OPTICAL WIRELESS SYSTEM FOR ACQUIRING IN-FLIGHT COMMUNICATION THROUGH VISIBLE LIGHT SIGNAL

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Abstract—We are exhausted of the fact that we cannot use internet on the flight. What can be the solution of this shortcoming? After the work of Harald Hass this problem seems can be rectified using visible light communication. This paper sightsees the practice of overhead lamp as the access point for short range optical wireless systems. The indoor uplink can be established using infrared and downlink by visible light. The distribution of optical signal power received in the user zone is determined by Monte Carlo ray tracing algorithm. The hardware implementation and results are also presented.

Keywords—Visible Light Communications, In-flight communications and optical wireless system.

I. INTRODUCTION

Currently most of the plane building companies are spending millions of dollars to provide the passenger with the luxury of internet access onboard. On this regard some companies come up with solution of wiring all the passenger seats or providing solutions for the incompatibility of plane instruments against Wi-Fi. The solutions suggested above are expensive and have its own disadvantages [1]. The major disadvantage is they increase the overall journey charges in terms of fuel consumption to carry the extra weight imparted by wiring the passenger seat. One of impacting solution of the above short coming is to implement optical wireless communication. In optical wireless (OW) system we use light as medium so there is no question of plane instrument incompatibility and as we are going to use the existing overhead lamp as access point so the weight imparted by the wiring of seats is also eliminated. In the overhead lamps we have LEDs. Many scientists had broken their backbone for successful communication through LEDs. M. Kavehrad [2] theoretically suggested the utilization of power line networks for both power supply and communication to the LEDs. Infrared communications cells had been created by Elgala et al to implement the communication [3]. In this paper the downlink had been established by using visible light communication while infrared link provides the uplink. An analysis of amount of signal power received by the passenger is also carried out. The paper is subdivided into three sections. Section II contains the existing model, proposed model and its system description while section III and IV deals with the link establishment through VLC and hardware implementation. Result and different analysis has been elaborated in section V and VI.

II. SYSTEM DESCRIPTION

A. Existing model

The existing model instigated the wiring system for every passenger seats which increase the weight to be carried and thereby increase the trip cost for the aviation industry.

B. Proposed model

With the aim of reducing the amount of cable needed, a wireless link seems to be an optimal solution. This work
focuses on this subsystem. In flight communication can be established under three steps. Firstly through satellite or a direct ground RF link internet connection is established between the aircraft and ISP. Secondly the internet access is distributed to all the passenger using the twisted pair cable or fiber optic cables. Ethernet can be distributed in aircraft using PoE system which leads to weight reduction in aircraft installation. Finally the user link is established with the fact keeping in mind to reduce the wiring requirement. An uplink is setup based on infrared channel from the communicating device to photodiode attached on the plane ceiling near the overhead lamp while the down link is setup by line of sight visible light communication through the LED lamp. For user uplink to devices working as adapters are used the first one, known as "lamp adapter", which receives the packets from the network. 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.

III. LINK ESTABLISHMENT AND ANALYSIS

A. VLC downlink channel setup

For down link channel setup we are going to use overhead LED lamp as the access point. The communications 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. Thus the data which need to be communicated is DPPM (differential pulse position modulation) modulated and then given as input to LED. The data is communicated using on and off flickering of LED light. To achieve this flickering of LED the pulse duration is varied [4]. For this variation shake only DPPM is implemented which varies the position of pulse with respect to input data. The performance can further be enhanced by using constant rate DPPM (CRDPPM) which eliminates the necessity of complex synchronism system [7-8]. The LED used for VLC is somewhat different from normal LED [4]. A quasi-white light source is typically generated by using a combination of red/green/blue (RGB) or yellow phosphor Blue (YB) LEDs [4]. The light emitted by the LED have wide emission pattern which leads to interference with the adjacent passenger’s overhead lamp light. This problem can be rectified using lens in the LED light. Along with it, a high photodiode FOV and reflection from different objects create interference which results in performance degradation. The distribution of optical signal power received over the passenger’s table is given by Monte Carlo Ray tracing algorithm [6]. The Impulse response for LOS system at different points of the user's table is given by

\[ P_e = \frac{\text{ Energy of the lamp} \times \text{ FOV of the photodiode} \times \text{ Reflection from different objects}}{\text{ Distance between transmitter and receiver}} \]

