Ethernet to Visible-Light Communications Adapter for In-Flight Passenger Data Networking

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***Abstract*—In this paper, the use of visible light communications (VLC) technologies for providing data access for passengers during flight is explored. An uplink channel based on using an USB adapter supporting a VLC receiver and an infrared emitter is also proposed. The potential capabilities of this optical access transceiver are also examined.**

Keywords-component; Visible Light Communications, In-flight communications, infrared uplink channel

I. INTRODUCTION

Nowadays, there are several proposals and solutions for providing low speed internet access for passengers during flight. Airlines and networking companies offer solutions for the plane-to-earth data link, combined with WiFi-based solutions suitable to be used avoiding compatibility problems with the flight instrumentation [1]. They are reliable and safe but the available baud rate for each user is limited and the EM compatibility problems are still present (not only with the plane systems, but also among the users themselves). Other proposals are devoted for multimedia delivery inside aircraft so as to provide seatback entertainment [2]. Providing wireless optical communications is a way of reducing the overall system weight induced by wiring each passenger seat. Radio frequency is the usual alternative for wireless communications but RF signals may interfere with the aircraft navigation systems. Other authors [3-4] have also studied the use of the on-board powerline networks for providing both electricity and communications by modulating White Light Emitting Diodes (WLEDs) and use them as both reading lights and optical transmitters. This can be a solution for broadcasting but lacks of the absence of an uplink channel to become a real network alternative.

A typical plane cabin offers some advantages for wireless optical connectivity, as it has no EM concerns, and the position of the passenger during flight is well defined (he is placed on a seat, with a reading lamp pointed to his position at a distance of about 1,5 meters). Positioning the data device (laptop, tablet, phone….) over the table, the coverage area of a typical infrared emitter pointing up will have a diameter about 50 cm so, focusing of the uplink channel will be easy. Finally, we shall employ an existing resource (the illumination lamp is always present, it is wired, and the use of LED instead of other illumination does not present major regulation concerns). Furthermore, SSL technology is by now under consideration for these applications by major plane providers due to their lifetime and chromaticity properties.

In this paper we propose a full optical wireless strategy for passenger connectivity in planes during flight. Using a VLC system as a downlink and an infrared link provides the uplink channel. Modulations and circuit implementations for a system prototype are also studied. This paper is organized as follows; a system description is presented in section II, while section III is devoted to the downlink HW and SW system implementation. Section IV provides information about the uplink device design. Finally, some conclusions are provided.

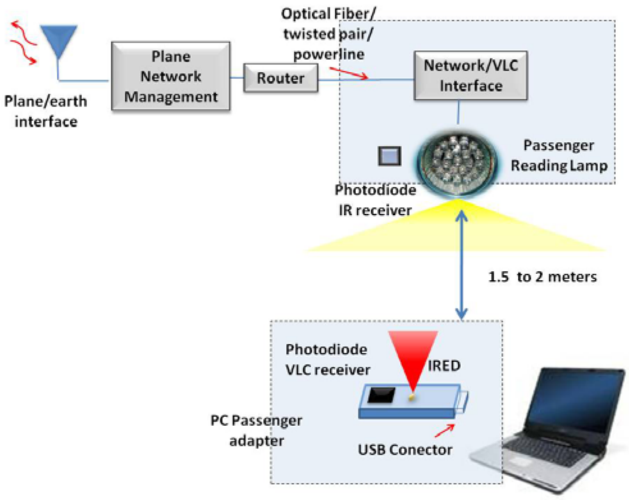

Figure 1: Block diagram of the proposed system

II. SYSTEM DESCRIPTION

Let us consider that LED lamps were now suitable for regular use as reading lights inside planes, so we could consider each passenger seat to be a communications micro-cell, with a line-of-sight VLC data link from the reading lamp and an uplink channel based on a line-of-sight infrared channel from the computer (or data device) to a photodiode on the plane ceiling (close to the reading lamp, see figure 1). Our communication device shall consist on:

