defined approach in order to guarantee fast prototyping of new networking protocols [4].

OpenVLC runs on a cost-effective yet powerful embedded board. The total unit cost of all the hardware components necessary to build OpenVLC is approximately sixty dollars. The source code and electronic schematic of OpenVLC are available at the following URL: <http://openvlc.org>. In its present form, OpenVLC already offers a flexible starter kit for VLC research in networking. The open approach allows anyone in the research community to contribute. Our expectation is that contributors coming from, e.g., optical, networking, localization, wearable computing communities, help with the experience of their specific disciplines to build a general purpose platform for research.

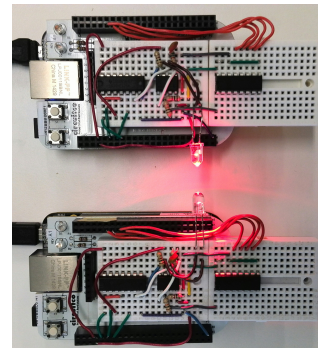


Fig. 1: OpenVLC: low-power LED-based VLC networks.

II. OPENVLC SYSTEM

OpenVLC is a software-defined and low-cost platform for networked VLC. The prototypes of OpenVLC equipped with low-power and high-power LEDs for communications are shown in Fig. 1 and Fig. 2, respectively. They are built around the BeagleBone Black (BBB) board [5], a cost-effective, user-friendly, and versatile single-board computer with a small form factor. OpenVLC consists of a BBB board, a VLC front-end transceiver and a software-defined system implementation. The front-end transceiver in Fig. 1 can adopt a single low-power LED together with a few basic electronic components for both transmission and reception. This approach can be of interest for devices and applications requiring a low brightness and direct links of communication, such as wearable devices and entertainment applications. While equipped with a high-power LED, as in Fig. 2, it becomes a transceiver for VLC networks providing high brightness in indoor environments and network infrastructure for the Internet of Lights.

OpenVLC’s software components are implemented as a *Linux driver* that communicates directly with the LED front-

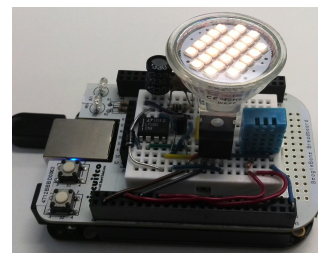


Fig. 2: OpenVLC: high-power LED-based VLC networks.

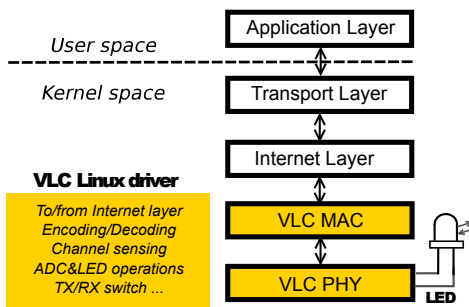


Fig. 3: Communication stack of OpenVLC in an embedded Linux operating system.

end and the Linux TCP/IP networking stack. As a result of this design, the VLC communication interface can take advantage of the vast range of Linux tools. The communication stack of OpenVLC is illustrated in Fig. 3. Details of the implementation can be found in [6].

III. RESEARCH DIRECTIONS

By integrating simple electronics, we aim to introduce smart lighting into low- and high-power LEDs. In its present form, the simplicity of our hardware makes OpenVLC of interest for applications with resource-poor and low-end devices. OpenVLC can achieve a MAC layer throughput in the order of the basic rate of IEEE 802.15.7 [3], and UDP throughput of 12.5 kb/s, operating at distances up to 1 m [6]. The performance of OpenVLC can be improved to reach out other domains of research investigations, using more powerful hardware and by customizing the software implementation according to specific application scenarios.

Potential performance enhancements of OpenVLC and its future research directions include:

Advancing the PHY layer design using matched-filtering, timing error recovery, and efficient modulations schemes including the Multiple Input Multiple Output (MIMO) technique. Higher performance could also be expected by using a dedicated hardware component for sampling the signal. These hardware can be the on-board Programmable Real-time Unit (PRUs) of the BBB, or an external components that can be attached to the board, such as Field-Programmable Gate Arrays (FPGAs) [7] or micro-controllers (MCUs). Besides, currently OpenVLC adopts the basic On-Off-Keying (OOK) modulation, but *advanced modulation schemes* can also be used by adding a Digital-to-Analog Converter (DAC) or by exploiting the Pulse-Width Modulation (PWM) pins of the BBB. In this way, the disadvantage of OOK in terms of inefficient bandwidth usage can be circumvented.

System integration of VLC with the RF technologies. This direction of research would allow to provide backward compatibility with previous embedded systems, thus creating bridges between classical Internet of Things with the smart environments of Internet of Light. The research challenges in networking include building a technology that can work also in presence of blind spot of light [8] or RF reception. The flexibility of the embedded board used by OpenVLC also allows for quickly adding sensors to it. A simple example is

shown in the platform with high-power LED of Fig. 2, that included a temperature and humidity sensor (on the right of the figure). This data can be both transmitted through Ethernet cable to the Internet and broadcasted via the high-power LED to end-users in the environment.

Implementing OpenVLC in the userspace. Recent research has explored the feasibility of implementing the PHY and MAC layers of ZigBee and WiFi in the userspace as downloadable software [9]. This approach would streamline the testing and deployment of modifications to existing and new protocols. In this direction, it would be also valuable to connect OpenVLC to other existing software (e.g., Matlab) to quickly test various modulation and coding schemes already available. With the PRUs of the BBB, it is possible to implement the MAC/PHY protocols of OpenVLC within the userspace of Linux without sacrificing the achievable performance such as data rate.

OpenVLC for localization The Internet of Light will need location information to provide context-aware services. Visible light based localization is showing great potential, despite it is still in its early phase of investigation [2], [10]. The reason is that the power decay of light signals is more deterministic than radio. A set of OpenVLC platforms such as Fig. 2 can act as beaconing devices in the visible light spectrum, and thus can be used for performing research in this field.

IV. CONCLUSION

OpenVLC is an open-source platform designed to enable VLC research in the field of networked embedded systems. OpenVLC has the goal to lower the barriers to entry to VLC research for embedded systems researchers, by leveraging the recent diffusion of embedded Linux boards. OpenVLC shows how a handful of commercial off-the-shelf components can suffice as a starter kit for VLC research in networking for the Internet of Light.

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