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Reconfigurable Intelligent Surfaces for RSMA-Based VLC Systems

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Introduction

The ever-increasing demand for high-speed wireless communication and the increasing number of devices connected to the internet have motivated the development of newer technologies that can support high data rates and complement the overcrowded radio-frequency spectrum. Visible light communication (VLC) is an emerging technology that utilizes the visible light spectrum to transmit data wirelessly, providing high-data rates communication while using the existing lighting infrastructure. The technology utilises light-emitting diodes (LEDs) as VLC transmitters, whereas photodoctors (PDs) are utilized as VLC receivers. However, VLC systems face several limitations due to the physical properties of light, including high penetration loss, high path loss, and limited field-of-view (FoV) for the VLC transmitters and receivers [1]. Reconfigurable intelligent surfaces (RISs) have recently emerged as a promising solution to overcome these limitations and to enhance the VLC systems performance. RISs are planar arrays of reflecting elements that can be programmed to manipulate the impinging light signals, enabling them to enhance the signal strength, directivity, and coverage of VLC systems [2]. Several works in the literature focused on the optimization of the RISs parameters to improve the VLC systems performance, including sum-rate maximization [3, 4], spectral efficiency maximization [5] and the enhancement brought by RISs to improve NOMA-based VLC systems [6, 7].

Motivated by the nature of the VLC channel and the limited modulation bandwidth of the LEDs, multiple access techniques are developed to accommodate multiple users sharing the same resources and to improve the spectral efficiency [8]. Rate-splitting multiple access (RSMA) is one of the promising multiple access techniques for VLC systems due to its advantages compared to other techniques, including high spectral efficiency [9] and high energy efficiency [10], to name a few. In the RSMA scheme, the message transmitted to the users is split into two parts: common and private. The common parts are jointly encoded into a single message to be decoded by all users, whereas the private parts are encoded into multiple private messages that will be decoded by each user individually. Such scheme design requires signals precoding at the transmitters and successive interference cancellation (SIC) at the receivers [11].

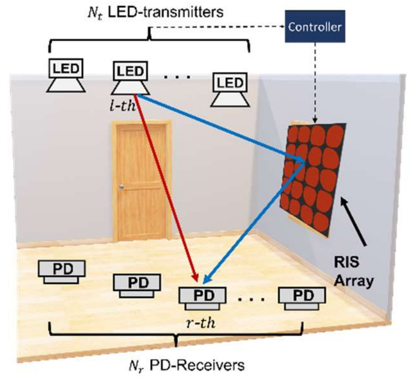

Fig 1: The considered indoor environment with N_t LED-based transmitters and N_r PD receivers, and a square RIS array to assist the downlink transmission.

System Model

We consider an indoor environment with N_t transmitters, N_r PD receivers and one RIS array comprising N units placed on one of the room's walls. We focus on the downlink transmission, where all users share the same spectrum resources. Without loss of generality, we assume that a central unit is connected to both the RIS array and the VLC transmitters, and it is able to reliably obtain the channel state information (CSI) of the VLC system. Generally, for RIS-assisted VLC systems, the light signal arrives at the PD receivers via the direct line-of-sight (LoS) path and the reflected paths through the RIS elements. The system's parameters are illustrated in Fig 1. Typically, the LoS paths of VLC systems follow Lambertian transmission, and the link is impacted by factors such as the transmitters and receivers' locations and orientations. On the other hand, the presence of RIS elements creates controlled non-LoS (NLoS) paths for the VLC systems. The reflected paths are considered an extended path composed of two components, one from the LEDs to the RIS units and another from the RIS units to the PDs. The authors in [2] derived an approximate expression of the specularly reflected components via RISs under the point source assumption, which we adopt in this work.

We assume a multi-input broadcast channel, where the N_t LEDs transmit N_r messages to their corresponding N_r users, and all LEDs serve users in the same bandwidth. Suppose the message U_k is assumed to be sent to the k-th user. For RSMA transmission, each message U_k is split into two parts, common part $U_{k,c}$ and private part $U_{k,p}$. Then, the common parts of all users are combined and encoded to form a common stream message called s_0, and the codebook is shared by all users [9]. On the other hand, each of the private messages is encoded into a private message s_k. To reduce the effect of multi-user-interference, a beamforming matrix W is defined as a linear precoder for the encoded streams. Without loss of generality, the streams are assumed to have a zero mean and are statistically independent, and the energy per stream is set to one. Further, we set the limit of the precoding matrix to guarantee that the LEDs work within their dynamic acceptable range.

At the receiver side, the received signal for the k-th receiver after the optical-to-electrical conversion and after removing the DC bias can be expressed as:

$$y_k = q_k^T x + n_k \quad (1)$$

where q_k is the total channel gain between the LEDs transmitters and the k-th PD. n_k is the noise at the k-th user's receiver accounting for the shot and thermal noises, which is modelled as additive white Gaussian noise (AWGN) with zero mean and variance σ_k^2.

Discussion

Given the considered system model, we investigate in this paper the performance of RIS-assisted VLC system deploying RSMA technique while considering the LoS components and the NLoS components reflected via the RIS elements. We study and quantify the advantages brough to the system's performance as a function of the number of RISs in the considered scenario as well as various system parameters. We provide a simulation study showing the superiority of the proposed scheme compared to other baselines.

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