Design and Implementation of an Ethernet-VLC Interface for Broadcast Transmissions

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***Abstract*—In this work, a complete interface between Ethernet and Visible Light Communications (VLC) networks is presented. It requires the use of previously proposed DPPM schemes for this kind of applications, but with some modifications so as to keep constant duty cycle in order to assure its use in illumination facilities [2]. The prototype has been tested using a 2Mbps VLC Link, obtaining distances of, at least, 3 meters in an interfering environment. The PPM characteristics allow transmission without severe signal degradation on this environment. This Ethernet-VLC interface is intended to demonstrate the capability of IP broadcast applications of this kind of devices. This interface performs packing functions and flow control.**

***Index Terms*—VLC communications, white LEDs illumination, pulse position modulation, Ethernet-VLC interface.**

I. Introduction

In the last years, different research lines have focused on energy saving techniques for illumination sources, since current lamps present very low power efficiency. In this way, new more efficient lighting devices are being developed to replace incandescent and fluorescent lights (including low-consumption bulbs). These systems make use of Solid State Lightning (SSL) which, compared to filament heating or electric arc (both of which are used in conventional lamps), allows to convert electric energy into optical emitted power more efficiently. They are based on LED devices, which provide high-level savings in energy consumption and have a lifespan between 10000 and 50000 hours.

Using illumination fixtures for data transmission is not a new concept; however, only the new SSL devices allow the implementation of feasible communication links because of their available bandwidth. As a consequence of the increasing development of these new devices, multiple contributions to VLC have been proposed [1][2].

The aim of these works is based on adding the communication capability to the lamp, while maintaining its main function as light source. Therefore, the transmitted data signal should not alter the illumination perception at the user eye. This implies some restrictions on the emitted signal in order to avoid light flickering. For this reason, in this work, a modified Differential Positioning Pulse Modulation (DPPM) technique, which always presents only a pulse in each transmission symbol, has been proposed.

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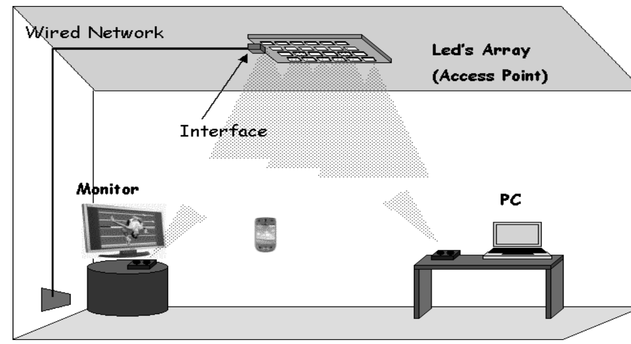

Fig. 1. System architecture.

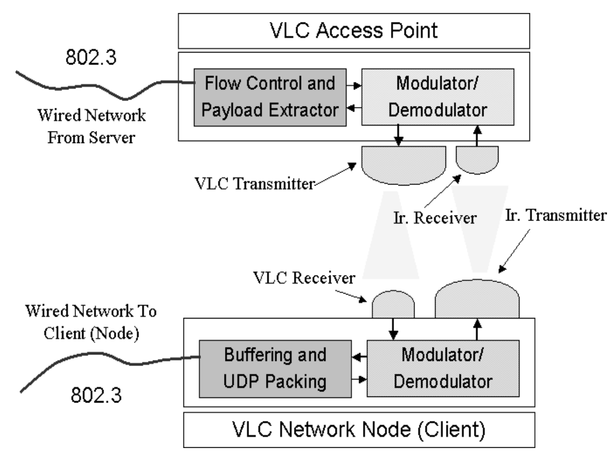

Fig. 2. System block diagram. Shadowed blocks are the main objective of this work.

On the other side, an interface between wired network (Ethernet) and Optical network has been developed. Due to the asymmetrical properties of these links, a flow control at the optical network access point has been implemented. Figure 1 illustrates the system architecture.

II. Proposed System

A. System Architecture

This system is designed to allow broadcast transmissions from a wired LAN (Ethernet in this case) to the VLC network. Because of the different bit rates in both systems, a flow control implementation is necessary at the VLC access point node. Taking into account all these factors, the complete system block diagram is shown in Fig. 2. This work focuses on Modulator/Demodulator and Flow Control Blocks development.

The system uplink shown in Fig. 2 consists of an infrared link between optical nodes and VLC access point, which

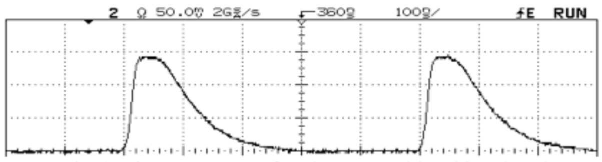

Fig. 3. Time response of a blue LED with white phosphorus.

