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Optimal LED deployment for mobile indoor visible light communication system: Performance analysis

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A B S T R A C T

The maximization of the system performance in a typical indoor visible light communication system is a major challenge while minimizing the overall resources for the deployment. The intelligent smart lighting systems can be optimized to reduce the requirement of various resources without compromising on the system performance. In this paper, we investigate the optimization of the light emitting diode (LED) resources within an indoor room scenario using a most efficient stochastic optimization technique-Hyper-heuristics evolutionary algorithm (HypEA). The performance of the communication system has been measured in terms of average area outage ratio, computational efficiency and mobility area analysis. The performance of the HypEA has been compared against the most experimented algorithm-Particle swarm optimization (PSO). The detailed investigation and analysis shows that HypEA is computationally more efficient and is able to achieve full mobility with almost 12.5 percent fewer resources as compared to PSO.

1. Introduction

The next generation intelligent lighting systems would consist of light emitting diodes (LEDs) for illumination as compared to conventional incandescent and fluorescent lamps. The advancement in LED lighting technology is not only lighting homes at a reduced power consumption but is also capable of carrying the information at much faster rate as compared to present Wi-Fi networks. Such systems are considered to be highly energy efficient, consume very low power and have very long life. The LEDs possess very high-speed modulation characteristics which make them attractive for indoor optical wireless communication (OWC). The visible light communication (VLC) system may also be viewed as one of the greenest and eco-friendly technology mainly due to high energy efficiency. The VLC is much safer and is not harmful to skin and eyes as compared to infrared (IR) communication even at a higher emitted power [1]. The cost of the VLC adoption is likely to be much cheaper due to the continuous decline in the cost of LED and other related optoelectronic building blocks. This would be a key enabler for making the VLC technique a much popular communication approach in future [2]. Therefore, VLC based on solid state smart lighting has potential to become the future of indoor OWC systems [3].

The recent studies indicate that a substantial portion (more than 70 percent) of wireless traffic originates indoors. This is usually catered through radio femto cells in order to improve the indoor capacity and the coverage mainly within the range of tens of meters [4]. An alternative solution to radio frequency (RF) technique is VLC technology which has the potential of delivering greater data rate densities ($b/s/\mathrm{Hz}/\mathrm{m}^2$) [5]. The VLC is also capable of reducing the carbon footprint in the information and communication technology (ICT) industry resulting in the energy efficient networks [6]. However, there are issues that remain from the inherent nonlinearity of LEDs, bandwidth limitations, signal modulation aspects, multi-access as well as power delivery to the transceiver. For a mobile VLC system, the directed and non-directed-line of sight (LOS) link topologies are preferred over other topologies from the perspective of receiver mobility [7]. Further, an IR-based mobile system comprising a single IR source and a mobile receiver based on non-directed-line of sight (LOS) diffused topology was investigated for its system performance by [8]. The channel capacity and average bit error ratio (BER) estimation along with detailed analysis of various other system parameters were also investigated by [9]. Therefore, it can be asserted that VLC will be able to provide ubiquitous communication network infrastructure for future generations [10].

The optimization of resources in a VLC system is a vital activity. The adopted techniques for optimization should assist in substantial resource saving in a large scale deployment scenario of a VLC system.

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However, the optimization of resources should not compromise on the other system parameters. A review on converged optical wireless networks using statistical techniques has been discussed by [11] to address the issue of queuing and clogging effects. An improved multi-objective evolutionary algorithm based on decomposition (MOEA/D) had been proposed to improve global optimization capability for pareto-optimal planar miniaturized multi-band antenna design [12]. Further, to optimize the complex spectrum sharing, the particle swarm optimization (PSO) technique had been adopted to maximize the sum throughput for the maximum number of secondary links that can be allocated to the network under interference constraints [13]. Another evolutionary technique known as cat swarm optimization (CSO) had been proposed for the synthesis of linear antenna arrays by [14]. In VLC systems, the evolutionary genetic algorithm has been first proposed by [15,16] to modify the optical intensity of LED transmitters for reducing the signal power fluctuations wherein the signal power dynamic range was reduced while maintaining the minimum desired level of the signal to noise ratio (SNR). Further, a VLC scheme has been investigated using PSO algorithm technique for an on-off keying (OOK) scheme by [17].

In this paper we propose an efficient and latest approach known as Hyper-heuristic evolutionary algorithm (HypEA) for the purpose of the optimization of an indoor VLC system. A detailed methodology along with the steps involved in HypEA implementation has been discussed by [18]. The main contributions of this paper are listed below-

- The optimal LED deployment for mobile indoor visible light communication has been investigated.
- The most computationally efficient and the recent approach-HypEA has been implemented to locate the optimal positions of LEDs for full mobility.
- The efficacy of the HypEA has been compared with the well experimented PSO algorithm.

The above findings establish the efficiency of HypEA in optimizing the LED placement and semi angle, to achieve the best possible system performance, without compromising on the other dependent system parameters.

The rest of this paper is organized as follows. The system modeling is presented in Section 2 and the problem formulation is shown in Section 3. In Section 4, we analyze experimental results and finally conclude the paper in Section 5.

