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Visible light signal strength optimization using genetic algorithm in non-line-of-sight optical wireless communication

Tahesin Samira Delwar, Willy Anugrah Cahyadi, Yeon-Ho Chung *

Department of Information and Comm. Eng., Pukyong National University, Republic of Korea

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ABSTRACT

Visible light communication (VLC) using the light emitting diode (LED) attracts attention from researchers as a future low power optical wireless communication. VLC generally considers a line-of-sight (LOS) link, although the LOS link can be affected by the obstacles between LED transmitter and photodetector (PD) receiver in a practical scenario. In the case of non-line-of-sight (NLOS) link, it is important to find a link with maximum possible received signal strength (RSS) to ensure optimum communication quality in VLC. In this paper, we propose a novel scheme for optimizing the RSS using a meta-heuristic searching algorithm known as genetic algorithm (GA). The proposed scheme is simulated using two white light emitting diodes (LEDs) as the transmitters and a PD as the receiver. The genetic algorithm (GA) is used to calculate the maximum RSS on the NLOS link within an indoor environment. GA determines an orientation of the maximum RSS at the receiver instead of measuring the RSS for every angle. Simulation results reveal that the proposed scheme accurately estimates the orientation that produces an optimum RSS value at the receiver.

1. Introduction

A recent advancement in communication technology demands high-speed data transmission. A latest survey reflects a ten-fold growth of mobile traffic over the last five years leading to an ever-increasing problem of spectrum congestion in radio frequency (RF) based communications [1,2]. Visible light communication (VLC) technology is considered a new variant of optical wireless communication (OWC) that overcomes this spectrum congestion problem. The potential of VLC is driven by the popularity of solid-state lighting through the use of light emitting diodes (LEDs) for illumination [3]. The VLC provides dual functionalities of both illumination and communication in a point-to-point wireless communication. A few more advantages of LED based VLCs are high-speed, cost effectiveness, and highly secured network [2,4].

Most of the studies conducted on VLC are based on line-of-sight (LOS) links. However, in a practical indoor scenario, LOS links might not always exist, thus relying on non-line-of sight (NLOS) links around the blockage. Therefore, the NLOS links, consisting of light paths through reflections from the walls, play a vital role in VLC. For the NLOS links to be used, an optimum light path needs to be determined for high performances VLCs. A straightforward solution to acquire the maximum received signal strength (RSS), which is the maximum light intensity, would be to redirect the PD towards an optimum angle. Several studies have addressed this issue, i.e., NLOS link channel characterization [5], different orientations of PD receiver [6], and tilting of the receiver (PD orientation) [7]. The scheme of changing orientation of PD in [7] is limited to the LOS link due to the limitation of the calculations. Authors investigated a scheme to measure the optimum orientation of the PD and rotating its plane, but failed to address how the PD could be rotated in practice [7].

The PD can be rotated mechanically to all orientations to find the maximum RSS in practice. It would, however, cause a considerable amount of delay in wireless communication since mechanical actuators move at a period of several seconds. In order to reduce the time required for rotating the PD toward an optimum angle, it is necessary to perform a calculation of the environment prior to the transmission. In a practical scenario, the calculation is considerably complex due to numerous light beams converging on the surface of the PD and many factors affecting the converging light beams such as reflectivity of wall, reflectivity of floor, reflectivity of ceiling, room dimension, transmitter position, and receiver position. Therefore, an optimization technique is employed to mitigate this complex calculation for finding the optimum path.

Two types of optimization techniques could generally be used, i.e., conventional method and meta-heuristic approach. A conventional method cannot be used for addressing practical issues, due to its

* Corresponding author.
E-mail address: yhchung@pknu.ac.kr (Y.-H. Chung).

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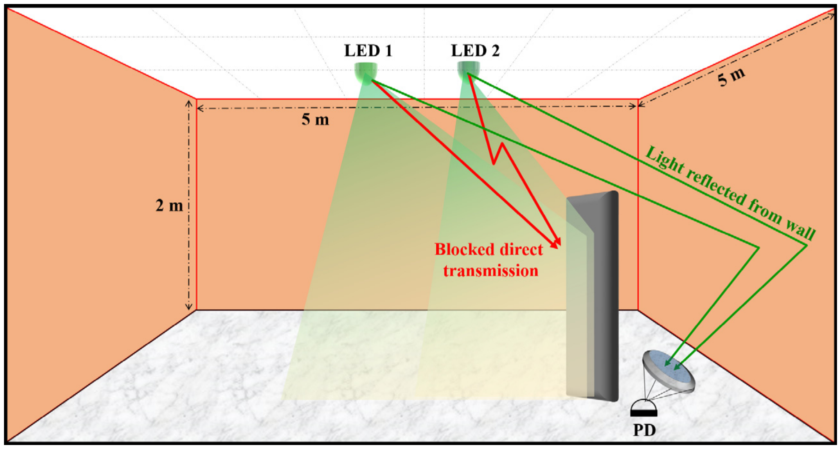

Fig. 1. System diagram of the NLOS scenario for the proposed scheme.

inability to optimize a multimodal function as in the case of NLOS scenario. Genetic algorithm (GA), on the other hand, is a meta-heuristic approach that can solve these issues in a large dataset more efficiently [8]. GA provides a more efficient substitute to traditional optimization techniques by using directed random search to locate the optimum solution in a complex data environment. GA is also a part of evolutionary algorithms and is preferred for industrial applications due to its satisfactory convergence to optimum solution, effectiveness, and its straightforward calculation for practical use [8]. The considerable industrial acceptance of GA over other algorithms has motivated the present study for employing GA in a practical NLOS VLC application.

