Lighting Extra Data via OWC Dimming

Xiao Zhang
Michigan State University
zhan1387@msu.edu

Li Xiao
Michigan State University
lxiao@cse.msu.edu

ABSTRACT

Most OWC systems use LEDs as transmitters and in poor channel conditions adopt or switch to the most robust On-Off Keying (OOK) modulation from complex high-order modulation schemes that are fragile with more error bits in poor optical environments. However, the data rate of OOK is limited to its low-density modulation design and its use of compensation symbols to support light dimming control. In this paper, we propose to identify bit patterns frequently occurred in the data stream, and map each bit pattern with a compensation symbol (CS) for which to carry more data bits for improved data rate and throughput. We also design non-flicker optical symbols and CS relocation schemes to support smooth lighting and communication. Experiments show that our proposed approach double the system throughput, the same improvement level as high-order modulations (8-CASK and 32-CSK) while maintaining low BER.

KEYWORDS

Optical Wireless Communication, Dimming Control, OOK.

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1 INTRODUCTION

Optical wireless communication (OWC) is a promising alternative solution for developing future high-density and high-capacity networks[2]. Most recent research has focused on high-order modulation schemes to improve throughput in OWC systems. In [3], authors proposed ColorBars to utilize Color Shift Keying (**CSK**) modulation to improve data rate via Tri-LEDs. They achieved up to 5.2 Kbps data rate on smartphones. Similarly, Yanbing et al. proposed **CASK**[4] to improve throughput of LED-Camera based OWC system. It used Composite Amplitude-Shift Keying to modulate data in a high-order way without complex CSK constellation design. CASK achieves up to 7 Kbps data rates by digitally control On-Off states of several groups of LED chips.

Problem statement: However, in poor optical channel conditions such as in the sunshine or underwater scenarios, the nonlinear effect of LED and short symbol distance makes decoding of the high-order modulation schemes more complex and fragile with more error bits and the need for more retransmissions. Thus most OWC systems such as LiFi adopt or switch from high-order to low-order modulation schemes for robust transmission with low bit error rate (BER) in changing environments with poor channel conditions, such as On-Off Keying (**OOK**).

OOK is defined as primary modulation in OWC standard[1]. It is commonly applied in poor channel conditions due to its simplicity for LED control at the transmitter and reliable decoding even under higher clock rate and long communication range with a lower cost than high-order modulations. However, bit rates are sacrificed because a modulation symbol represents fewer bits, 1 bit per OOK symbol.

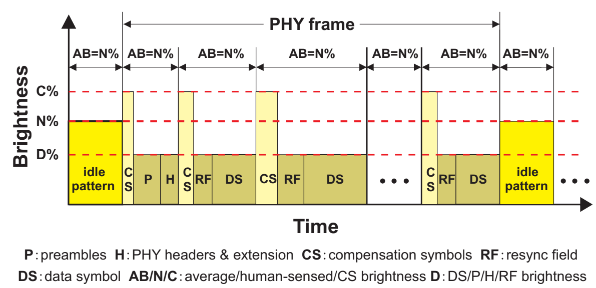

Figure 1: OOK dimming control with CSs [1].

Compensation symbol (CS) is designed in OOK modulation for light dimming control in order to seamlessly incorporate wireless communication[1]. As shown in Fig. 1, the entire PHY frame is split as multiple subframes in OOK-OWC systems. In each subframe, continuous CS symbols whose numbers are proportional to the symbol numbers of this subframe are inserted in front of OOK symbols to adjust the average brightness (AB). Moreover, CSs are solely used

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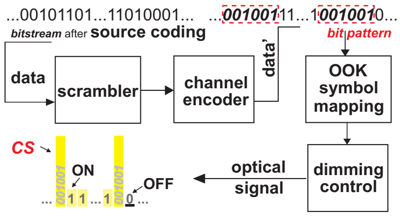

Figure 2: OOK-based OWC transmitter[1]

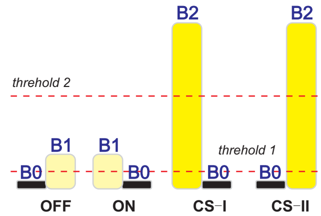

Figure 3: Non-flicker symbols.

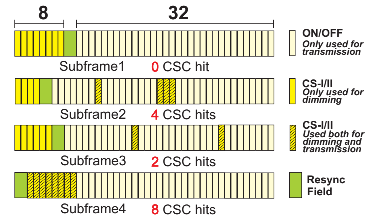

Figure 4: CS symbol relocation.

for dimming, which takes up transmission resources in the time domain and further limits the data rate.

Motivation: (1) Bit patterns exist in transmitted bitstreams. A bit pattern is a bit sequence (i.e., multiple continuous bits), which frequently occurred in entire traffic during a historical period, as shown in Fig. 2. **(2) Compensation symbols** have not been used for transmission in OOK-based OWC before our approach. Related work focused only on dimming itself without considering transmission potential. Considering significant symbol distance between CS and OOK symbols, why not utilize CS as **side-channel** to carry more bits for improved performance?

Proposal: In this paper, we investigate novel approaches to exploiting compensation symbols solely for dimming previously to carry data bits for improved data rate and throughput in OOK-based OWC networks. In our approach, compensation symbol coding (**CSC**), CSs are used in both dimming controls and data transmission. When there exists a bit pattern in the transmitted bitstream, it can be represented by one CS symbol that is relocated to the location of the bit pattern. Bit patterns are mined offline and notified by preambles only once before all transmissions.

Hypotheses: The network throughput improves remarkably because of improved data rate and decoding performance. **(1) Data rate**: CS symbols become data symbols without taking up transmission resources in the time domain anymore. Moreover, each CS symbol carries more bits than an OOK symbol. **(2) Decoding**: CS symbols have a lower detection error rate than OOK symbols. Furthermore, the receiver decodes CS symbol to its corresponding bit pattern directly instead of decoding multiple OOK symbols for that bit pattern, which reduces decoding error possibilities.

We conduct **experiments** and present **results** below:

(1) We explore the possibility that multiple bit sequences frequently occur in real-world data traces (SIGCOMM17 and CAIDA19). Furthermore, we propose a greedy offline mining algorithm to identify multiple bit patterns because the overall throughput improvement depends on the length of a bit pattern and its occurrence frequency in the data stream.

(2) We design non-flicker OOK/CS symbols based on experiments, as shown in Fig. 3 for smooth lighting and communication functions. It ensures the robust identification

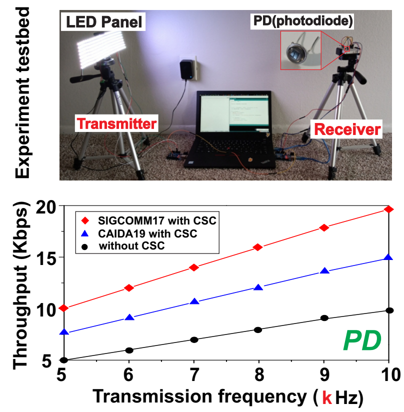

Figure 5: Throughput improvement by CSC.

of symbol types in a changing environment. Initially, CSs are inserted continuously and proportionally into subframes for constant lighting. However, in our approach, CSs are relocated to discrete locations to denote bit patterns, which may introduce flickers. We further propose CS relocation schemes, as shown in Fig. 4 for stable lighting.

(3) We conduct experiments on testbed in different transmission frequencies, as shown in Fig. 5. The results demonstrate CSC's efficacy in boosting the throughput of OOK-OWC systems. Our method doubles the system throughput and achieves the same improvement level of high-order modulations (8-CASK and 32-CSK) with low BER.

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