Li-FiAR: Networking Augmented-Reality Devices through Visible Light

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Abstract

We have seen rapid deployment of augmented reality devices. However, these devices currently suffer from limited battery life. They require frequent recharge, especially when capturing and streaming information wirelessly. In particular, these devices stream information over the radio spectrum using transceivers that are power-hungry, and wireless communication dominates the energy budget of these devices. We present our ongoing work to design a system called Li-FiAR, which proposes integrating Li-Fi with augmented reality devices. Specifically, we implement a transmitter and receiver and integrate them with an augmented reality device. We argue that Li-Fi receivers may consume less power than their radio counterparts while benefiting from the spatial nature of light propagation. This enables novel application scenarios for augmented reality. We demonstrate the transmission of images and audio through Li-Fi, presented on an augmented reality device in this work.

CCS Concepts

• **Hardware** → **Networking hardware**; **Sensor devices and platforms**; **Wireless devices**; • **Human-centered computing** → *Ubiquitous and mobile computing*.

Keywords

Visible Light Communication, Networking, Augmented Reality

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1 Introduction

Light Fidelity (Li-Fi), or Visible Light Communication (VLC), has seen significant interest over the past decades and is now being widely deployed. Li-Fi complements or sometimes provides an alternative to radio frequency (RF) communication systems [1, 2].

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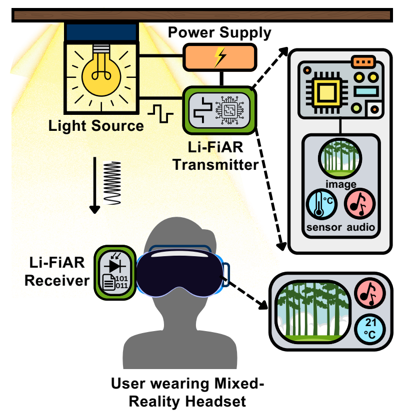
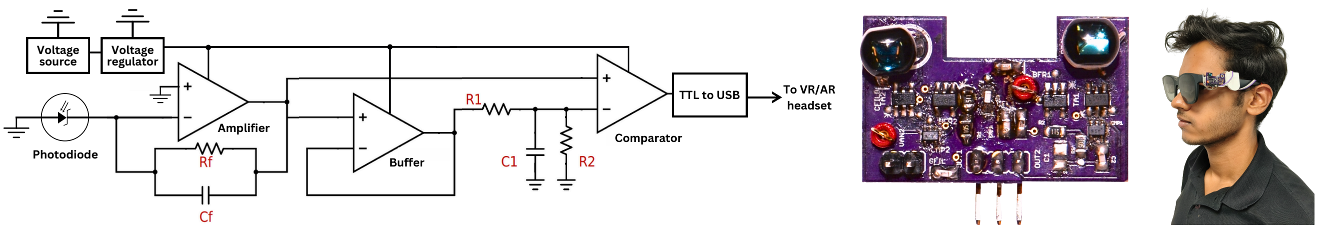


Figure 1: The Li-FiAR transmitter continuously transmits data streams such as images, sensor data, and audio modulated over light. The Li-FiAR receiver is connected to the augmented-reality headset worn by the user. The demodulated Li-Fi transmissions are presented on the augmented-reality device either visually or acoustically.

It offers numerous advantages, including utilizing a part of the orthogonal electromagnetic spectrum to widely deploy RF-based systems. This mitigates challenges related to cross-technology interference. Furthermore, light rays do not propagate through walls, which bodes well from a privacy perspective, preventing leakage of sensitive information outside the user's area. This facilitates spatial reuse and offers a means to physically secure data transfers. Novel networking abstractions, such as room-area networks [3], are implemented straightforwardly with Li-Fi.

There has been interest in using Li-Fi for devices like desktop computers; however, it has not been sufficiently explored for newer computing systems like augmented-reality (AR) headsets. AR headsets such as Apple Vision Pro, Meta Quest 3, and Meta Ray-Ban glasses are gaining momentum, enabling novel interactions with the physical environment. Since users typically wear these devices while moving through different spaces, mobility and form factor become critical considerations. Moreover, the environment where the user operates significantly influences the overall experience.

