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# Improved multiple access resource allocation in visible light communication systems

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ABSTRACT

Discrete multi-tone (DMT) and optical orthogonal frequency division multiplexing (OFDM) modulations are well-known methods used to transmit high data rate information in visible light communication (VLC) applications over the illumination infrastructure. However, the use of these techniques in a multi-user environment requires effective subcarrier and power allocation design in order to achieve the maximum data rate offered by the spatial distribution of the transmitters and receiver as well as to minimize the efficiency reduction of the illumination system due to the communication. This could be achieved by minimizing the communication signal power in an appropriate way. In this paper, we propose a heuristic allocation algorithm that minimizes the system subcarrier transmitter power while keeping the required data rate and error bit rate. The numerical calculation was done for given parameters. The results indicate that transmitter power reduction of more than 10% in a most scenario is achieved in comparison to previous algorithms.

## 1. Introduction

The growing demand for high data rate wireless communication applications, such as mobile high definition video streaming and online backup storage, are devouring the wireless radio frequency (RF) spectrum, so that wireless capacity has become scarce. One of the technologies proposed to enhance the wireless system capacity is visible light communication (VLC). VLC offers unlicensed and available bandwidth in the visible light region [1,2] that can be exploited on top of illumination LEDs. In addition, the necessity for cheap, simple and green wireless communication technology to support the emerging concept such as the internet of things (IOT) [2], renders VLC the natural candidate to augment RF wireless technology. For maximum utilization of the existing bandwidth of the intensity modulation direct detection (IM/DD) regime, a combination of DC-biased optical orthogonal frequency division multiplexing (OFDM)), is proposed [3]. In a multiple access environment (e.g. in office, aircraft or shopping mall networks) VLC is expected to provide simultaneous access and maintain high data rates for all users. Many researchers have proposed a variety of techniques to improve multi access (MA) communication performance, mainly based on transmitter diversity and evaluated in terms of noise, signal to interference ratio and signal to interference plus noise ratio [4,5]. In [6], a heuristic-based resource allocation algorithm that uses VLC transmitter diversity to increase the average per-user bit-rate by reuse of subcarriers and distributes power between allocated subcarriers per transmitter is proposed. The algorithm harnesses the natural flexibility in resource allocation of DMT, in addition to its inherent spectral efficiency. In [7,8] the authors indicate that the loading of the communication functionality always comes with extra power consumption or reduction of illumination system energy efficiency in comparison to illumination-only systems in particular, with OFDM as well as binary modulation such as PAM. In this paper we extend [6] by proposing an improvement in our allocation algorithm by adding an optimization phase that performs minimization of the subcarrier transmitter power while the bit-rate is kept constant. The reduction of communication signal power is very important due to the fact that a) reducing the communication signal could increase the energy efficiency of the illumination system due to the fact that VLC and illumination systems requires always extra power consumption compared to illumination-only systems [7,8]) lower communication power could reduce optical OFDM clipping noise [9].

In our work, the allocation process is split into two phases. First, subcarrier assign to each user as proposed by [6]. Second, power allocation optimization by minimizing the allocated power for maximum bit-rate for each sub-carrier. By minimizing the allocate power we reduce the cross interference and robust each lighting device against nonlinear

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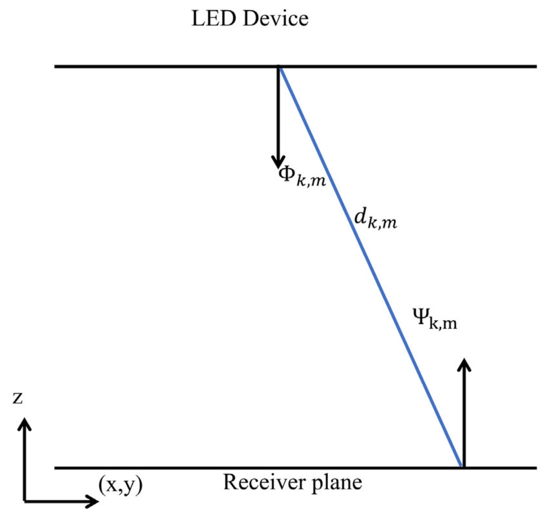


**Fig. 1a.** Communication channel geometry for line of sight.

distortion that occurred in high power [9,10]. Furthermore, practical LED's suffer from limit dynamic range due to clipping which occurs below the LEDs turn on power and above the allowed power. This could lead to degradation in performance. In [9], the authors study the influence of practical LED with different levels of brightness on the performance of VLC ACO-OFDM based system. They show that the clipping of the LED degraded the communication performance especially in high brightness environment where higher biasing is applied. In [10] the effect of biasing is study for the case or DCO/ACO-OFDM. It has been shown that increasing the average electrical/optical power at the transmitter could decrease the effective SNR.

The rest of this paper is organized as follows: in Section 2 the VLC optical channel is introduced. Section 3 details the proposed MA resource allocation scheme. In Section 4 we outline the proposed solution. Simulation results for different communication scenarios are presented in Section 5 with a concluding discussion

## 2. Optical channel

In indoor environments, the received optical signal paths are classified into two main categories. The first is a line-of-sight (LOS) path between the transmitter and the receiver (Fig. 1a). The second is a non-LOS (NLOS) path, resulting from multi path reflection of the light from walls, ceiling or other objects in the room (Fig. 1b). In real life indoor environments there is variety of reflecting surface materials, such as plastic, plaster, gloss paint, wood, metal etc. All the above, can cause wavelength dependent reflection and mixed specular diffuse reflections [11,12].

