International Journal Of Engineering Research and Technology (IJERT)
IFET-2014 Conference Proceedings

VISIBLE LIGHT COMMUNICATION SYSTEM VIA A READING LAMP FOR IN-FLIGHT ENTERTAINMENT

Sheela Bernardine Josy.T, Heena.A, Pushparaj. J
Dr.S.J.S Paul Memorial College of engineering and technology,
Puducherry-605502.

Abstract

Visible Light Communication seems to be the emerging technology in the upcoming generations. The visible light communication (VLC) refers to the communication technology which utilizes the visible light source as a signal transmitter, the air as a transmission medium, and the appropriate photodiode as the signal receiving component. By this emerging technology, various applications have been devised and here, we present a novel application technique .This paper explores the use of a reading lamp as an access point for a Visible Light Communications (VLC) downlink channel. We have established an infrared uplink channel based on a network adapter, supporting both the VLC receiver and an infrared emitter. The optical signal power distribution over the passenger area has been studied using a Monte Carlo Ray-Tracing algorithm.

.INTRODUCTION

Offering data access during flight has recently become an area of interest for

many plane building companies and airlines. Moreover, the availability of wireless bandwidth opens the door for new entertainment services such as video selection and collaborative games. While some networking companies are offering solutions for the plane-to-earth data link, others are providing Wi-Fi-based solutions to deal with compatibility problems with the flight instrumentation. However, the available baud rate for each user is limited and the EM compatibility problems are still present (not with the plane systems, but among other users when the amount of them increases). Other proposals are devoted to multimedia delivery inside the aircraft so as to provide seatback entertainment[1]. Wireless optical communications is a way of reducing the overall system weight induced by wiring each passenger seat. Wireless optical connectivity offers some advantages on a typical plane cabin as it has no EM concerns. The position of the passenger during flight is well defined: she/he is usually placed on a seat with a reading lamp pointing to her/his position at a distance of about 1.5 m, and having a data device (laptop, tablet or phone) over the table. The coverage area of a typical infrared emitter pointing upwards has a diameter of about 50 cm, so focusing the uplink channel should be easy. Furthermore, we shall employ an existing resource as the illumination lamp. As the use of LEDs instead of other illumination sources does not present major regulation concerns, many plane providers appreciate their lifetime, low power consumption and chromaticity properties. There are several research groups working in this area. The use of onboard power line networks for providing both electricity and communications by modulating LED lamps, creating infrared communications cells to implement the user link have also been devised. In this paper we propose a full optical wireless strategy for passenger connectivity in planes during flight. It uses a VLC system as a downlink, while an infrared link provides the uplink channel. Modulations and circuit implementations for a system prototype are also studied. Moreover, we introduce new network adapter architecture, an exhaustive description of the system performance and an analysis of the power budget on the passenger seat.
This paper comprises of the system description, the downlink VLC simulation and the Hardware system implementation.

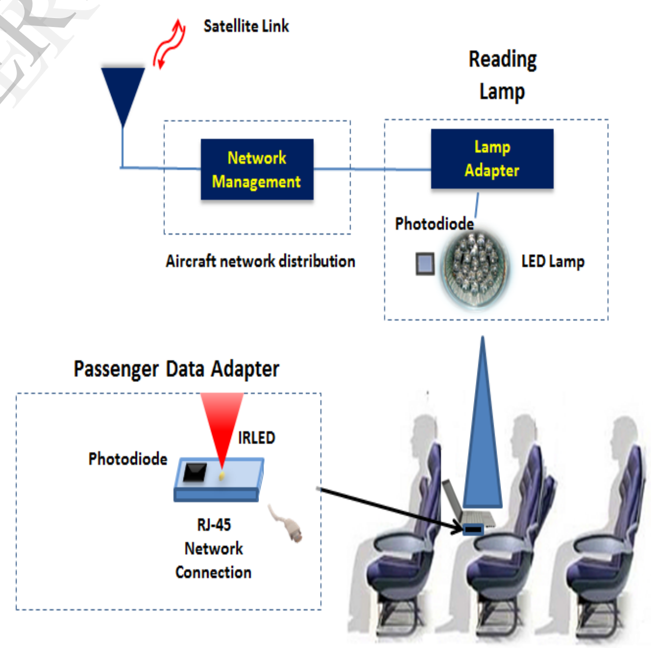

Fig. 1: Block diagram of the proposed system.