- A VLC adapter for the passenger device, probably connected through a USB (but a RJ-45-based plug-in should be also considered). With an infrared emitter and a photodiode for the VLC data downlink, as well as the interface routines. This universal adapter can be provided (or hired) by the airline. There are available several USB-to-Ethernet commercial interfaces.
- A VLC emitter consisting on a passenger LED reading lamp, this lamp can be connected to a powerline channel or to a specific fiber optic or wired data link. As this wire does not affect the plane instrumentation, nowadays limitation on the use of fibers as wires inside plane will not be easily overcame.
- A Network adapter for the interconnection of the VLC system to the regular structured PLC or fiber data line

III. VLC DOWNLINK

In order to use an illumination lamp as a Visible Light Communication device we should need two simultaneous modulation schemes: one for establishing the illumination level and a second one for data transmission. In our proposal we use DPPM [4], changing the symbols between positive and negative values so as to obtain the required high or low illumination levels. Other modulating methods as OFDM or OOK have been proposed, but they are not suitable to be used simultaneously in communications and illumination systems due to light flickering, optical power level, light fluctuations dependence of the data transmitted, and electrical efficiency of the driver [5-6]. The communications behavior of LED lamps is limited by rise and fall times (400 ns for white phosphor LEDs), so the ON and OFF states require long temporal duration. The ratio between the ON and OFF times, is controlled by the PPM, determining the illumination level of the lamp. The LED ON/OFF switching should be fast enough for avoiding light flickering, fixing the lower frequency limit at several hundred of Hz. On the other side, the high data rates to be achieved impose are limited by rise and fall time to some MHz (unless you use additional techniques as color filtering etc.).

We shall work with data coming from PLC, twisted pair or optical fibre. For simplicity we shall consider a regular Ethernet access arriving to the lamp. We shall prefer this possibility better than PLC because the last is noisy and there are alternatives as POE systems that offer easy solutions for powering the lamps. In a final development the nature of the wire should not to be neglected because it may cause changes on the cabin (if shielded cables or new ducts are needed)

A. *Optical Emitter*

The emitter is based on a commercial lamp, and we consider also an IR receiver close to it. Driver configurations use SN75452 open collector-logical gate chips. They are able to switch current values up to 100s of mW, as required for the illumination LED. Finally the implemented scheme makes use of several 75452 gates, each of them driving a group of 5 parallel connected LEDs. On this example we are considering blue-phosphor simple LED, giving a bandwidth limited to 2-3 MHz (up to 4 Mb/s), but RGB multichip configurations will provide easily 50-60 Mb/s of joint baud rate.

The Interface between the data access and the optical access point is based on transmitting information through the optical downlink only using encapsulated in UDP packets. So they should be extracted from their original format and then re-encapsulated. The interface block performs the payload extraction and encapsulation and the flow control between Ethernet network and serial interface. 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 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.

Multiple access strategies are not considered a major concern for this application as the VLC emitter can be optically limited (e.g. by using proper lenses) to illuminate only the passenger's table, and the uplink is pointing up. If needed, contention protocols can be used, but these considerations are out of the main scope of this paper.

B. *Ethernet-Wireless Optical Systems Adapter*

As it was mentioned above, there are two different adapters in the system: the lamp and the passenger one. Both have a completely similar functionality although they differ in the power supply and final optical devices that they use to make the electro-optical conversion. The lamp adapter is feed with a PoE (Power over Ethernet) device and uses a visible light LED to do the transmission, whereas the passenger one uses the USB port as power supply, which offers up to 500mA, and IR LEDs to implement the uplink channel.

The designed adapter is responsible for both managing the Ethernet Controller, which means to control the packet read and write processes, and make the DPPM codification/decodification. To implement the first task, we have chosen a PIC18F97J60, manufactured by Microchip, which has an embedded Ethernet Controller. This fact not only offers a total system cost reduction, but also makes easier the communication task between both devices. This microcontroller is characterized by having five 8-bits-width ports, 4 external switch pins and several communication modules. Its system clock is based on a 25Mhz external clock, providing enough speed to our application. To implement the DPPM codification/decodification task, we have selected a Xilinx Cool-Runner2 CPLD (128 Macrocels), which offers a so good time performance, with a low cost and power consumption. Both devices are connected by two 8-bit buses, one for the uplink channel and other for the downlink one, and two data available lines. Figure 2 shows the block diagram:

The PIC18F97J60 has been programmed to be always in the idle state, waiting for either Ethernet or external pin interruptions. When first occurs, it generates a packet, which consists of a header (3 bytes), a packet length field (2 bytes), the captured Ethernet packet at the MAC layer, and a status byte, which fixes if there is or not a pending packet to transmit. Figure 3 shows the mentioned packet structure.