For getting a good system recital the receiving device must be present in the rectangular region shown in the figure 3. The SIR value will vary with the change in the ‘n’ value [9]. Signal to noise ratio is the ratio of signal power received by the photo detector to the noise power. The SNR is not same everywhere along a particular user’s table. It is maximum near the center beam of LED light and keep on decreasing when we move sideways. This fluctuation in SNR degrades the system performance. By help of Monte Carlo Ray Tracking algorithm the impulse response of LOS as well as multipath VLC can be determined, which can be used to calculate the SNR of the system by

\[ \text{SNR} = \frac{\text{Modulation Index}}{\text{Noise Power}} \]

Where the R is the responsivity of the photo detector, \( H (C) \) is channel direct current (DC) gain [12], \( P_r \) is the received power, \( M_i \) is the modulation index and \( f(t) \) is the modulating DPPM signal.
Different modulation and codification schemes had been studied to decrease the interference. For example OFDM technique provides a better multipath and narrowband interference rejection response illustrated by Harald Hass [10]. Further VPPM or VOOK can also be used which has been standardized in 802.15.7. The data communication in VLC is done by switching the LED on and off which leads to flickering of light. The human eye is very sensitive to light flicker but irritation due to flickering depends on lighting conditions and the individual. The upper limit severity of flickering is standardized by the International Electrotechnical Commission (IEC) [11].

B. Hardware implementation

Meanwhile no well-defined channel models for this transmission system exist in the literature so we are supposed to determine the performance using an experimental set up. 1) Link chain: For link chain establishment we had used two msp430 launch pads boards for, one for the transmitter section and the other for the receiver block. Specifically speaking evaluation board with the Texas Instruments msp430g2553 which is an ultra-low power microcontroller is used. The evaluation board have 16 bits input. For development of code for DPPM interference and algorithms MATLAB had been used. Microcontroller are programed in such a way that it remains idle until it is interrupted by Ethernet or from the external pins. When it is interrupted microcontroller breeds a frame with 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. The frame format of the packet generated is as shown

<table>
<thead>
<tr>
<th>Header</th>
<th>Status</th>
<th>Packet length</th>
<th>Ethernet Packet</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 bytes</td>
<td>1 byte</td>
<td>2 bytes</td>
<td>36 bytes</td>
</tr>
</tbody>
</table>

A block diagram of the mantled components of our system is as shown

2) LED characteristics: Normally two types LEDs are used. One contrived using a blue LED chip and a phosphor and the other the white LEDs are fabricated by mixing light from LEDs of the three primary colours, such as red, green, and blue. In the later one LED all the colours are emitted simultaneously making it seems white in colour. For the prototype a single chip 5mm white LED is used. The preference for this LED is because of its less cost and standardization. Also the luminous intensity of the LED must be 11000mcd or more [4]. The photodiodes used are negative or positive siliconplanar which have maximum response in the visible spectrum. When light rays impinges on the photodiode equivalent amount of current is produced, the magnitude of which is proportional to the incident light power. This current is then converted to voltage signal by the transimpedence configuration. The photodiode must have less dark current with the upper limit of 2000mA and receiving planar area of 9.8mm2 and is preferred to be used in photovoltaic mode for better linearity and less noise. The reason for photodiode to satisfy the above structural characteristics is to attain very low offset when the photodiode is operated in the photovoltaic mode.