In our work, we consider an ideal Lambertian source and Lambertian reflections. The LOS DC gain between transmitter $k$ and receiver $m$ is given by [11,12]

$$h_{k,m}^{LOS} = \begin{cases} \dfrac{\omega+1}{2\pi d_{k,m}^2} A_{PD} \cos^{\omega}(\Phi_{k,m}) & 0 \le \Psi_{k,m} \le \Psi_c \\ \cdot \cos(\Psi_{k,m})\, T_s(\Psi_{k,m})\, g(\Psi_{k,m}) & \\ 0 & \Psi_{k,m} > \Psi_c \end{cases} \tag{1}$$

where $\Psi_{k,m}$ is the angle of incidence, $\Phi_{k,m}$ is the angle of irradiance, $A_{PD}$ is the physical area of the photodetector, $d_{k,m}$ is the distance between transmitter $k$ and receiver $m$, $\omega$ is the order of Lambertian emission, $T_s$ is the gain of an optical filter, $g$ is the gain of an optical concentrator, and $\Psi_C$ is the receiver field of view (FOV). The geometry of the channel is depicted in Fig. 1a where $n_0$ is the refractive index. The NLOS DC gain after the first reflection from the wall surface is given by [11,12].

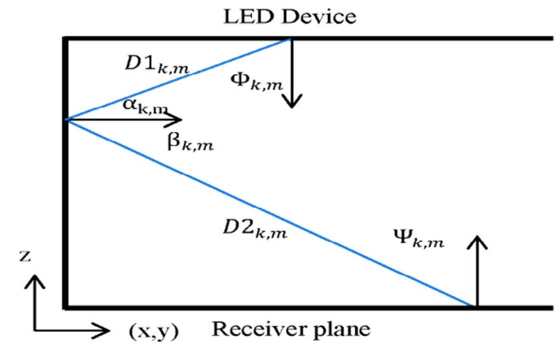


**Fig. 1b.** Communication channel geometry for the first reflection NLOS path.

$$dh_{k,m} = \begin{cases} \rho \dfrac{\omega+1}{4\pi^2 D1_{k,m}^2 D2_{k,m}^2} A_{PD} \cos^{\omega}(\Phi_{k,m}) & \\ \times \cos(\alpha_{k,m}) \cos(\beta_{k,m}) \cos(\Psi_{k,m}) & , 0 \le \Psi_{k,m} \le \Psi_c \\ \times T_s(\Psi_{k,m})\, g(\Psi_{k,m}) & \\ 0 & , \Psi_{k,m} > \Psi_c \end{cases} \tag{2}$$

where $D1_{k,m}$ is the distance between transmitter $k$ and a reflective point, $D2_{k,m}$ is the distance between the reflective point and the receiver $m$, $\alpha$ is the angle of irradiance to the reflective point, $\beta_{k,m}$ is the angle of incidence to the reflective point, and $\rho$ is the reflectance factor. The total NLOS DC gain is the sum over the four walls, and is given by $h_{k,m}^{NLOS} = \int_{wall} dh_{k,m} dA_{wall}$ where $dA_{wall}$ is the reflective area, in planes $x \times y$ or $y \times z$, corresponding to the considered wall. Finally, the total DC gain is given by $h_{k,m} = h_{k,m}^{NLOS} + h_{k,m}^{LOS}$. When the transmitter is out of the FOV of the receiver, only the NLOS component is considered. The channel can be safely considered as flat fading over the entire OFDM frame for bandwidths up to 20 MHz [9].

## 3. Problem formulation

In the considered environment, all receivers and transmitters sheared the same optical channel, and the same DMT communication resources. Meaning that all transmitter are shearing the same sub-carriers, and the power is limited by the maximum allowed for each transmitter. Therefore for DMT communication system with $K$ transmitters, $M$ receivers that share $N$ subcarriers, and for the given environment, the electrical power for receiver $m$ consists of the transmitted power from all the transmitters in the room and their transmitted power to all other receivers, therefore the power for subcarrier $n$ is given by $Pr_{k,m}^n = \sum_{k=1}^K \left|h_{k,m}^n\right|^2 p_{k,m}^n + \sum_{k=1}^K \sum_{\substack{j=1 \\ j\neq m}}^M \left|h_{k,j}^n\right|^2 p_{k,j}^n + \eta$ where $k$ represents the transmitter, $h_{k,j}$ is the interference channel gain from transmitter $k$ to receiver $j$, $h_{k,m}^n$ is the channel gain, $p_{k,m}^n$ is the allocated electrical power, $\eta = N_0 B/N$ is the noise power, where $N_0$ is the noise power spectral density, $B$ is the signal bandwidth, and $N$ is the number of subcarrier. Considering the cross-interference from the other transmitters and the noise, we can write the electrical signal-to-interference-and-noise ratio (SINR) for receiver $m$ for subcarrier $n$ as

$$\gamma_m^n = \frac{\sum_{k=1}^K \left|h_{k,m}^n\right|^2 p_{k,m}^n}{\sum_{k=1}^K \sum_{\substack{j=1 \\ j\neq m}}^M \left|h_{k,j}^n\right|^2 p_{k,j}^n + \eta} \tag{3}$$

In this paper we address the problem of data rate maximization per user, where the resource allocation is divided to three steps. In the first step, we assume that VLC systems define the illumination as the primary application while the communication is the secondary application. As a results the transmitter power is function of the illumination