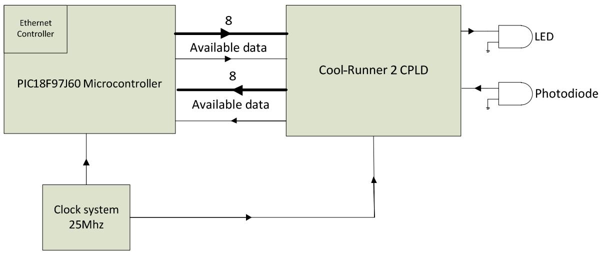

Figure 2. Ethernet Adapter block diagram

HEADER (3 Bytes)	Packet length (2 Bytes)	Ethernet Packet at MAC layer (Variable length)	TX status (1 Byte)

Figure 3. Data packet structure.

Every 4µs, each byte of the generated packet is put in the bus at the same time that a positive pulse appears on the available data line, indicating to the CPLD that there is a new byte to transmit. When an external pin interruption occurs, the inverse process should be made. An easy state-machine have been developed to extract correctly the "Ethernet packet at MAC layer" field, packing and sending it again to the embedded Ethernet Controller. The Cool-Runner2 CPDL implements a shift register and a DPPM encoder, which takes 2 bits every 1us and decides the next pulse distance taking into account the previous transmitted symbol as well [7]. Table I shows the distance calculation, in chips periods, used to encode the data to transmit.

TABLE I. DPPM DISTANCE CALCULATION FOR EACH SYMBOL.

Symbol	*Subhead*
00	5
01	2 or 6
10	3 or 7
11	4 or 8

Each symbols consist of five slots, 200ns each one, being needed a system bandwidth of 5MHz. With this configuration we reach up to 2Mbps, which is enough to offer to the passengers a good internet access service. Regarding the DPPM decoder process, we have also added a control block, which generates the interrupt signal (10us width) and the following data available pulses, used by the microcontroller to take the bus data.

C. Adapter For The Passenger Data Device

The adapter to be used by the passenger is designed to contain a VLC receiver, an IR emitter and the receiver part of the optical-to-Ethernet interface (if it is to be USB connected, additional features should be added, but they are available in commercial devices and not covered by this paper). VLC receiver structure is depicted in Figure 3a. The optical signal reception is carried out by PIN photodiodes (with 15 MHz bandwidth, 0.45 A/W optical sensitivity at a 660 nm wavelength and an active area of 66 mm^2). After the photodiodes, the electrical signal is pre-amplified using a trans-impedance configuration connected to a boost-trap circuit. Boosttrap is used to reduce the effect of spurious capacities in the photodiodes improving the frequency response, if a single photodiode is used, or maintaining the reception bandwidth, when several photodiodes parallel connected are needed so as to increase reception area. The second stage is composed by an amplification block and an active filter in sallen-key configuration for noise reduction. Finally the received signal is delivered to a ML detector.

The uplink is implemented through a 512 kbps infrared link, using a set of eight SFH4200 IREDs as transmission system, at a wavelength of 950 nm. The driver scheme is similar to that used at the downlink, but in this case, we use four SN75452 gates connected in parallel for driving more current through the IRED array. The circuit is presented in figure 3b. Both receiver and downlink schemes are similar. Additionally, we added a black coverage –transparent to infrared light- inside the dome used for protecting the infrared photodiodes from dust and humidity. Using this combination downlink/uplink we can assure a reliable communications with the VLC access point node. Specifically, it gets link distances about 3 m with a field of view higher than 30º, enabling a wide area for positioning the mobile node. This is by far more than needed for a single passenger seat inside a commercial flight. FOV can be adjust so as to avoid interferences with other passengers.

