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Fountain code-based error control scheme for dimmable visible light communication systems

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ABSTRACT

In this paper, a novel error control scheme using Fountain codes is proposed in on–off keying (OOK) based visible light communications (VLC) systems.

By using Fountain codes, feedback information is needed to be sent back to the transmitter only when transmitted messages are successfully recovered. Therefore improved transmission efficiency, reduced protocol complexity and relative little wireless link-layer delay are gained. By employing scrambling techniques and complementing symbols, the least complemented symbols are needed to support arbitrary dimming target values, and the value of entropy of encoded message are increased.

1. Introduction

In recent years, visible light communications (VLC) has become one attractive technology because of their advantages of eye-safe, electromagnetic-interference free, license-free, high signal-to-noise ratio (SNR) and high security [1]. An important application of the VLC system is multimedia broadcasting in which the users can be served by the light-emitting diode (LED) transmitter in the same room with stream multimedia data. In such a LED-based VLC system, a LED-based transmitter transmits encoded multimedia data on demand to users for playback in real time. The users buffer the data and begin playback after a fixed delay. The interruption is not tolerated once the playback begins.

In many scenes such as hospital, office etc., the sources of communications, LED lights are easily and frequently obstructed due to the frequent and random movement of people or objects. This will result in unexpected and frequent interruption of communications. In general, error control mechanisms are adopted when interruption occurs during the transmission. Two prominent mechanisms – automatic repeat request (ARQ) [2,3] and channel coding with forward error correction (FEC) [4–6] – are normally adopted. In LED-based VLC system, ARQ has little complexity, which requires a reliable feedback channel, thus large memory size and large delay are needed. FEC can overcome these drawbacks but with the expense of transmitting a large amount of redundant data. Furthermore, the information is difficult to be recovered if packet loss occurs. Also, some hybrid schemes of FEC and ARQ [7,8] are proposed. In [7], the proposed scheme needs to make the error control decisions according to media and channel characteristics. In [8], the proposed scheme needs a simple per-packet acknowledgment scheme.

According to the unique properties of the VLC systems, both the performance of illumination and communications needs must be addressed at the same time. IEEE 802.15.7 VLC task group has preceded the standardization [9]. In this standard, VLC systems should have a constraint that the average intensity adapts to the dimming requirement chosen by the user. To meet this requirement, various transmission schemes at the modulation level have been presented in [10–12]. However, few works have addressed error control schemes that satisfy the above requirement in OOK-based VLC systems [13–16]. Those schemes either have special algebraic structure of constant weights or need complicated encoding/decoding structure. Furthermore, they are all sensitive to the code rate.

In this paper, we propose a new error control scheme for VLC system in which Fountain codes [17,18] are embedded. The proposed coding scheme is characterized by three advantages.

(1) Based on scrambling and compensating, various dimming target values can be supported easily and the least complemented symbols are needed.

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(2) According to the properties of the Fountain codes, the new scheme is rateless. That fits well for the channels in which interruptions occur frequently due to that the encoded bits of the same original message are generated continuously till the successful transmission is completed.
(3) By using Fountain codes, protocol complexity and packet delay can be reduced due to the fact that only the information of correct receiving needs to be feedback.

The paper is organized as follows, in Section 2, we introduce the proposed VLC system model in which Fountain codes is embedded as an error control scheme, whilst considering the dimming target. Section 3 describes the detail encoding and decoding process of the proposed scheme. Section 4 analyzes the relationships among the parameters of actual code rate, dimming target value and allowable decoding failure rate. Finally we draw the conclusions.

2. Model of proposed VLC system

The system described in this paper is a bidirectional communications. In this paper, we mainly concentrate on the downlink part of VLC system whose configuration is shown in Fig. 1. For the downlink transmission, we mainly consider the signal received from the direct path. In situations where the direct path to the source is blocked, the communications is regarded as interrupted. Another independent system, such as RF or infrared (IR) communications, can be used for the lower data-rate uplink channel to send the acknowledgment information in which self-interference from the full-duplex communication can be avoided.