In the present study, we propose a GA based optimization for a practical NLOS VLC system that calculates the optimum orientation of the PD. The proposed scheme addresses an offline calculation and GA optimization considering numerous converging light beams on the PD in a simulated 3D environment. The geometrical structure of the room along with the locations of the transmitter, receiver, and the obstacle are defined and fed into the simulation. After the optimization processes have been carried out, the optimum orientation of the PD, i.e., the angle at which the maximum RSS is received, is obtained for best signal reception. The simulation on convergence to optimum RSS, i.e., the condition that satisfies the optimization criteria (no significant fitness value improvement for next generation), has been validated at two different positions for both receiver and obstacle in the present study. The GA optimization is carried out before the transmission and thus the calculated optimum orientation of the PD is useful for rotating the PD directly. As opposed to the previous study that is limited to conventional method (Newtonian) and LOS link only [7], the proposed scheme employing GA using a multimodal function on its heuristic approach is capable of calculating many factors, i.e., reflectivity of wall, reflectivity of floor, reflectivity of ceiling, room dimension, transmitter position and receiver position for NLOS link. To find the orientation of the PD, two fundamental values should be calculated in the NLOS VLC, i.e., angle-of-arrival (AOA) of light beams converging on the PD and amplitude of each received light intensity (RSS).

The remaining part of the paper is described as follows. Section 2 describes the proposed system model while simulation results are described in Section 3. Conclusion is finally drawn in Section 4.

2. System modeling

The transmitted light signal in VLC experiences reflections due to the presence of walls, a ceiling, and a floor within an indoor environment that cause dispersion and variation in RSS on the receiver side. Most reflections in an indoor environment are considered Lambertians, which largely consists of diffuse reflections [7]. In this present study, the VLC system is established in a cubic room having dimensions of 5 m × 5 m × 2 m. The simulated room environment was assumed to have no interference from other light sources such as computer display and sunlight. The room consists of two LEDs working as transmitters and one fixed receiver (user) considered in two different NLOS positions. Each reflector has distinct spectral reflectance and each reflectivity range varies with the changes of wavelength [9]. That is, we transmit the signal from two white LEDs whose wavelengths range from 390 nm to 700 nm, while a PD receiver is employed with a responsivity of 0.41 A/W at a wavelength of 550 nm. It should be noted that we employ the PD with the fixed wavelength for the ease of the analysis. Moreover, The room walls are composed of plaster whose average reflectivity is 0.7 and the floor is composed of dark gray concrete whose reflectivity is 0.15. The ceiling is considered to be made up with concrete with white portland cement whose reflectivity is in the range of 0.7 to 0.8. Therefore, the reflectivity of floor, wall, and ceiling are defined as 0.15, 0.7, and 0.8 respectively. The system diagram of the NLOS environment considered in the proposed scheme is reflected in Fig. 1.

A shadowing phenomenon might occur in the LOS link of VLC transmission due to obstacles. Thus, it becomes necessary to find maximum RSS in the vicinity of PD [10]. In the proposed scheme, GA is used for optimizing the RSS in the VLC reception. Obviously, there are several paths of NLOS links from the transmitter to the PD after being reflected from the different walls within the room. The process of calculating the best path from all available paths is defined as optimization. The optimization is called multimodal optimization, whose complex problem cannot be solved by using a gradient method [11]. Hence, the requirement of non gradient methods, one of which is GA [12]. The reason behind using GA in present study is evident, due to the ability of producing optimized results with high accuracy while considering a complex and large hypothesis space [13]. In our present study, it is clear that we are dealing with an enormous number of input–output combinations due to a large number of coordinates and their corresponding RSS in the hypothesis space.

2.1. Mathematical modeling

Since the LOS links are blocked by an obstacle, the communication in VLC is only possible through the reflected signals coming from different sides of the room, i.e., NLOS links. In the proposed scheme, we focus on a single reflection from one wall that is depicted in Fig. 2 [6].

The parameters of the system for a single transmitter are described as follows. α_1 denotes the angle between light beam and the LED axis (normal line to the ceiling), whereas α_2 denotes the angle between the line of reflected light beam to PD and the normal line to the wall. In addition, Ψ_1 is the angle between incident light beam on the reflecting wall and the normal line to the wall, whereas Ψ_2, which is the AOA of the light, is the angle between reflected light beam on the PD and