SYSTEM DESCRIPTION

An internet in-flight system can be divided into three main subsystems:

Ground to aircraft link: It provides the connection between the aircraft and the Internet Service Provider (ISP). It can be implemented by a satellite or a direct ground RF link. This block can be removed if only entertainment services like video and audio broadcasting are to be offered by a company.

Network distribution: Shielded twisted pair cables are the most commonly used ones inside the aircraft, however optical fiber is expected to be used in the future.

User link: With the aim of reducing the amount of needed cable, a wireless link seems to be an optimal solution to the requirements of the user.

Let us consider 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 Fig. 1). Two communication devices working as adapters have been developed: the first one, known as "***lamp adapter***", gets the packets from the regular distribution network (Ethernet or PLC) and behaves as a bridge, replicating the information at the optical interface. The second one, known as "***passenger data adapter***", is characterized by having a similar behavior, using the Ethernet or USB port of the mobile devices instead of the aircraft distribution network as data source or sink. Therefore, the only difference between the adapters is the working wavelength of the optical link (VLC from distribution network to user, and IR in the other direction).

DOWNLINK CHANNEL USING VLC AND its ANALYSIS

In the upcoming system topology, each passenger is considered to be inside a microcell. However, it could be possible that nearby users or cabin illumination lamps generate harmful interference due to a wide lamp emission pattern or a high photodiode FOV. In addition, reflections on different objects could dramatically reduce the system
performance. Hence, here we opt for the use of optical lenses for collimating the light beam in the passenger's table. A simulation based on a Monte Carlo-Ray tracing algorithm has been performed in order to calculate the Signal Noise Ratio (SNR) at different points of the user's table [6]. We have considered 3 emitters, corresponding to the three reading Lights and 740 receivers distributed over the passenger's table. The following table shows the parameters that are considered.

Table 1

Parameters Considered

Parameter	Value
Photodiode Area	66 mm2
Photodiode FOV	120º
Photodiode responsivity	0.63 A/W
Photodiode darkness current	2 nA
Transimpedance BW	5 MHz
Amplifier NEP	750 W/√Hz
Number of rays	100.000
Number of reflections	10
Objects reflection coefficients	0.6-0.7

Fig. 2 shows the cabin model developed, which has been used to determine the environment under study. It is called to be as the Aircraft Environmental model.

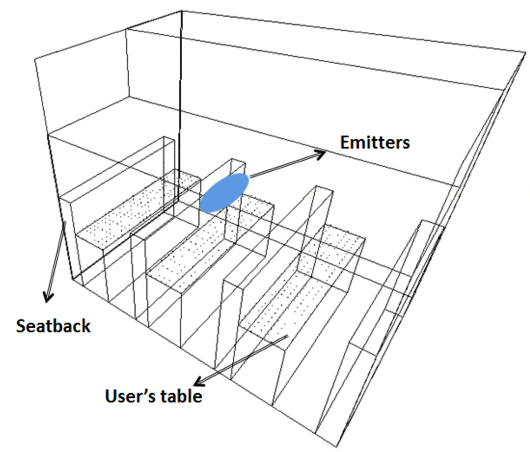

Fig. 2. Aircraft environment model.

Different results varying the lambertian coefficient (n) of the lamp have been performed, getting reflectance patterns, and then SNR and SIR distribution patterns from a top view.

