RIS-Assisted Visible Light Communication for Outdoor Applications

Salah Abdeljabar, Mahmoud Eltokhey, and Mohamed-Slim Alouini

I. Motivation

Wireless communications have become an essential utility of our everyday lives. Much social and economical growth has been witnessed in the past decades owing to the existence and affordability of wireless communications [1]. As the wireless community is laying the ground for the next generation of wireless communications (beyond 5G and 6G), considerable focus has been turned to linking its development with the United Nations Sustainable Development Goals (UN SDGs). This linkage has been highlighted in several reports and publications, ranging from general to more specific recommendations. Wireless communications can contribute to the SDGs by offering infrastructure and access to digital services that will result in growth, efficiency, and sustainability [2]. In fact, the core principle of the 2030 Agenda is to "leave no one behind", and wireless communications are one of the core technologies for connectivity and access to the Internet worldwide; hence, it plays a crucial role in achieving the UN SDGs.

In this work, we focus on visible light communication (VLC) systems and their deployment in outdoor environments. More specifically, we highlight various reconfigurable intelligent surfaces (RIS)-Assisted outdoor VLC systems and discuss some of the benefits they provide to mitigate line-of-sight (LOS) blockage and VLC transceivers' misalignment. In particular, we focus on RIS-Assisted unmanned aerial vehicles (UAVs)-based VLC and RIS-Assisted vehicular VLC. Finally, we propose a novel architecture for connecting outdoor VLC systems to indoor ones with the help of RIS.

II. Introduction

In recent decades, interest in visible light communication (VLC) has grown rapidly with the developments in solid-state technologies and the growth of high-power light-emitting diodes (LEDs). The motivation behind using the illumination light for communication is to save energy by exploiting the illumination to carry information using the existing lighting infrastructure and use technology that is "green" compared to radio frequency (RF) technologies. In addition, the technology occupies a large unlicensed/unregulated spectrum, providing high data rates to meet the requirements of 6G wireless communications, not to mention its immunity to RF interference which makes it suitable for various applications [1].

The authors are with King Abdullah University of Science and Technology (KAUST), CEMSE division, Thuwal 23955-6900, Saudi Arabia. (e-mail: salah.abdeljabar@kaust.edu.sa; mahmoud.eltokhey@kaust.edu.sa; slim.alouini@kaust.edu.sa).

The use cases of VLC in outdoor scenarios include LED-based street lights to provide wireless coverage for pedestrians, and VLC-based vehicle-to-everything (V2X) technology where the headlights and taillights of the vehicles are utilized to transmit VLC signals [3]. VLC can also support terrestrial communications where flying vehicles, such as unmanned aerial vehicles (UAVs), utilize VLC technology to act as an aerial base station, providing illumination and communications to users. Such utilization could be favored in applications such as search and rescue missions and for providing lighting and communication in hazardous locations [4].

On the other hand, despite the abundant advantages provided by VLC systems, they face several challenges that hinder their deployment, particularly in outdoor setups. The line-of-sight (LOS) components for the VLC link has the most significant contribution to the received signal; however, the VLC link is sensitive to link blockage due to the physical properties of light. Furthermore, due to the limitations on the beam width of VLC transmitters and the field-of-view of VLC receivers, link misalignment caused by transceiver mobility degrades the VLC link performance.

In recent years, considerable research efforts have been proposed to improve the VLC link quality. Utilizing multiple transmitters and multiple receivers, cooperative communication techniques, and optical relays are examples of such efforts [5]. However, these developments focused only on the transmitters and receivers while considering the wireless channel as a given (unchanged) parameter in the system. Nevertheless, recently, reconfigurable intelligent surfaces (RIS) have been proposed to add a new dimension of controllability to the system by enabling the channel to become intelligent and programmable.

RISs are low-cost elements capable of reconfiguring the incident signals and either reflecting, refracting, focusing or filtering them intelligently to improve the communication performance. Optical RISs mainly have two hardware architectures: mirror arrays and metasurfaces [6]. For mirror arrays, the lightwave propagation can be manipulated by the rotations of planar mirrors, where the reflections follow Snell's law. Realizing such RIS can be done by mounting each mirror unit on top of micro-electro-mechanical systems (MEMSs). The orientation of the mirrors is adjusted within two degrees of freedom, thus optimizing the non-LOS link reflected through them. On the other hand, metasurface-based RISs are realized using materials whose physical properties can be adjusted electrically with field-programmable gate arrays or other electric/magnetic field-excited controllers. The reflected wave's phase, amplitude, and polarization are some properties that can be manipulated via metasurface arrays [5].

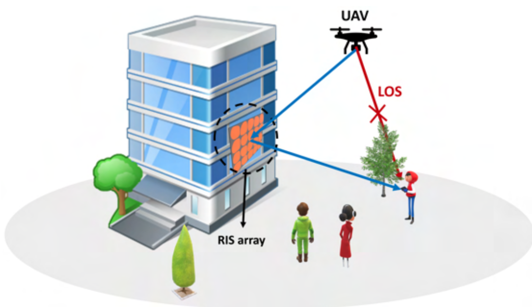

Fig. 1: RIS-Assisted UAV-based VLC network, where users are served by both the LOS link from UAVs and the other reflected link through RIS array.