2. The system model

In the present simulation setup, we consider a small room/office illuminated with LED lighting for which the location of the LEDs is to be optimized for the required level of system performance. The size of the room is considered as 5 × 5 × 3 in meters along with the three-dimensional coordinates as presented in Fig. 1. Let there be total N number of LEDs which are deployed at locations (x_i,y_i,c), $i \in (1,2,3,...,N)$. The receiver location is described as (x_o,y_o,c_h) and the LEDs have been deployed at the ceiling of the room on x–y plane at the height c on the ceiling. We are using OOK modulation scheme which is the most widely used technique in OWC systems. At the transmitter side, the modulated bit stream is converted into an optical signal using LED transmitters. Thus, the modulated bit stream using intensity modulation/direct detection (IM/DD) then propagates into the free space medium and is then received at PN/PIN photo-detector receiver which is placed at communication floor at height c_h on x–y plane.

In an indoor VLC channel, the directed light of sight (D-LOS) component comprises the maximum pulse power (95.16 percent) at the photo-detector receiver as per the analysis done by Komine et al. [19]. The first reflection and second reflection contribute to only 3.5 and 1.2 percent of the power. Considering the fact that the D-LOS components contribute to the majority of the received optical power at photo-detector receiver, the reflected power components can be ignored in order

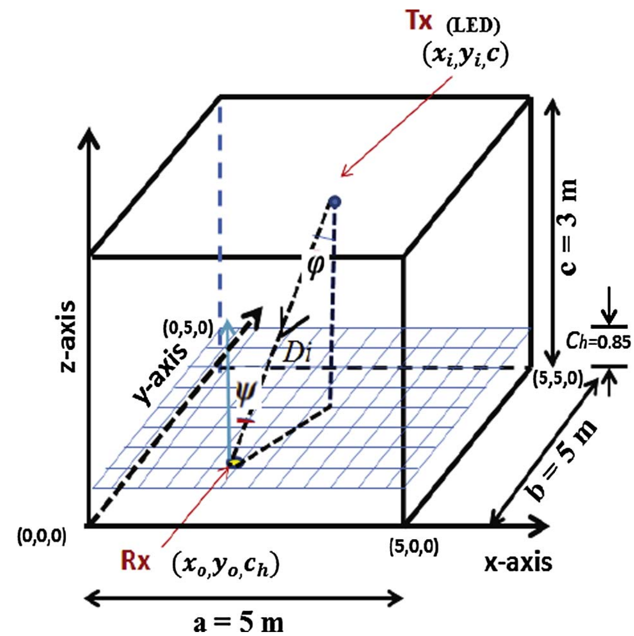

Fig. 1. The simulation set up for indoor VLC system.

to reduce the computational complexities. The information in a VLC channel is transmitted through light waves having frequency of the order of 10^{14} Hz. However, the photo-detector dimensions are of the order of thousands of wavelengths which leads to efficient spatial diversity. This eventually prevents multi-path fading [20]. Thus, the multi-path fading effect can been neglected. In the proposed VLC system design, the distributed LED placement is considered resulting in minimal or no shadowing effect.

The quality of transmission in an optical channel is typically dominated by the shot-noise [21]. The desired signals contain a time-varying shot-noise process which has an average rate of 10^4–10^5 photons/bit. However, considering the use of a narrow band filter, intense ambient light striking the photo-detector receiver leads to a steady shot-noise having a rate of the order of 10^7–10^8 photons/bit. Therefore, we can model the ambient-induced shot-noise as a Gaussian process and neglect the shot-noise caused by the transmitted optical signals [22]. In case of little or no ambient light present inside an indoor room, the dominant noise source is receiver pre-amplifier noise, which is also signal-independent and Gaussian. Accordingly, the instantaneous current in the photo-detector at the receiver, $Y(i)$, can be written as

$$Y(i) = \zeta X(i) * h(i) + \eta, \tag{1}$$

where ζ represents the responsivity of the photo detector in A/W, $X(i)$ is the transmitted optical signal which is non negative i.e. $X(i) \geqslant 0$, $h(i)$ denotes the channel impulse response and η is the additive white Gaussian noise (AWGN) with zero mean and variance σ^2. The channel impulse response, $h(i)$, between the i^{th} LED and the receiver is given as in [20] as

$$h(i) = \begin{cases} \frac{(m+1)A}{2\pi D_i^2}\cos^n(\phi)T_s(\psi)g(\psi)\cos(\psi), & \text{if } 0 \leqslant \psi \leqslant \psi_c \\ 0, & \text{if } \psi \geqslant \psi_c \end{cases} \tag{2}$$

where n denotes the order of Lambertian emission and is expressed in terms of semi angle $(\phi_{1/2})$ at half illuminance of an LED as, $m = \ln 2/\ln\cos(\phi_{1/2})$, A is the area of the photo detector receiver, D_i is the distance between an LED and the receiver, ψ is the angle of incidence, ϕ denotes the angle of irradiance and $T(\psi)$ presents the gain of the optical filter. The gain of an optical concentrator is denoted by $g(\psi)$ whereas the receiver's field of view is expressed as ψ_c. The optical concentrator's gain, $g(\psi)$, is given as