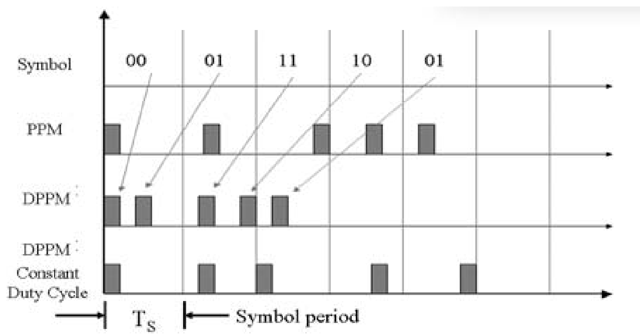

Fig. 4. Different pulse position modulations waveforms.

performs a command channel for the downlink broadcast transmissions. The main limitation of this link is determined by its low power transmission and wide coverage area, employing optical devices that do not need critical alignments, so that, a low data rate link (125 Kbps) has been selected.

B. Visible Optical Channel Characteristics

As already commented on, the main restrictions of these systems are the limited bandwidth and the need of maintaining constant luminescence along all communication time due to their simultaneous use as conventional lamps. Long sequences of "zeroes" or "ones" in an On-off Keying (OOK) communications system could cause illumination flickering.

At the same time, high communications rates are not possible because of their high rise and fall times. For typical white LED lamps, minimum pulse width allowed is about 200ns as shown in Fig. 3. Besides, this channel is affected by interference signals caused by ambient light, especially by incandescent and fluorescent lamps, with frequency components under 1 MHz.

C. DPPM Modulator and Demodulator

Pulse position modulating (PPM) techniques are extensively used in wireless optical links, due to their high average-power efficiency and artificial illumination effect reduction [2][3]. Moreover, this technique allows the system to work with lights turned "off" and "on", and with varying PPM pulse width without optical power losses. This is achieved by means of a variation in the chip pulse duration. In this case, 20% of symbol duration has been selected for the "turn off" mode and 80% for the "turn on" mode.

The main inconvenience of these modulation techniques is the need of complex synchronism systems to ensure correct detection. To avoid this, Differential Pulse Position Modulation (DPPM) could be selected, which presents non coherent detection capability at the receiver. However, the bit rate is not constant during transmissions [4] and this can affect the system performance as illumination fixture [2]. In this work, a modified 4-DPPM has been developed in order to solve this problem. This technique ensures that transmitted signal duty cycle is always the same, so that light intensity variations do not occurs. Figure 4 shows the waveforms corresponding to the Pulse Position Modulations cited above.

TABLE I
DISTANCES FOR EACH SYMBOL

Symbol	Distance (Chip periods)
00	5
01	2 or 6
10	3 or 7
11	4 or 8

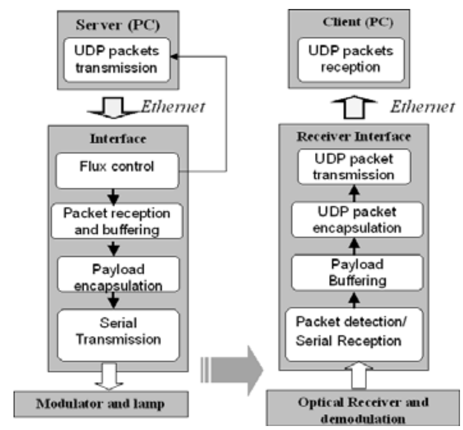

Fig. 5. Transmission/reception complete flow chart.

In fact this is a PPM scheme where position of the next chip is given by:

$$P_N = \left\{ \begin{array}{ll} P_{N-1} + D_N - L & f\ or\ (P_{N-1} + D_N) \geq L \\ P_{N-1} + D_N & f\ or\ (P_{N-1} + D_N) < L \end{array} \right\}$$

Where L = number of chips available, P_{N-1} = Last chip position and D_N = Symbol value. This modified DPPM scheme presents the same bandwidth and power requirements than the conventional PPM one, but allows non coherent detection at the receiver, like in a DPPM receiver. This is achieved by counting clock samples between rising edges (distances, including a guard interval to compensate LED fall time). Correspondence between symbol and distances for the proposed scheme is shown in Table 1. It can be seen that there are two possible distances for the same symbol in some cases. The transmission block selects the appropriate one in order to ensure the constant duty cycle (20%) of the transmitted signal explained before. To obtain a duty cycle of 80%, the transmitted signal is inverted.

D. Interface Ethernet-Optical Access Point

The developed system transmits information encapsulated in UDP packets. The interface block performs the payload extraction and encapsulation and the Flow control between Ethernet network and serial interface. These processes are shown in Fig. 5.

