

Impact of Variable Field of View in Indoor Visible Light Communications Networks

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Abstract:

We propose a dynamic field of view receiver in a dense network of overhead optical access points. Through analysis, simulation, and experimentation, we demonstrate a 3X improvement in SNR over fixed field of view optical receivers.

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1. Introduction

Increases in number and performance of mobile devices puts new demand for capacity in indoor wireless networks. Piggybacking optical communications on lighting devices is an attractive approach to yield this new capacity especially with a high density of devices and motivates our interest in studying visible light communications (VLC) (Fig. 1(a)). Parameters such as field of view (FOV), orientation, velocity, and distance are responsible for SNR variability at an optical receiver. In this work we explore the impact of varying parameters including FOV in order to maximize SNR in the presence of many VLC APs located in close proximity. Our objective here is to reduce noise by eliminating as many non-signal optical sources as possible.

The impact of receiver FOV and orientation is also studied in [1]. Here the authors develop a system model and related experiments to characterize an indoor space and establish how FOV impacts the design of handover between APs. The work in [1] highlights the importance of studying these parameters in theoretical models and how they affect overall system performance which motivated this study.

The main components of this work include the development of a new dynamic FOV receiver, formulating a static optimization problem and algorithm, and a demonstration of performance gains through analysis and simulation.

2. Network and System Model

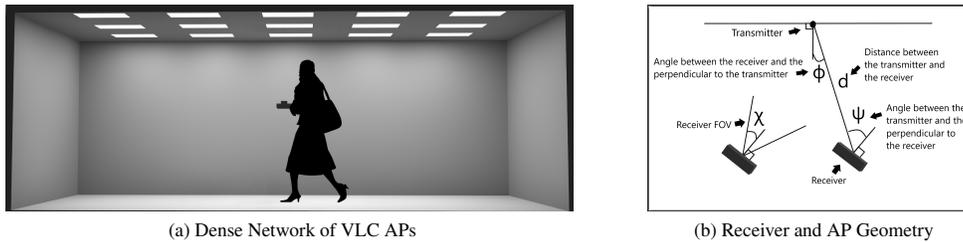


Fig. 1: Network Scenario and System Model

We consider signal transmission via Intensity Modulation with Direct Detection (IM/DD). The conversion between the electrical and optical domains is considered. We operate in the system's linear range and evaluate the peak-to-peak amplitudes of the received $A_y^{(i)}$ and transmitted $A_x^{(i)}$ electrical current signals which are related as follows [1, 3]:

$$\frac{A_y^{(i)}}{A_x^{(i)}} = \begin{cases} \frac{C_T C_R (m+1)}{2\pi d_i^2} \cos^m(\phi_i) \cos(\psi_i) & \psi < \chi \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where C_T and C_R are empirically measured proportionality constants that account for the fixed parameters within the system that relate to the transmitter and receiver gains respectively. Meanwhile, m is the Lambertian emission

order and we use no filter or optical lens. χ is the receiver's FOV, ϕ_i is the emittance angle, ψ_i is the acceptance angle and d_i is the distance between the i^{th} transmitter and the receiver, as shown in Fig. 1(a).

We use commercial LED-based CREE luminaires in our testbed and adopt their characteristics to populate our model. They are rectangular, and we model each one as a grid of $w \times n$ point sources (or elements). For an OOK-modulated signal, the SNR can be modeled as:

$$SNR_j(\chi) = \frac{\sigma_s^2}{\sigma_a^2} = \frac{(\sum_i A_{ji} 1\{\psi_{ij} \leq \chi\})^2}{\sigma_a^2} \quad (2)$$

where σ_s^2 is the signal variance and σ_a^2 is the noise current variance. A_{ji} is the received electrical amplitude from element i within the source j , $\sum_i^{wn} A_{ji}$ is the total electrical amplitude received from source j , wn is the number of elements in the luminaire grid and $1\{\cdot\}$ represents the indicator function.

For a shot-noise-dominated system, the noise current variance σ_a^2 is modeled as follows [2,3]: $\sigma_a^2 = \bar{i}_d^2 + \bar{i}_q^2$. Shot noise is caused by both dark current noise \bar{i}_d^2 and quantum noise \bar{i}_q^2 . $\bar{i}_d^2 = 2qI_dB$ where q is the electron charge, I_d is the dark current and B is the receiver bandwidth. Meanwhile, quantum noise $\bar{i}_q^2 = 2qBRP_n$ where R is the receiver responsivity [Amp/Wt] and P_n [Wt] is the average optical noise power incident on the photodiode.

$$P_n(\chi) = \sum_k \sum_i \frac{P_{txDC}}{wn} \frac{(m+1)A}{2\pi d_{ik}^2} \cos^m \phi_{ik} \cos \psi_{ik} 1\{\psi_{ik} \leq \chi\} \quad (3)$$

As for P_n we use Eq. (3), where P_{txDC} is the transmitted DC optical power that contributes to the noise. It is normalized as we divide it by the number of elements in the luminaire grid wn .

3. Optimization Problem

Our goal is to optimize the SNR at the receiver by varying the receiver's FOV. We define χ_{min} as the minimum FOV to pick only one transmitter within the FOV and χ_{max} as the maximum FOV that can cover all the sources in the room when the receiver is flat and facing the lights. The optimization technique applies information about the physical space including luminaire location, room dimensions, and location and orientation of the receiver, and reveals the FOV and transmitter producing the optimal SNR. We also introduce the Velocity Orientation Variable FOV (VOV-FOV) algorithm. This algorithm is based on the optimization problem but tunes the FOV differently based on the state of the user velocity.

4. Measured Data

Data are collected under different operating conditions in our testbed at Boston University to show the impact of tilt, position, and FOV. We take four experimental runs: (1) Measuring Received Signal Strength (RSS) from one transmitter for different FOVs for an untilted circular aperture receiver. (2) Measuring RSS from one transmitter for different FOVs for a circular aperture receiver with $\theta_{elev} = 120^\circ$. (3) Measuring RSS from all transmitters for a fixed FOV for an untilted circular aperture receiver. (4) Measuring RSS from one transmitter for different FOVs for an untilted non-circular aperture receiver. The experiments show that the analysis and simulation are consistent with the data measured.

5. Conclusion

In this work we describe a dynamic-FOV receiver and the corresponding variable field of view algorithm intended to adapt to the velocity, position, and orientation of a mobile device in a dense VLC indoor network. The results, supported by analysis, simulation, and experimentation, show the potential to greatly enhance performance for VLC links by manipulating the FOV of a receiver. The work demonstrates promise for implementation of novel receiver architectures that are able to compensate for device dynamics under mobility.

References

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