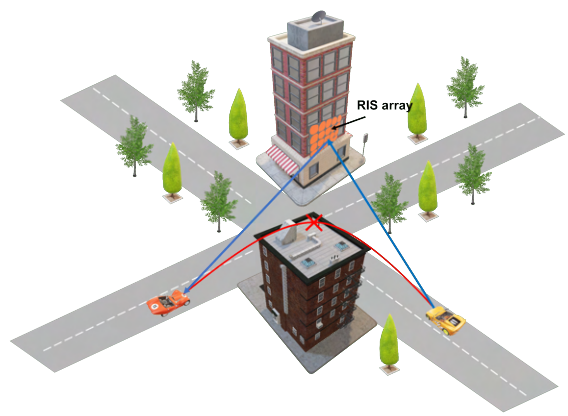

Fig. 2: Example of RIS-Assisted V2V VLC links, where the RIS arrays are used to overcome LOS blockage at road intersections.

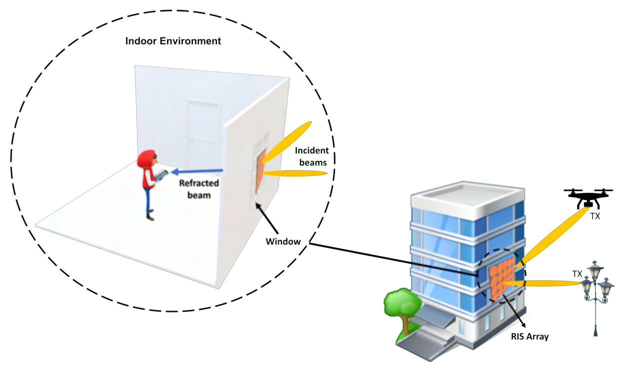

Fig. 3: RIS-enabled Outdoor-to-Indoor VLC communication system. RIS elements installed on the windows support communication from outdoor VLC systems to indoor users.

III. RIS-Assisted Outdoor VLC Systems

This section highlights various use cases of RIS-Assisted VLC systems for outdoor scenarios.

A. RIS-Assisted UAV-based VLC

UAV-based VLC offers a flexible and cost-effective solution for providing illumination and on-demand communication for ground users [4]. However, the LOS link between flying UAVs and ground users could be blocked via trees and other obstacles and thus degrade the system's performance. RIS arrays are envisioned as a viable solution to improve the system's robustness against shadowing and extending signal coverage. Particularly, in Fig. 1, we show an example where RIS arrays installed at building facades can help maintain data transfer between UAVs and ground users.

B. RIS-Assisted Vehicular VLC

Vehicular VLC utilize vehicles' headlights and taillights to establish communication and transfer data in V2X applications. However, maintaining LOS link and transceiver alignment between vehicles in highly mobile environments is challenging. For example, vehicles approaching road intersections may have the link blocked due to high buildings as depicted in Fig. 2. RIS arrays installed in buildings' facades are envisioned to provide a non-LOS link between vehicles in such a scenario. Also, another use case of RIS-Assisted V2X is to support communication between vehicles moving parallel to each other. Since VLC transceivers have a limited FOV, maintaining the alignment between two vehicles moving beside each other is difficult. Hence, RIS arrays installed on streetlights are envisioned to support the communication, where the RIS arrays are optimized to reflect the optical beams arriving from one vehicle towards the other.

C. RIS for VLC Outdoor-to-Indoor Communication

The latest developments in RIS arrays have shown that they can be mounted on top of the VLC transmitters and receivers, where the RIS elements can be used to control the passage of the signals and steer the refracted beams [7]. Given the aforementioned technology, RIS arrays are envisioned to be installed at the windows of the buildings to allow communication between outdoor and indoor VLC systems. In particular, in Fig. 3, we show the envisioned system where outdoor VLC-based UAV and streetlight systems communicate with indoor users.

References

[1] H. Haas, J. Elmirghani, and I. White, "Optical wireless communication," p. 20200051, 2020.

[2] K. Ojutkangas, E. Rossi, S. Aalto, and M. Matinmikko-Blue, "Linking mobile communications with the united nations sustainable development goals: Mapping process," 2020.

[3] A. Memedi and F. Dressler, "Vehicular visible light communications: A survey," *IEEE Communications Surveys & Tutorials*, vol. 23, no. 1, pp. 161–181, 2020.

[4] M. W. Eltokhey, M.-A. Khalighi, and Z. Ghassemlooy, "UAV location optimization in MISO ZF pre-coded VLC networks," *IEEE Wireless Communications Letters*, vol. 11, no. 1, pp. 28–32, 2022.

[5] S. Aboagye, A. R. Ndjiongue, T. M. Ngatched, O. A. Dobre, and H. V. Poor, "RIS-assisted visible light communication systems: A tutorial," *IEEE Communications Surveys & Tutorials*, 2022.

[6] A. M. Abdelhady, A. K. S. Salem, O. Amin, B. Shihada, and M.-S. Alouini, "Visible light communications via intelligent reflecting surfaces: Metasurfaces vs mirror arrays," *IEEE Open Journal of the Communications Society*, vol. 2, pp. 1–20, 2020.

[7] A. R. Ndjiongue, T. Ngatched, O. A. Dobre, and H. Haas, "Double-Sided Beamforming in OWC Systems Using Omni-Digital Reconfigurable Intelligent Surfaces," *arXiv preprint arXiv:2203.03781*, 2022.