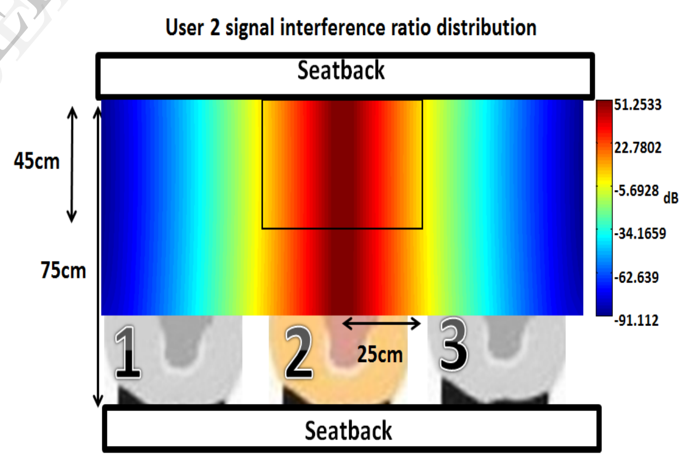

Fig 3. SIR distribution for user 2.

The rectangle represents the passenger's table, where the device should be placed, although a good system performance can be offered in all the area of the passenger's seat. Fig. 3 shows SIR values at different points of the user's table when a LED lamp with n=50 is used. Under this situation, the worst
ratio is up to 16.85 dB.

Based on the above confirmations, we can affirm that the system performance reduction is negligible so as there is a BER deterioration of 0.25 dB. In spite of that, the effect could be mitigated increasing the lambertian coefficient of the lamp or even employing WDM (Wavelength Division Multiplexing) techniques over RGB LEDs. Fig. 4 shows the Signal Noise Ratio distribution over the user's table, which shows values up to 70 dB. These ratios do not affect the system performance.

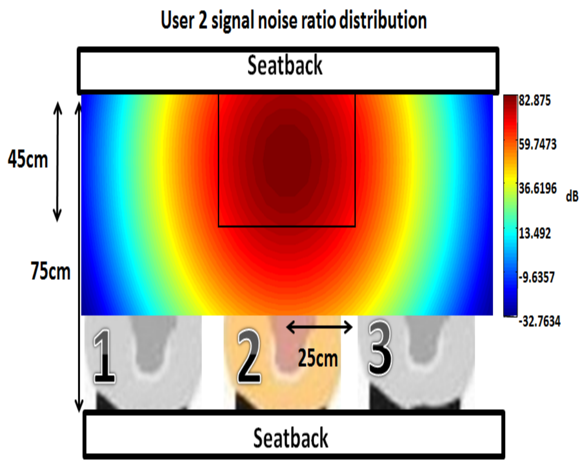

Fig. 4. SNR distribution for n=50 for user 2.

IMPLEMENTATION OF USING VLC IN DOWNLINK CHANNEL

In order to use an illumination lamp as a VLC device, a codification scheme that allows a constant illumination level at the lamp and data transmission is needed. In this work, CRDPPM (Constant Rate DPPM) is considered because of its simplicity and low cost of implementation, which is only based on an edge detector and a counter. This scheme does not only offer the advantages of DPPM (which encodes the data by modifying the distance between the pulses), but also allows a constant bit rate, which makes the implementation of multimedia applications easier. In addition, it is suitable to be used simultaneously in communications and illumination systems due to the absence of light flickering. Different codification schemes have been studied as well. OFDM techniques offer both good multipath and narrowband interference rejection response, but imply quite expensive hardware requirements [9]. VOOK and VPPM schemes have been proposed in the under development VLC standard (802.15.7) as modifications of the OOK and PPM codifications respectively, with the aim of adding dimming capabilities. However, OOK does not guarantee the absence of flickering and both of them (OOK and PPM) have lower spectral efficiency than DPPM. Regarding the PPM scheme, it is characterized by having a better system performance against AWGN, but it is not a real necessity in VLC applications as the SNR values are commonly really high. The synchronization task, on its part, turns out to be much more difficult to accomplish than in CR-DPPM. If VPPM or VOOK are eventually defined as the codifications for the standard, many of these results would also be applied without significant modifications.

