High Throughput Mobile Visible Light Communication

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***Abstract*—Visible Light Communication (VLC) data capacity can be in the order of Tera-bits-per-second (Tbps) as it operates on an unrestricted terahertz band (400-700 THz) of the electromagnetic spectrum. However, in practice, all the existing VLC systems are limited in data rate, in the range of Kbps-Mbps. In this paper, we introduce a novel state-of-art VLC system for achieving ultra high data rates from the perspective of designing a high-speed VLC receiver. In our designed VLC receiver architecture, along with high sampling rates photodiode, we integrate an image sensor–like shutter mechanism that filters noise and interference. Through this unified design, the receiver will be able to select the exact area over which the transmitted signal is detected on the array, and thus isolates signal from noise to improve the Signal to Noise Ratio (SNR) significantly which leads the ultra high-speed in VLC systems. In this paper, we discuss the design details of our proposed VLC prototype and study the feasibility of the system through proof-of-concept experimentation.**

***Index Terms*—Visible Light Communication, High data rate, Noise & Interference cancellation**

I. Introduction

The growing number of mobile devices and applications is straining the capacity of wireless mobile spectrum and has created what can be referred to as spectrum-crunch. So, it's been a necessity to utilize the unused bands of the electromagnetic spectrum such as optical frequencies for wireless data communication through the Visible Light Communication (VLC) technology [1], [2]. The existing technologies like MIMO [3] which is complex, camera communication [4] which is limited in frame rates, are not capable of providing the desired data rate in VLC systems. Also, the recent efforts of VLC technology including Li-Fi [5], OpenVLC [6] are extremely limited in data capacity. So, achieving ultra-high data rates in VLC close to its wireless data capacity is the key vision of our research.

The Shannon's Capacity theorem suggests that data rate capacity is the logarithmic function of the Signal to Noise Ratio (SNR), with higher SNR values, higher throughput can be ensured. For getting higher SNR values, the noise level must be negligible or need to be reduced in a greater extent. From this point of view, we aim to reduce noise and interference to improve the SNR significantly by designing a VLC receiver architecture. Being motivated by the concept of Visual MIMO [4] [3], We combine the advantages of photodiodes and image sensors and propose a novel receiver architecture that emulates the functionality of image sensor arrays using a single photodiode [7]. We integrate a pixelated shutter mechanism as image sensing arrays to filter the noise and interference spatially from the signals. We have built a custom made shutter mechanism shown in Figure 1 using the LCD shutter glasses. The details of the designed VLC receiver architecture has been presented and discussed in [7].

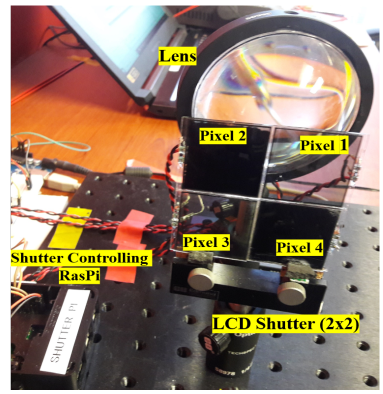


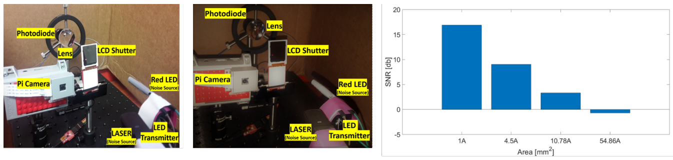
Fig. 1: Designed LCD shutter Mechanism

II. Research Problem

In this section, we will discuss what are the key challenges in designing such high-speed receiver architecture and how are we trying to solve these to ensure high throughput in VLC system.