Wireless communication remains a significant energy-intensive task on mobile devices, including AR headsets [4]. A typical Wi-Fi transceiver consumes hundreds of milliwatts of power. Consequently, when streaming videos—a common use case for AR headsets—battery life remains abysmal at tens of minutes. Efforts to lower power consumption for wireless communication have focused on energy-efficient transmitters [1, 4]. However, these primarily target applications that broadcast small amounts of sensor



(a) Schematic of the Li-FiAR Receiver (b) Li-FiAR Receiver Prototype (c) Headset User

Figure 2: (a) The Li-FiAR receiver consists of a photodiode, trans-impedance amplifier, buffer amplifier, comparator, and passive circuitory. The output of a comparator is a digital signal which is converted to USB logic and connected to the augmented-reality headset (b) The receiver prototype (c) User wearing the XREAL AR headset interfaced with the Li-FiAR receiver.

information. Furthermore, low-power RF receiver design remains a largely unresolved challenge, with recent efforts again targeting sensor applications [5, 6]. The capacity of batteries that allow for a comfortable form factor and the challenges of efficient reception results in a short battery lifespan. This makes prolonged usage of AR headsets infeasible with continued usage beyond few hours.

The RF frequencies employed on AR headsets pose a challenge in inferring the device's location. Due to the constrained form factor, it is challenging to introduce several antennas to support accurate localization. This makes it challenging to support functionality where physical environment location is required for delivering services on these devices. Imagine a scenario where a user wearing a AR headset receives specialized transmissions based on location, such as information related to an exhibit in a museum.

We present our ongoing work to design, Li-Fi for AR headsets, Li-FiAR. Li-Fi offers numerous favorable characteristics for AR headsets. It supports high-bitrate communication and utilizes a larger part of the electromagnetic spectrum than radio. While state-of-the-art systems can demonstrate bitrates of few Gbps, they typically involve complex receivers [7], making them less appealing for power-constrained AR headsets. Consequently, we identify that a key challenge is designing a Li-Fi receiver with a small form factor that can be easily integrated into AR headset seamlessly.

We provide a Li-Fi receiver design that can support Mbps bitrates and is as small as a coin. We identify a general architecture for a Li-Fi receiver and carefully select various components to ensure low-power reception and integration with augmented-reality headsets.

The spatial propagation of light offers unique opportunities, as shown in Figure 1. This can help provide information anchored to physical locations. This may be relevant in scenarios such as museums, where end-users wearing AR headsets could receive rich information from overhead lights. We prototype a simple scenario to demonstrate this capability, integrating the proposed Li-Fi receiver with an AR headset to transmit photos and sound.

Previous efforts on developing Li-Fi transceivers for AR devices [8] have focused on industrial applications, such as clean rooms, and on achieving high data rates, and overlooked the significant power consumption ranging up to hundreds of mW. In contrast, despite being an early work, our Li-Fi receiver consumes under 50 milliwatts while supporting a bitrate of megabits, offering comparable energy efficiency in some cases to RF transceivers employed in existing AR headsets.

2 Design

The Li-FiAR comprises a custom transmitter and receiver, a light source, and an XReal AR headset as illustrated in the Figure 1.

Li-FiAR Transmitter. The Li-FiAR transmitter consists of a baseband generator, a power MOSFET, and a light source. We employ a commodity-embedded platform for generating baseband signals. We use the onboard UART interface present on the microcontroller, implementing an on-off keying (OOK) modulation scheme to generate a baseband signal. This baseband signal represents images and audio to be transmitted over light and it switches a IRF540NS power MOSFET on or off, thus, functioning as a relay. This MOSFET is selected for its high switching frequency, low cost, and wide availability which further drives high-power loads, specifically a light source like an LED or bulb in this case. We employ a commercially available, monochrome and single-element 2B7C LED, which operates at 20 V and supports high-frequency switching. Consequently, the light emitted is modulated according to the baseband signal.

Li-FiAR Receiver. A Li-Fi receiver consists of a photodiode connected to a trans-impedance amplifier (TIA), which subsequently feeds into a digitization process. For capturing the modulated light data, we employ the SLD-70BG photodiode, known for its high sensitivity in the visible spectrum, particularly around 550 nm. Specifically, we choose the LTC6268 TIA from Linear Technology to ensure a high gain bandwidth (GBP) of 500 MHz while maintaining low power consumption, facilitating sufficient signal amplification and bitrate support. To minimize power consumption during digitization and demodulation, we incorporate a thresholding circuit [9, 10], which is implemented using a comparator. The schematic and various stages of the receiver are depicted in Figure 2(a). The gain settings of the TIA play a pivotal role in the receiver's performance. We use two gain configurations: a high-gain setting with R_f = 510 kΩ for well-lit office environments and a low-gain setting with R_f = 110 kΩ, which is optimized for low-light conditions and to mitigate SNR reductions due to mobility. As shown in Figure 3, the TIA's low gain setting is better equipped to receive data due to better SNR in mobile conditions. Although, we demonstrate experiments a lower data rate, the high GBP ensures the achievement at atleast tens of Mbps of bandwidth, thus enabling higher data rate.