The communication behavior of LED lamps is limited by rise and fall times (100 ns for white phosphor LEDs), so the pulse width should be at least 200 ns, which is the upper bound of the lamp switching rate. In addition, the LED switching should be fast enough to avoid light flickering, fixing the lower frequency limit at several hundreds of Hz. The ratio between the ON and OFF periods determines the illumination level of the lamp. The novel topology might work with data coming from PLC, twisted pair cables or optical fiber. The first solution avoids the necessity of performing any changes in the cabin topology as it uses the power lines of the aircraft itself to transmit the data. However, it could be noisy and generates EM interference with the aircraft instrumental systems. We shall consider an alternative: Ethernet as a distribution network inside the aircraft and the use of a Power over Ethernet (PoE) system to feed them up, and so the same shielded twisted pair cable will be used to transmit the data and to power the lamps. This fact generates a weight reduction in the aircraft installation needed to offer this kind of services. As commented on above, there are two different adapters: The ***lamp adapter*** and the ***passenger adapter***. Both of them have a similar functionality, but they differ in the power supply needed and the final optical interface they use to make the electro-optical conversion. The lamp adapter is fed with a PoE device and uses a visible light LED to do the transmission, whereas the passenger adapter uses the USB port as power supply, which offers up to 500mA at 5V.

A. Ethernet-wireless optical system adapter

The interface between the Ethernet data and the optical access point is based on a bridge between the network and the optical downlink. This bridge detects the packets, modifies them at the MAC layer and finally codifies the frames in CRDPPM to be transmitted through the VLC downlink. Multiple access strategies are not to be considered a major concern for this application as the VLC emitter can be optically limited by lenses to illuminate only the passenger's area, and the uplink is pointing upwards.

The designed adapter is responsible for both managing the Ethernet Controller, which means to control the packet read and write processes, and making the CR-DPPM codification/decodification. In order to implement the first task, a microcontroller with an embedded Ethernet module has been chosen. This property does not only offer a total system cost reduction, but also makes the communication task between both devices easier. 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 25 MHz external clock, providing enough speed to our application. To implement the DPPM codification/decodification task, a CPLD (128 Macro cells) has been selected as it offers good time performance together with a low cost and low power consumption. PIC and CPLD are connected by two 8-bit buses, one for the uplink channel and the other for the downlink one, and two data control and synchronization lines. This topology can be easily improved by using a higher performance 32 bits microcontroller and a 100BaseT Ethernet connection and higher clock frequency.

Fig. 5 shows the block diagram:

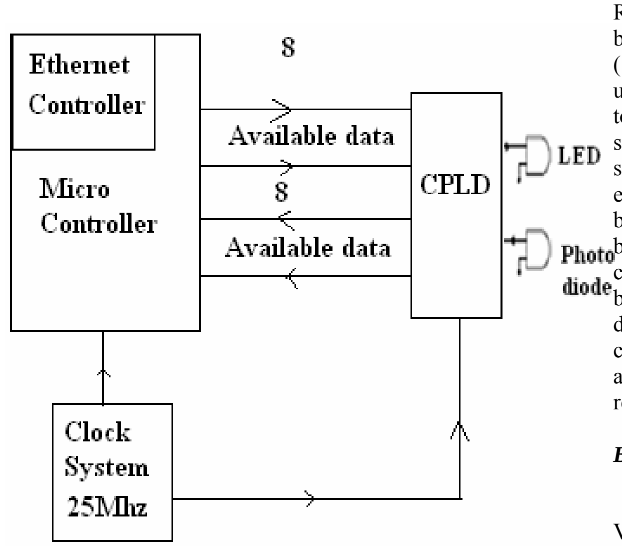

Fig 5. Ethernet Adapter block diagram.

The microcontroller has been programmed to be always in the idle state, waiting for either Ethernet or external pin interrupts. When the former 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 indicates whether there is a pending packet to be transmitted or not.

Each byte of the generated packet is delivered to the bus every 4 µs. At the same time, a positive pulse appears on the control line, indicating to the CPLD that there is a new byte to be transmitted. When an external pin interrupt occurs, the process takes place in the inverse order. An easy state machine has been developed to extract correctly the Ethernet packet at the MAC layer field, packing and sending it again to the embedded Ethernet Controller. The CPLD implements a shift register and a DPPM encoder which takes two bits each microsecond and decides the next pulse distance taking into account the previous transmitted symbol .Table II shows the distance calculation in chips periods used to encode the data to be transmitted.