IV. UPLINK AND DOWNLINK CHANNEL

The passenger adapter designed contains a VLC receiver and IR emitter. 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. The VLC receiver converts the packets coming along with optical light signal into the electrical signal which is amplified using a transimpedence, which reduces the effect of bogus capacities in the photodiodes. This circuit also enhance the frequency response when several diodes are connected in parallel with each other. For the electro-optical conversion by single chip of blue-phosphorus LED a bandwidth up to 5- 6 MHz is allowed while the RGB white LED provides of 50-60 Mbps joint baud rate. An open collector-logical gate chips is used for driving configuration to excite the LEDs in the lamp. These used chips are able to switch current values up to hundreds of mA, which is required for the illumination of LED. The optical signal reception is carried out by PIN Photo- diodes with 15 MHz bandwidth, 0.45 A/W optical sensitivity at a 660 nm wavelength and an active area of 66 mm2 . Here optical to electric conversion takes place and processed. 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. Modified DPPM is used to increase the communicating device battery which is based on switching off the IREDs when no packet is transmitted. Overall 740 infrared detectors are placed
above the user’s table. The IRED emitter pointing upward has the coverage of about 50 cm. So the data transmitted in the uplink can be easily received by the infrared detector placed over the ceiling near the overhead lamp. With the tremendous increment in the optical technology further multi-input-multi-output technique with enhanced modulation can also be implemented [5]. The two adapters used (lamp adapter and passenger adapter) perform the same deed of electro-optical conversion with slight variance in power supply. The lamp adapter is fed with PoE while power for Passenger adapter is supplied through USB port of communicating device with passenger.

V. ANALYSIS

We have already discussed about the SIR pattern determination and also the SNR calculation using the Monte Carlo Ray Tracking algorithm [6&12]. Bit Error Rate is meaningless for DPPM because the symbols in the DPPM signal do not have equal duration. Hence the analysis of the modulation is done on the packet lost rate. The non-uniformity in symbol duration also leads that the symbol boundaries are not known prior to detection. The packet error rate is given by the equation given in the next page.

\[ P_{DPPM} = KQ \left( \frac{R_P}{\log_2 L} \right) \]

Here \( R_p \) is the average bit rate, \( N_0 \) is the noise PSD, \( L \) is number of distinct waveform and \( T_c \) is the chip duration.

The packet lost rate of a wired and a wireless Ethernet using VLC can be compared as

![Fig. 7. Packet Loss Rate measurements](image)

From the graph it can be illustrated that the packet loss is more in the proposed system as compared to wired system. This problem can be shorted out using higher performance microcontroller. For analysis of the experimental setup several tests transmitting video and different coded signals were sent and received with rate of 1Mbps. With brighter LED (e.g. RGBWhite LED) we can achieve data rate of 40-50 Mbps. The data rate can be further improved by optical filtering, transmitter equalization and receiver equalization [13]. System performance can be enhanced by implementing MIMO technique [5] and utilizing OFDM modulation [10].

VI. RESULT

Ethernet network transmit the packed and coded data to passenger adapter through wireless optical downlink. The data are coded into 42 byte ARP (Address Resolution Protocol) frame. When a video fragment of 108 length is sent from the Ethernet adapter to passenger adapter zero error is found on them. Thus it can be clinched that error probability is less than 10⁻⁷ for distance of 2 meter between the two adapters. Experimentally calculated round trip time (RTT), Jitter and throughput of the setup system are 28.1 milliseconds, 3.38 milliseconds and 1 Mbps respectively. A section of CR-DPPM encoded data that had been sent and its slightly distorted received output is shown in the figure.

![Fig. 8. Experimental result](image)

CONCLUSION

From this paper we are expecting a low cost optical wireless system for In-Flight communication devoid any danger of EM interference with aircraft instrument. Using VLC downlink and Infrared system uplink, full wireless connectivity can be established. Adapter designed for the passenger communicating device provide handy solution using the Ethernet port ruling out the need of extra driver installation. Rapid and personalized In-flight entertainment and services can be provide by the wireless media through the presented system. This technology is immune to radio interference and also does not produce any, so providing a safe and entertaining journey. Data rate can be increased using RGB LED, and further advanced modulation techniques along with higher performance microcontrollers. Since each couple lamp-photodiode acts as a dedicated access point for each seat Protocol requirements on the optical channel are reduced.

REFERENCES


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