Dissertation titled:

Design and Development of High Data Rate Indoor Visible Light Communication Links

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Abstract:

Visible light communication (VLC) is being envisioned as an enabling technology to provide the much-needed spectral relief for the ever-increasing demand for Internet connectivity and data consumption. In this thesis, we tackle the challenges in the development of high data rate indoor VLC systems to cater to the ambitious targets of the fifth generation and beyond of communication networks.

The visible light signals, which carry information from transmitter panels, can reach the receiver through numerous paths because of the reflections from walls. Due to these multipath reflections and spatial distribution of light-emitting diode (LED) transmitters, there is an inherent delay spread in the VLC channels. So, there is a need to include the effect of multiple reflections (occurring in the practical indoor environment) in the performance evaluation of indoor VLC links. We present the detailed derivation of the multipath VLC channel model and obtain various channel parameters (RMS delay and coherence bandwidth) to characterize the multipath channel. We incorporate the effect of inter-symbol interference (ISI) in the bit error rate (BER) performance of the multipath VLC system and analyze the average BER of the system under different practical scenarios. We also provide some key recommendations for the design of practical VLC systems by outlining the data rates that can be served under various system configurations.

Since VLC uses illumination sources for lighting as well as communication, it is required to provide dimming control for proper lighting and enhanced error performance for reliable data communication. We address both these issues holistically. We formulate and study the power spectral densities of dimming-based modulation schemes, namely variable on-off keying (VOOK) and variable pulse position modulation (VPPM), and hence, derive their bandwidth requirements and spectral efficiencies. Moreover, the capacity of VLC systems is severely limited by the ISI occurring as a result of the multipath propagation of light signals in VLC. We propose to ameliorate the error performance of VLC systems by using channel equalization for ISI mitigation, thereby enhancing the system capacity. We develop the analytical model of a dimmable VLC system employing channel equalization and use this model to study the effect of dimming and data rate on the error performance of VOOK and VPPM schemes. We present simulation and analytical results to show that the performance of dimming-based modulation schemes is significantly improved using channel equalization.

Besides ISI, another major hindrance to the achievable data rate in VLC systems is the low modulation bandwidth of the light sources. This limitation can be significantly overcome by using non-orthogonal multiple access (NOMA) to multiplex users in the power domain. We propose to enhance the fairness among users in terms of their error performance and the achievable data rate in a NOMA-VLC system. Based on numerical and simulation results, we show that the fair power allocation (FPA) scheme not only provides significantly higher fairness but it also entails better error performance, improved energy efficiency, and enhanced system

throughput as compared to the existing power allocation schemes. We also demonstrate that the FPA scheme exhibits superior performance even when the system parameters, like the number of users, transmitter semi-angle, and detector field-of-view, are changed. However, due to high inter-user interference at the receivers, NOMA suffers from a poor outage performance, especially if the number of users is large.

We propose to boost the outage performance of a NOMA-based VLC system by incorporating multi-user cooperative diversity over radio frequency (RF) links, thereby transforming it into a hybrid VLC-RF system with cooperative NOMA (CoNOMA). We formulate the expressions for the outage probability of the proposed system and analyze the outage performance for various power allocation schemes used in NOMA. We study the effects of increasing the number of users and the target data rate on the system's overall outage performance. We also model the reliability of the multi-user CoNOMA system using Markov chains and evaluate the various reliability parameters for each user.

We also explore the application of VLC to indoor localization. Indoor positioning systems (IPSs) based on VLC shall be at the forefront of indoor localization technology in the near future. However, the existing VLC-based IPSs employ active devices that consume power and are costly. We develop a novel VLC-based IPS that circumvents the requirement of active devices by using the proposed optical identification algorithm, thereby enabling the IPS to be highly scalable, robust, energy-efficient, inexpensive, and flexible. To implement this algorithm, we propose the designs of a wavelength-sensitive receiver and a passive optical identifier which consists of a unique combination of optical reflectors. We present an analysis of several practical aspects related to the physical realization of the proposed IPS, like system scalability, target mobility, system reliability, algorithmic complexity, and implementation cost. To analyze the system performance, we determine its spatial resolution and the positioning error for different grid sizes.