Table II

DPPM DISTANCE CALCULATION FOR EACH SYMBOL

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

Each symbol consists of five slots, 200 ns each. A system bandwidth of 5 MHz is needed. With this configuration we reach up to 2 Mbps, which is enough to offer the passengers a good internet access service. Regarding the CR-DPPM decoder process, a control block has been added. It generates the interrupt signal (10 us width) and the following data available pulses used by the microcontroller to take the bus data. In order to maintain the illumination level of the lamp, 00 symbols are transmitted when there are no data to be sent from the Ethernet connection. The downlink electro-optical conversion is based on a commercial blue-phosphor simple LED lamp which allows a bandwidth up to 5-6 MHz, although RGB multichip configurations will easily provide 50-60 Mbps of joint baud rate. To excite this lamp we have implemented a driver configuration using open collector-logical gate chips driving 3 LED parallel blocks. These devices are able to switch current values up to hundreds of mA, as required for the illumination LED.

B. Adapter for the passenger data device

The designed passenger adapter contains a VLC receiver, an IR emitter and the receiver part of the optical-to-Ethernet interface. 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 mm2). The generated electrical signal is pre-amplified using a trans-impedance configuration previously connected to a Bootstrap circuit, which is used to reduce the effect of spurious capacities in the photodiodes. This circuit improves the frequency response, especially when several photodiodes are parallel connected to increase reception area. The second stage is composed by an amplification block. Finally, the received signal is delivered to an ML detector. This scheme is also used in the uplink receiver, although an IR filter has been added. Fig .6 shows the receiver topology.

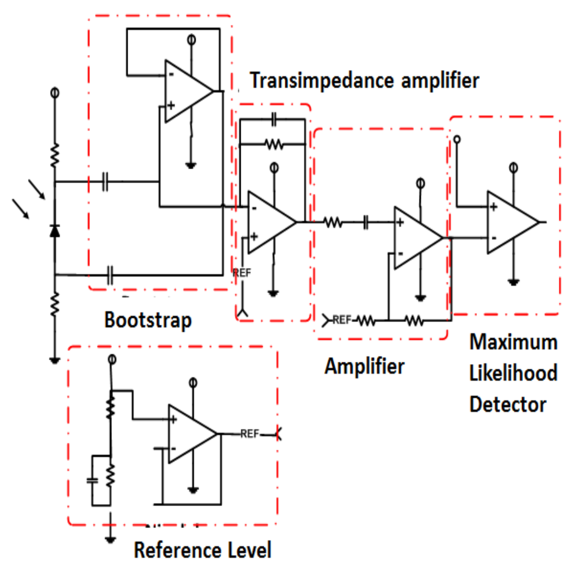

Fig 6. Receiver scheme.

The uplink is implemented by using a 2 Mbps infrared link and a set of 3 IREDs used as transmission system at a wavelength of 950 nm. In order to increase the laptop battery autonomy, a modified DPPM codification has been implemented. It is based on switching off the LEDs when there is no packet to transmit, and generating a single pulse before the packet itself, allowing the receiver to recover the transmitter state. With this modification it is expected to reduce power consumption up to a half without losing the advantages of the DPPM codification. The developed device is shown in Fig. 7.

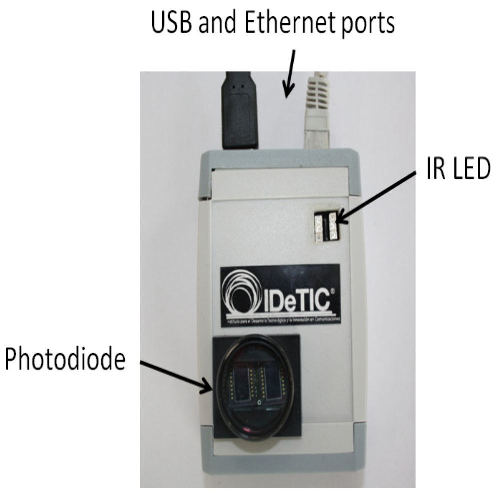

Fig 7. Developed device.

RESULTS

As already mentioned, 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. Fig. 8 shows the waveform of the generated packet, specifically, an ARP (Address Resolution Protocol) frame of 42 bytes length.