Flow control is necessary because optical transmission rate is about 2 Mbps and Ethernet frames arrive to the access point at 10Mbps data rate. Payload from UDP frames are

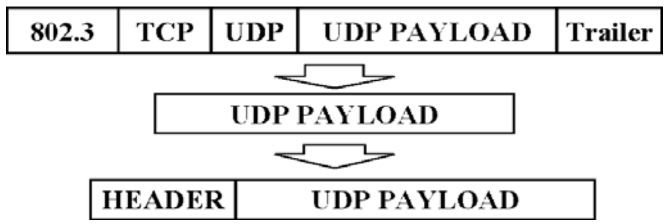

Fig. 6. Payload extraction and packaging.

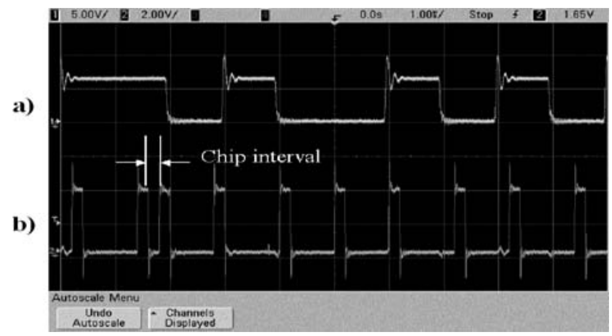

Fig. 7. Waveforms: **a)** data and **b)** modified 4-DPPM received signal.

buffered before their transmission through optical link. After UDP payload extraction, encapsulation is carried out to ensure correct detection.

A header is added to each UDP payload before its serial transmission and modulation. At the receiver side, this header is detected and data are buffered. Figure 6 shows this packaging process.

After that, the receiver encapsulates the buffered payload in a UDP frame and transmits it to the client node by an Ethernet connection, so that the complete process is accomplished. UDP facilities are included in the employed Xilinx core.

III. System Implementation

The proposed scheme has been implemented using a Xilinx Spartan-3 design kit, which includes Ethernet MAC facilities and cores to negotiate communications between the wired network and the optical link. This design kit implements the following features: flow control, modulation/demodulation and UDP frames payload unpacking and packing. The complete system has been tested over a visible optical link composed by a commercial visible LED lamp (20 white LED diodes array, each of them with the time response shown in Fig. 3). At the transmitter, a circuit based on SN75452 open collector logic gates has been used. The reception circuit basically consists on a transimpedance amplification stage and two HAMAMATSU S7510 photodiodes, with a total active area of 132 mm2.

IV. Results

As commented before, the main characteristic of the proposed 4-DPPM codification is its constant duty cycle for every symbol. Thanks to the different possibilities of distances between pulses for codifying the 2 bits symbols (see Table I), it can be possible to implement a DPPM, with the restriction that in each symbol time there will only be a pulse. Figure 7 shows waveforms resulting, corresponding to data and modified 4-DPPM codified signal. For the complete system performance test, lost packets in the presence of different interferences have been estimated. Reception is not considerably affected by the interference caused by a fluorescent lamp and natural illumination.

Results for an interfering optical signal generated by an OOK modulated LED lamp with a bandwidth of 400 KHz (taken as a worst case interference example), are shown in Fig. 8.

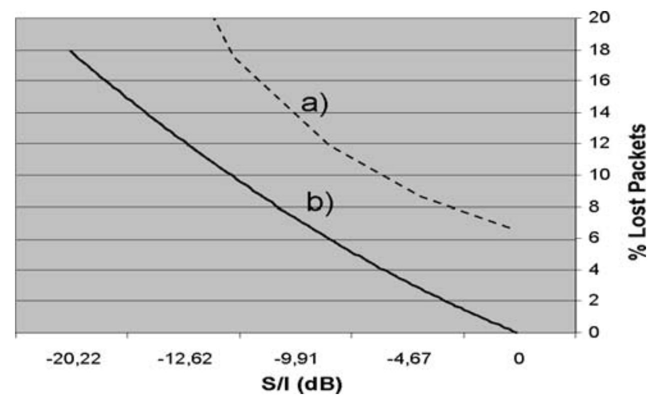

Fig. 8. Measured lost packets percentage versus S/I. **a)** OOK, **b)** proposed constant rate 4-DPPM.

V. Conclusions

In this work a new VLC system architecture has been presented. This scheme performs data broadcast from a server in a cable network by means of visible optical links implemented using commercial LED lamps. A modified DPPM scheme has been also developed to ensure constant illumination intensity and constant bit rate. Therefore, these devices work simultaneously as communications systems and as illumination sources. Finally, an interface Ethernet-VLC prototype has been implemented. This could be easily used for conventional internet connections and applications.

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