Assuming K source information packets set $\boldsymbol{U}=(\boldsymbol{u_1}, \boldsymbol{u_2}, \ldots, \boldsymbol{u_K})$ are the input of the Fountain encoder, each packet $\boldsymbol{u_k}$ consists of a sequence of N symbols. The details of Fountain coding will be explained in next section. The Fountain encoder generates a potentially limitless output packets $\boldsymbol{C}=(\boldsymbol{c_1}, \boldsymbol{c_2},\ldots)$. Each packet $\boldsymbol{c_k}$ consists of a sequence of N symbols. The codeword $\boldsymbol{c_k}$ is further encoded by the scrambling code. We use scrambling here for the purpose of randomizing a binary codeword, and increasing its entropy and change the dimming value. The dimming value is guaranteed to be 50% without any additive compensation symbols. To obtain the predefined dimming target value, the output of scrambling coding needs to pass through dimming compensator which can be used for controlling the total number of 0's and 1's by using complemented symbols (CS). After generating OOK-modulated signal $s(t)$, the LED emits the corresponding light signal $x(t)$, which has the average optical power $P_t\left(=1/T\int_0^T x(t)dt\right)$, where T denotes light signal duration.

After passing through the optical channel $h(t)$, $x(t)$ is received by a photodiode (PD). Then, the received signal $r(t)$ is given as

$$r(t) = R{\cdot}x(t) \otimes h(t) + n(t)$$

where "⊗" denotes convolution, R is the PD conversion efficiency (A/W), and $n(t)$ is additive white Gaussian noise (AWGN) which contains the shot and thermal noise.

The decoding method proceeds in the exactly opposite way. The OOK-demodulated symbols firstly pass through the process of descrambling and elimination of compensation symbols. After receiving enough encoded packets, Fountain decoding can be performed to recover the original K packets.

3. Proposed codec for VLC system

The first fountain codes are the Luby Transform (LT) codes invented by Luby [17]. The degree distribution is the heart of the design of LT codes. Luby originally introduced the ideal soliton distribution (ISD). Robust solution distribution (RSD) is then introduced via modifying the ISD to improve the decodability.

In a digital fountain codec, a transmitter generates a potentially limitless number of encoded symbols from K input symbols according to a carefully-designed degree distribution, i.e. RSD. The receiver recovers the K input symbols from a certain number (equal to K or slightly bigger than K) of symbols.

To realize LT codes, first a degree d is chosen at random from a degree distribution called the RSD $\Omega(d)$,

$$\Omega(d) = \frac{\rho(d) + \tau(d)}{Z}$$

where

$$\rho(1) = 1/K;$$

$$\rho(d) = 1/(d(d-1)); \quad \text{for} \quad d = 2, 3, \ldots, K$$

$$\tau(d) = \begin{cases} \frac{s}{Kd}; & \text{for} \quad d = 1, 2, \ldots, \left(\frac{K}{s}\right) - 1 \\ \frac{s}{K}\ln\left(\frac{s}{\delta}\right); & \text{for} \quad d = K/s \\ 0; & \text{for} \quad d > K/s \end{cases}$$

$$Z = \sum_d \rho(d) + \tau(d)$$

where $s \equiv c\ln(K/\delta)\sqrt{K}$ is the expected number of one-degree output symbols, δ is the allowable failure probability of the decoder to recover the data for a given number L of encoding symbols, c is a constant with values smaller than 1 giving good results [18]. The number of encoded packets required at the receiver to ensure that the decoding can run to completion, with probability at least $1-\delta$, is $L=KZ$.

3.1. Encoder

Fig. 2 illustrates the encoding procedure of the proposed

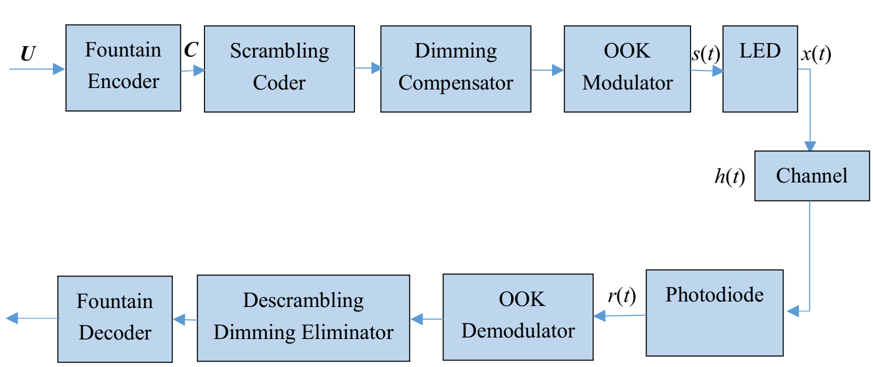

Fig. 1. Downlink configuration of the proposed VLC system.