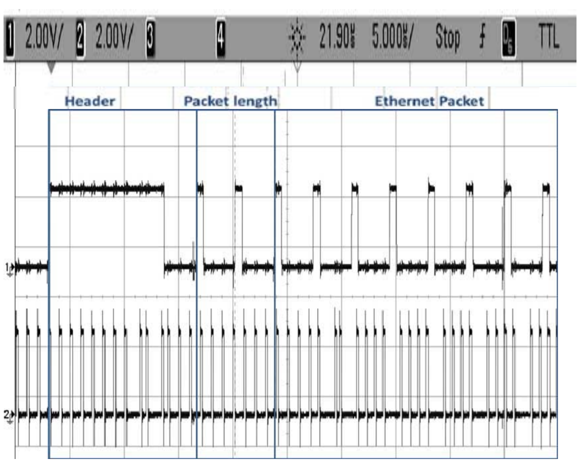

Fig 8. ARP frame, packed and DPPM coded by the developed adapter.

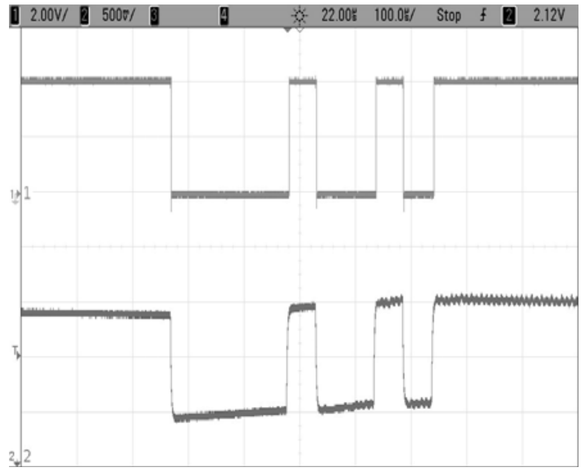

Fig 9. Experimental testing of the VLC prototype. Normalized received signal for the link at 1.2 meters distance (before being rectified). Emitted (up) and received (bottom) signals.

This transmission was carried out using a commercial 5 W SSL lamp. In order to test the system capacity for on-board entertainment services, several tests transmitting video from different sources coded in MPEG -TS were performed. It was extracted from a laptop through the Ethernet PC card at a baud rate of 1 Mbps. These data were CR-DPPM encoded and optically transmitted. The symbol error rate was estimated comparing emitted and received sequences of coded video. As we transmitted several video fragments of 108 length and zero errors were found on them, it is possible to estimate that error probability should be below 10-7 on a 2 m link in the above conditions.

To validate the complete system, several network measurements have been made. A 10 Mbps Half-duplex Ethernet link has been selected. With the aim of making a fair system comparison, a traffic shaping and monitoring commercial software has been used to set the maximum transfer rate at 2 Mbps, which is the upper hardware limit of our system. Bearing this limitation in mind, flux control algorithms are recommended to avoid packet losses. However, as most of the internet protocols are based on TCP, algorithms of this type are not necessary because the protocol itself regulates the window size of the transmitted packets and allows their retransmission. Nevertheless, UDP data grams are sent to the network without reliability or flux control capabilities. Taking this into account, throughput, Round- Trip-Time (RTT) and Jitter (variations on the RTT) measurements can be obtained capturing TCP packets with a simple software tool for network analysis. Moreover, UDP packets have been used to obtain packet loss measurements. Table III shows the results.

For these measurement statistics, three network configurations have been employed:

a) Wired Ethernet 10 Mbps (without bandwidth limitation).

b) Wired Ethernet 2 Mbps (limited by software).
c) Ethernet with our developed VLC interface.

Table III

NETWORK STATISTICS

Parameter	Wired		VLC system
	10 Mbps	2 Mbps	
Round Trip Time (ms)	13	45.7	28
Jitter (ms)	1.93	2.21	3.68
Throughput (Mbps)	9.6	1.89	0.983

With the aim of improving these results, we are developing a similar device using a 16 bits width microcontroller which offers higher internal data transfer and shortens MCU times.
Both the above mentioned systems are characterized by having a similar behavior, although the new developed device loses a few more packets than in the wired Ethernet scenario. This could be easily solved using a higher performance microcontroller.