1) Hardware Design: The key components of the proposed VLC receiver design are the high–speed photodiode, a shutter mechanism, and a computing unit to control the shutter in an automated fashion [7]. The shutter must need to understand and control which lights should be allowing in the photodiode as signals and which should be blocked or eliminated as noise. This functionality must be performed meticulously by the computing unit of the shutter to ensure higher SNR in the receiver. In [7], we design an experimental setup to conduct noise filtering and interference cancellation experiments using the custom made shutter and RaspberryPi as computing unit, shown in Figure 2 (a) & (b).

2) Shutter Controlling Algorithm Design: It is evident that our designed shutter mechanism must be intelligent enough to perform the spatial noise or interference filtering automatically.



(a) (b) (c)

Fig. 2: Our measurement setups for (a) Open box testing and (b) Closed box testing (c) SNR versus selected area of reception.

But, there is a key challenge to implement such an algorithm, as the receivers are not aware of or do not have any information of the incoming or transmitted signals. However, we try to tackle down this problem by designing an automated shutter controlling protocol which can be implemented in our receiver architecture. The algorithm follows two steps: i) Discovery phase and ii) Identification phase based on unique identifiers with each signal. In [8], we have clearly explained our shutter controlling protocol with extensive experimentation results as feasibility tests.

III. Preliminary Results

A. Spatial Noise Filtering and Interference Cancellation

Through proof-of-concept experimentation, in [7], we have extensively studied the feasibility of noise and interference reduction using our hybrid architecture. Using the setup shown in Figure 2(b), we conducted an experiment to measure the SNR for different choices of the reception area on the LCD shutter. Consider A = 57.40mm^2, we conducted these measurements for 4 area selections and plotted the SNR versus different areas of shutter opening in Figure 2(c). The selected areas are: (i) 1A: Only the area corresponding to the actual area of the photodiode was open (ii) 10.78A :An area in between the LED illumination and PD surface area was open (iii) 4.5A: Only the area corresponding to the LED illumination on the shutter was open (iv) 54.85A: Entire shutter was open.

We observe that the significant improvement in SNR (around 18 db), shown in Figure 2(c), when the area corresponding to the exact photodiode area is opened while other parts of the shutter are closed and this phenomenon proves the feasibility of the idea of noise isolation based on the area selection on the shutter.

B. Multiple Access in VLC

Accessing multiple users without sacrificing the channel bandwidth is one of the key challenges in VLC. In this work [8], we introduce a receiver design based on pixelated shutter mechanism that can enable multiple access using a single photo-receptor. We develop an automated shutter controlling algorithm, discussed earlier section, which can automatically identify the actual signals to be allowed in the receiver and block the other signals. We consider bit-error-rate (BER) and packet-error-rate (PER) as performance metrics, and lower BER (around 10^{-3}) and PER (around 3-5%) values indicate the feasibility of multiple access on a single photodiode from two light emitting diode (LED) transmitters and the performance of the communication link at higher frequencies [8].

IV. Conclusion & Future Work

In this work, we aim to develop a novel architecture of hybrid VLC receiver based on the unified design of integrating a photodiode and an LCD array that acts as a pixelated shutter. To identify and separate noise and interference from the desired signals, we present an automated shutter controlling algorithm (fast spatial tracking mechanism) in the receiver. In our preliminary research efforts, we have demonstrated the feasibility of our VLC receiver architecture by conducting measurements study of noise and interference identification and separation using our proposed shutter controlling algorithm.

Mobility is one of the major challenges in VLC as optical links are highly directional and with a smallest movement of the transmitter or receiver can significantly degrade the link quality. So, as a future work, we will be continuing the experimentation of fast spatial tracking mechanism to evaluate the performance of our VLC receiver in different possible mobility conditions (either transmitter or receiver or both are moving). In the near future, we will also integrate our high-speed VLC receiver architecture to achieve higher data rate in hybrid opto-acoustic and underwater VLC systems and applications. We believe that the research outcome of our project will set a foundation to achieve ultra high-speed (data rate) in VLC systems for different indoor, outdoor, mobile, and underwater applications.

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