IV. RESULTS

As is was mentioned above, the received data from the Ethernet network, is packed, coded and transmitted through the wireless optical link, which uses visible light LEDs in the downlink channel and IR in the uplink one. Figure 4 shows the waveform of the generated packet, specifically, an ARP frame of 42 bytes length.

To test the behavior of the developed system, several web connections using different services have been made. We have also used an Ethernet sniffer to check the amount of transmitted, received, corrupted and retransmitted packets. However, we have not made any statistical study yet. Here we present three main sets of results. The first is related with the quality of the downlink signal arriving to the user, the second is about its capability of working in the presence of other illumination sources, finally, we will study the application of this system not only for network connection, services, but for providing on-board entertainment, as could be customized video transmission or supporting collaborative games. Figure 5 shows a comparison of emitted and received signal for the downlink

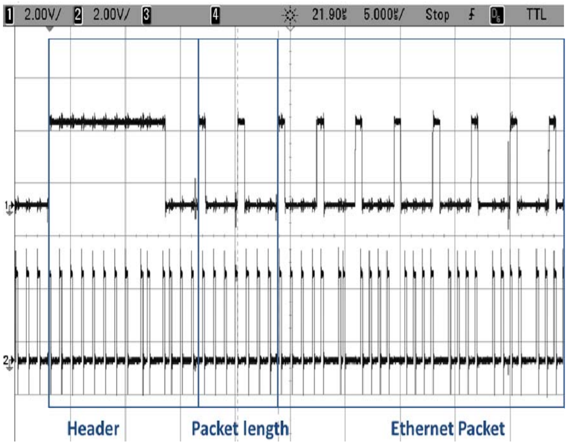

Figure 4. ARP frame, packed and DPPM coded by the developed adapter

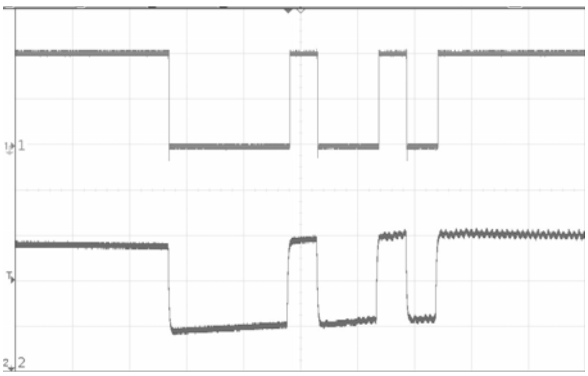

Figure 6. Experimental testing of the VLC prototype. Normalized received signal for the link at 1.7 meters distance, (before being rectified). Emitted (up) and received (bottom) signal.

This transmission was carried out using a commercial 5W SSL lamp. In order to test the system capacity for on-board entertainment services, we have performed several tests transmitting video from different sources coded in MPEG -TS. It was extracted from a laptop through the Ethernet PC card at a baud rate of 2 Mbps. These data were CR-DPPM modulated and optically transmitted. The symbol error rate was estimated comparing emitted and received sequences of coded video. As we have transmitted several video fragments of 10^8 length and zero errors were found on them, we can estimate that error probability should be below 10^{-8} on a 2 meters link in the above conditions.

When considering loss of frames we are testing transmission inside a room simulating the situation of a plane cabin (a seat with a small table, and a reading lamp and a PIN photodiode in the ceiling at a distance about 1.5 to 2 meters) in two operative conditions: absence or presence of artificial lighting. We are using 30 second video segments (generated by means of the freeware Network Traffic Generator and Monitor). Table I shows the ratio of transmitted/lost frames in presence/absence of illumination noise.

V. Conclusions

In this paper a new field of application for visible light communication systems is presented. Full wireless optical connectivity is obtained by using not only a VLC system for downlink but an infrared system for uplink. It requires the use of an adapter for the passenger computer but offers the possibility of a fast implementation and gives a new opportunity of providing personalized on-flight entertainment by wireless media (even used in combination with regular RF-based WiFi on-board systems, and this technology does neither suffer, nor produce, interference with radio systems). Baud rates can be significantly increased, compared to RF systems, because EM compatibility concerns are not present. Protocol needs on the optical channel are also reduced as each couple lamp-photodiode acts as a dedicated access point for each singular seat.

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