Demo: A Software-defined Visible Light Communications System with WARP

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ABSTRACT

In this demonstration, we present a software-defined visible light communications system using the Rice-developed WARP board. The presented system currently allows for both VLC and RF physical layer prototyping as well as collection of channel traces for MAC layer developments. In the demonstration, we will show transmissions of optical-OFDM frames using one LED as well as RF OFDM transmission at 2.4 GHz. For the optical-OFDM transmissions, we will demonstrate both ACO-OFDM and DCO-OFDM. The presented system is a promising candidate for research on future VLC or VLC/RF hybrid systems.

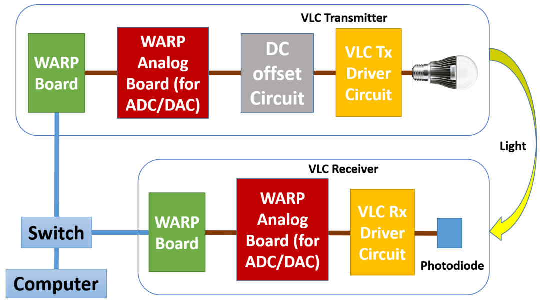

Figure 1: System architecture for a single Tx-Rx pair.

1. INTRODUCTION

With the increasing number of wireless users and the size of data transfers, there is a growing demand for capacity. Visible Light Communications opens an unique opportunity to increase spectrum since the currently un-used spectrum is un-regulated and virtually omnipresent. Extensive research efforts has been done for VLC systems since the early 2000s. Currently, the speed of a single-LED link has already reached Gbps speeds using micro-LEDs, RGB system, or MIMO. Besides indoor wireless LAN, VLC has also been proposed for other applications such as indoor localization and vehicular communications.

To facilitate further VLC research, we present a Software-Defined VLC platform. We leverage Rice University's WARP open research platform, originally designed for RF systems, to support VLC research. We will demo our system to show its capabilities.

2. SYSTEM DESCRIPTION

In this section we provide a detailed description of the demo system.

2.1 Single Optical Tx-Rx Link

Our system uses the Rice University developed WARP boards and WARPLab 6 reference design [1]. The system architecture for one transmitter-receiver pair is shown in Figure 1. The computer connected to the WARPs by Ethernet performs the data encoding and decoding, simplifying PHY layer changes.

For the ADC and DAC, we use the Rice-developed Analog Board, which is compatible with WARP V1.2. The Analog Boards are not useable with the provided WARPLab FPGA designs, so we modified the WARPLab to realize compatibility with WARPLab. Currently, each WARP board can mount one Analog Board, where each Analog Board can provide two DACs and two ADCs each with a sampling rate of 40 MHz. Given that commerical LEDs typically provide $<$ 20 MHz modulation bandwidth, this sampling rate is enough for most off-the-shelf LEDs.

Since the DACs provide a common-mode DC voltage of 1.65V that cannot be changed digitally or on-board, we built an op-amp circuit to change the voltage swing and the offset. The output of the DC offset circuit is fed into the LED driver circuit that only takes a positive signal. The driver circuit uses BJTs to convert a voltage to a current, which can change the brightness of the LED, thus modulating the signal onto the LED's brightness or optical power. At the receiver, the photodiode converts light to current, then the VLC receiver circuit converts current to voltage and amplifies the signal; the amplification factor on the receiver can be manually adjusted. The receiver circuit provides $+-$ 1V, the same voltage range as the Analog board, so an interfacing circuit is not needed here.

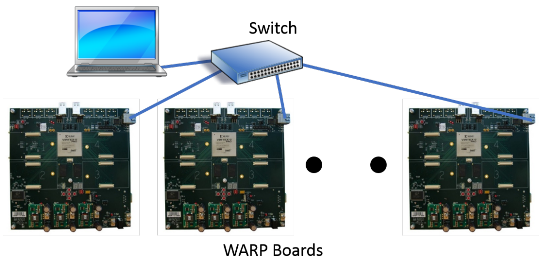

Figure 2: The WARPLab design allows multiple WARP boards to be connected to and controlled by a single computer.

2.2 WARPLab

For this demo, we use WARPLab FPGA design on the WARP boards and its complementary Matlab functions on the computer. WARPLab is a powerful design originally developed by Rice University and currently updated by Mango Communications. It facilitates rapid physical layer prototyping by providing the Matlab and WARP board interface. On top of the ability to control WARP via Matlab, WARPLab also allows for multiple WARP boards, up to 16, to be connected to a single computer, as is shown in Figure 2. Since each WARP board can now support either two LEDs or two photodiodes, this translates to up to 16 unique Tx-Rx pairs (eight boards for transmission and eight boards for reception). Such number can be further extended by connecting multiple switches to a central controller, as is done in [2], where 64 WARP boards were connected together. This scalability opens the possibility of using WARPLab for large-scale VLC-MIMO schemes such as spatial modulation [3].

WARP was originally designed for RF interfaces. With our modified design, WARPLab supports three 2.4 GHz or 5 GHz RF interfaces per board in addition to the LEDs or photodiodes. Each of the four interfaces can be configured to transmit or receive independently. Such capability opens the door to vast possibilities for VLC/RF hybrid systems.

3. DEMONSTRATION

Using two WARP boards, we will establish three communication links: two using VLC, and another using RF. For each of the links, we will show the constellation maps and the channel's frequency response updated periodically to demonstrate the capability of the platform.

All links will use QAM-OFDM modulations. The RF link will use standard OFDM for transmission, while the VLC links will use optical OFDM. There are two main types of optical OFDM: the DCO-OFDM and the ACO-OFDM.

The optical links use Intensity Modulation and Direction Detection (IM/DD), which imposes two restrictions to the baseband signal. First, the signal to be transmitted optically must be real since the carrier phase is not used to carry information. Second, the signal must be positive since it represents instantaneous optical power.

To satisfy requirement one, both ACO-OFDM and DCO-OFDM must meet the Hermitian symmetry requirement. For DCO-OFDM, approximately half the total subcarriers carry data. For ACO-OFDM, the data are allocated on the odd subcarriers of the subcarriers DCO-OFDM use, and the even subcarriers are set to zero; approximately a quarter of the total subcarriers carry data. When using ACO-OFDM, negative parts of the time-domain OFDM signal can be clipped without affecting the data, since the clipping noise falls onto the even subcarriers [4] [5].

ACO-OFDM already meets requirement two since the negative parts of the signal are simply clipped. DCO-OFDM adds a constant DC offset to the OFDM signal $X(t)$ such that $X(t) \geq 0$. Since the WARP Analog Board's DAC produces a constant offset, we use the DC offset circuit to demonstrate this type of modulation and show that a higher DC offset translates to higher optical power.

4. ACKNOWLEDGMENTS

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5. REFERENCES

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