Finally, in order to test the behavior of the developed system, several web connections using different services have been performed. An Ethernet sniffer has also been used with the aim of checking the amount of transmitted, received, corrupted and retransmitted packets. Thus by means of the newly developed devices, adapters and by using an appropriate coding technique using Visible Light Communication through a reading lamp we enable a good in Flight Entertainment.

CONCLUSION

In this paper, a low cost VLC system for in-flight applications is presented. Full wireless optical connectivity is obtained by using a VLC system for the downlink and an IR system for the uplink. The developed adapter for the passenger laptop offers a versatile solution using the Ethernet port without the installation of an extra driver. Working at the MAC layer also allows full transparency to the user applications. The presented system can be rapidly implemented and provides personalized in-flight entertainment and services by wireless media. This technology does neither suffer nor produce interference with radio. Baud rates can be significantly increased using RGB LEDs lamps and ASIC devices. Protocol requirements on the optical channel are also reduced because each couple lamp-photodiode acts as a dedicated access point for each singular seat. Thus the newly innovated system of providing an In Flight Entertainment by a reading lamp with the means of Visible Light Communication seems to be much user friendly giving a happy journey to the passengers.

REFERENCES

[1] Y. Zheng and M. Zhang, "Visible light communications-recent progresses and future outlooks", *Symposium on Photonics and Optoelectronic (SOPO)* 2010, pp. 1-6, China, June 2010.
[2] M. Kavehrad, Z. Hajjarian and A. Enteshari, “Energy-Efficient Broadband Data Communications using White LEDs on Aircraft Powerlines”, *ICNS Conference 2008,* pp. 1-6*, USA,* May *2008.*
[3] H. Elgala, R. Mesleh and H. Haas, “Indoor broadcasting via white LEDs and OFDM”, *IEEE Transactions on Consumer Electronics*, vol. 55, no. 3, pp. 1127-1134, Aug. 2009.
[4] R. Perez-Jimenez, J Rufo, J. Rabadan, C. Quintana and F.J. Lopez- Hernandez, “Visible Light Communication Systems for Passenger In- Flight Data Networking”, *IEEE International Conference on Consumer Electronics*, pp. 445-446, USA, Jan. 2011.
[5] C. Quintana, V. Guerra, J. Rufo, J. Rabadan and R. Perez-Jimenez, "Ethernet to Visible-Light Communications Adapter for In-Flight Passenger Data Networking", *World Congress on Engineering and Technology 2011*, China, Sept. 2011.
[6] O. González, S. Rodriguez, R. Perez-Jimenez, B.R. Mendoza and A. Ayala, “Error Analysis of the Simulated Impulse Response on Indoor Wireless Optical Channels Using a Monte Carlo-Based Ray-Tracing Algorithm”, *IEEE Transactions on Commun*ications, vol. 53, no. 1, pp. 124-130, Jan. 2005.
[7] S. Da-Shan and J.M. Kahn, "Differential pulse-position modulation for power-efficient optical communication", *IEEE Transactions on Communications,* vol. 47 , pp. 1201-1210, Aug. 1999.
[8] S. Meihong, Y. Xinsheng and Z. Zhangguo, "The Modified PPM Modulation for Underwater Wireless Optical Communication", *International Conference on Communication Software and Networks*, ICCSN '09. pp. 173-177, China, Feb. 2009.
[9] H. Elgala, R. Mesleh, H. Haas and B. Pricope, “OFDM Visible Light Wireless Communication Based on White LEDs”, *Proc. of the 64th IEEE Vehicular Technology Conference (VTC)*, pp. 22–25, Dublin, Apr. 2007.
[10] F. Delgado, I. Quintana, J. Rufo, J.A. Rabadan, C. Quintana, and R. Perez-Jimenez, "Design and Implementation of an Ethernet-VLC Interface for Broadcast Transmissions", *IEEE Communication Letters,* vol. 14, no. 12, pp. 1089-1091, Dec. 2010.