3 Evaluation

Setup. We conducted experiments and evaluated Li-FiAR in a university indoor environment. The Li-FiAR transmitter is positioned alongside the light source on the ceiling of the room. The Li-FiAR receiver is interfaced, and positioned on the XREAL headset, which

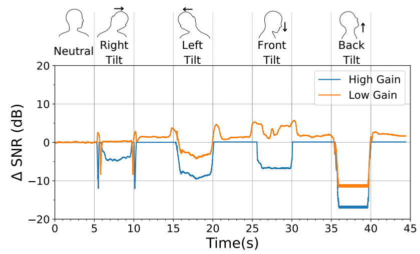


Figure 3: The signal-to-noise ratio of the received modulated signal at the receiver decreases with an increase in degree of tilt mobility of the user's head with respect to the direct LOS path connecting the light source and the receiver.

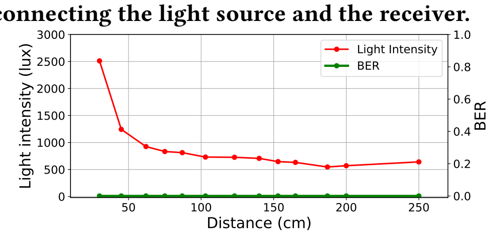


Figure 4: We observe a low bit error rate as we vary the location of the Li-FiAR receiver from the transmitter while broadcasting audio and images. For typical distances of a light source on the ceiling and the receiver in our target scenarios, the link reliability provided by Li-FiAR remains good for the transmission of information.

serves as the augmented-reality device worn by the user as shown in Figure 2(c).

Change with Mobility. We evaluate the effect on SNR of the received signal due to mobility or tilt of the user's head with respect to the vertical line-of-sight (LOS) path connecting it to the light source. The experiment was conducted in a dark environment with no ambient light and the Li-FiAR receiver with headset worn user placed 0.5 m from the ceiling. Here, we set the light source to be on continuously without modulating any data. Figure 3 demonstrates that the SNR decreases with increase in the degree of tilt.

Reliability of Received Data. We evaluate the reliability of Li-FiAR in the presence of standard ambient light which states that it does not require specific operating light conditions. The transmitter was set to stream frames of images continuously at 115.2 kbps. The user with the headset and the receiver stood at varying distances from the ceiling. We observe in Figure 4 that while the light intensity decreases with increasing distance, the bit error rate of the received stream of images still remains 0. It is noteworthy that even at a maximum distance of 2.5 m, the system was able to receive the images without any errors. The current data rate for reliable reception is 115.2 kbps, however, with further fine-tuned selection of passive elements in the receiver circuit, it can easily be boosted up to tens of Mbps, proving to be comparable with commodity RF transceivers as shown in Table 1.

4 Discussion and Conclusion

We have presented our early work on integrating Li-Fi with augmented reality devices. We are working on further improving the receiver's sensitivity, bitrate, power consumption and energy efficiency to make it more favorable compared to conventional radio frequency-based mechanisms. We aim to implement denser and more reliable modulation schemes like FDM, OFDM, etc to further increase the data rate upto hundreds of Mbps and support multiple users. Our work also has potential applications beyond augmented reality, such as in smartwatches and other wearable devices. While there has been some work on using cameras to communicate small amounts of information to mobile devices [11, 12], high data rate communication in an energy-efficient manner remains an open challenge. Additionally, our system could potentially support localization on augmented reality and wearable devices, building on recent works that use Li-Fi for localization of such devices [13]. We would also like to touch on the inherent drawbacks of using Li-Fi as a communication medium. One of the major concerns with light as a medium is establishing a LOS path between transmitter and receiver, as well as issues related to occlusion. To address these challenges, reflective surfaces can be employed to redirect light beams and maintain connectivity without requiring a direct path. Additionally, multiple light sources and receivers can be strategically placed to support more users and ensure uninterrupted communication.

Method	Peak Power Consumption	Maximum Data Rate	Energy Efficiency
UBI206 (WiFi)	22 mW	72 Mbps	0.3 nJ/bit
ATM3201 (Bluetooth)	3 mW	2 Mbps	1.5 nJ/bit
LiFiAR (Li-Fi)	50 mW	10 Mbps	5 nJ/bit

Table 1: The Li-FiAR receiver with possible optimizations demonstrates comparable energy efficiency and data rates with low-power commodity RF transceivers.

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