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Visible light for communication, indoor positioning, and dimmable illumination: A system design based on overlapping pulse position modulation

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ABSTRACT

In this paper, we design a dimming compatible visible light communication (VLC) system with asynchronous and optimum indoor positioning method in a standard office room in combination with asynchronous and optimum indoor positioning method according to illumination standards under channel constraints. We use overlapping pulse position modulation (OPPM) to support dimming control by changing the code weights. The system parameters such as a valid interval for dimming together with an upper bound for bit rate according to the channel delay spread are investigated. Moreover, considering the dispersive VLC channel and using Monte Carlo (MC) simulations, a method is proposed to determine the minimum code length in different dimming levels in order to achieve a valid bit error rate (BER). Then, the trellis coded modulation (TCM) is suggested to be applied to OPPM in order to take advantage of consequent coding gain which could be up to 3 dB. Finally, in order to enable asynchronously and with high throughput data transmission of LEDs for the purpose of indoor positioning, we propose using one-persistent carrier sense multiple access (CSMA) network protocol. Using received signal strength (RSS) based trilateration, the two dimensional positioning error of around 10 cm is verified by the simulation results.

1. Introduction

Nowadays, we are witness of a rapid growth in the communication service demands. It is expected that by 2020 an amount of 44 Zettabytes (44×10^{21}) of communication data will be on demand to be generated. The demand for wireless bandwidth capacity as predicted by Cisco (Cisco VNI.) shows a 10 times growth in mobile traffic till 2019. On the other hand, during the same years, the mobile carriers are predicted to be accelerated by 9% [1]. Moreover, the consumer electronics

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such as smart phones are expected to provide a high speed wireless communication in combination with the location based service (LBS). Meanwhile, the power consumption of such electronic devices which are approximated to be more than two times greater than the population of the world in numbers, should be optimized and be as low as possible. Therefore, the most important goal of the communication technologies is to save the energy in a large scale in order to enable the existence of future sustainable society [2].

Optical wireless communications has brought forward a potential framework for reaching secure, high-throughput, and cost-effective wireless communications in free-space [3,4], underwater [5–7], and multi-user indoor environments [8,9]. Specially saying that LiFi (light fidelity) technology, as a complementation of WiFi (wireless fidelity) is a smart solution to the aforementioned challenges. This disruptive technology which is a completed and enhanced form of visible light communication (VLC) can offer a complete package of illumination, high-speed data transmission in a network scale, and indoor positioning. To address the misconceptions regarding this technology, one can say that it is able to transmit hundreds of megabyte of data in a non-line-of-sight (NLOS) manner. The sunlight exposure to its receiver (generally a photodetector (PD)) can be considered as a direct current (DC) signal which is out of the range of the received signal. In the case that this exposure does not saturate the PD, the sunlight not only is not a problem for such systems, but also by employing the photovoltaic elements as the receiver, it is possible to harvest the energy to feed the receiver circuit. Additionally, the LiFi systems are able to provide dimming control by employing the appropriate modulation schemes [10,11].

To highlight the importance of this technology, let us mention some of its potential applications in our everyday life. LiFi technology can play an important role in the 5th generation of wireless communication networks (5G) as a coexistence with WiFi [12] providing full-duplex high-speed indoor access. It can enable light as a service (LaaS) in the market. It can contribute to road safety systems as the number of self-driving cars is rapidly growing. It will enable the asset tracking, for example, in a hospital to be aware of the situation of the wheelchairs and trolleys using visible light positioning techniques. The other application of the VLC positioning system would be in the museums to detect the location of a visitor and then to start playing the information media about the targeted asset [13]. It is over two decades that the research and investigation in the field of optical wireless communications (OWC) including VLC and specially LiFi is being done and a number of invaluable books has been published in this area [14–18] guiding the future researchers become familiar with the principles.

As mentioned earlier, VLC provides illumination in parallel to communication and positioning. Additionally, flicker mitigation and intensity control, also known as dimming control, are two noticeable requirements of such systems according to IEEE 802.15.7 task group [19]. Thus, utilizing robust modulation schemes that supply high data rate along with dimming control are imperative. Some dimming adaptable procedures for flicker-free high data rate VLC systems based on IEEE 802.15.17 standard are studied in [20]. The standard references in the channel model for typical indoor environments such as home and office are well investigated and proposed as IEEE 802.15.7r1 [21].

Among different kinds of modulation schemes, pulse position modulation (PPM) and its families are appropriate for intensity modulation with direct detection (IM/DD) communication systems such as VLC, since the chips within a code word can directly modulate a driver at the transmitter side. In recent years, many research interests have been attracted to overlapping PPM (OPPM) and its applications due to its high spectral efficiency and low bandwidth requirement. In [22] a method for supporting dimming by changing the amplitude of OPPM symbol pulses is proposed. Nevertheless, this may result in undesired chromaticity shift of the emitted light due to the characteristics of LEDs [23]. Researchers in [24] proposed multiple PPM (MPPM) to support dimming while transmitting data stream. They explored that MPPM outperforms variable PPM (VPPM) and variable on-off keying (VOOK), in terms of spectral efficiency and power requirement. Moreover, a solution to address the dimming control along with data transmission is suggested in [25] by changing OPPM code word weight.

This research is inspired by the need to design a VLC system with more spectral efficiency and less power requirement. In this paper, regarding dimming support by changing code weights of OPPM symbols, we consider a practical scenario within a standard room and design a system according to constraining parameters. To do so, we first determine an interval for dimming percentage in which the illumination standards are taken into account. Then, we calculate the maximum data rate for inter-symbol interference (ISI)-free transmission by simulating the dispersive channel response. Next, we propose a method to determine the maximum usable code length corresponding to a maximum bit error rate (BER) in the presence of different brightness percentages. Owing the fact that the modification in modulation and using coding schemes are essential to performance enhancement of VLC systems [26], we suggest applying trellis coded modulation (TCM) in order to take advantage of the corresponding coding gain which results in an improvement in the power requirement of OPPM. The validity of such application is depicted by simulation results. Finally, to complete the system design, we give a solution to channel access for different users for the purpose of unique code transmission. This enables the two dimensional indoor positioning within a hypothetical office room environment.

The rest of the paper is organized as follows. In Section 2, we briefly introduce the system and channel model. In Section 3, the system design according to OPPM scheme is investigated followed by the simulation results. Section 4, addresses the issue of channel access for the purpose of unique code transmissions together with an indoor positioning method compatible with the proposed system and finally, Section 5 concludes the paper.

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