Diffuse wireless optical link for aircraft intra-cabin passenger communication

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Abstract

A diffuse wireless link based on a cellular layout - with a central station and a number of individual transceivers per cell – is investigated as a means for the relaying of passenger security and safety related information and the provision of in-flight communication and entertainment services. Measurements within a cabin mock up on a basic setup employing LED sources and PIN photodiode detectors and relying solely on diffuse –non line of sight-transmission have demonstrated that data rates of several Mb/s are readily feasible with minimal signal degradation and well within the stipulated eye safety limits.

Keywords: Diffuse wireless optical link, optical wireless networks

1. Introduction

The work presented in this paper relates to the ATENAA project, funded by the European Union, aiming, in specific workpackages, to establish broadband wireless optical communication for commercial aviation. The work presented here addresses the realization of a diffuse optical link for the aircraft interior. The scheme anticipates the division of the cabin into individual cells. Each cell comprises a central station positioned at the ceiling of the aircraft cabin and a number of transceivers located at the passenger seats. The transmitters are LED based, conforming to safety restrictions and the receivers employ large area PIN photodiodes. The data rate achievable is of the order of 10 Mbit/s. Applications envisaged include video streaming, e-gaming, internet access, security, health monitoring, crew inter-communication and other value-added services offered at airports (such as car rental, hotel reservation, etc.).

2. Implementation schemes and advantages

By using diffuse optical techniques for the establishment of a broadband link, instead of RF, inside the aircraft cabin, phenomena of interference with existing RF avionics equipment can be entirely avoided. Furthermore, the use of a wireless optical scheme offers advantages over wired solutions from the aspects of weight minimization, increased safety, ease of installation and reconfigurability.

Among all infrared link designs, diffuse links (nondirected-non-LOS links) are the most robust and easiest to use, since neither aiming of the transmitter or receiver nor LOS path between the transmitter and the receiver is required. Although, the appearance of the 802 standard, based on a LOS configuration, has overwhelmed commercial applications, as the number of links, the request for higher data rate and link security in proprietary layers increases, the interest in diffuse IR links in non interfering co-existence with RF links has been rekindled. Diffuse links, however, suffer a higher path loss than their LOS counterparts, requiring higher transmit power and a receiver having a larger light-collection area. Typical diffuse transmitters employ several 850–980 nm LEDs, which are sometimes oriented in different directions, to provide a diversity of propagation paths. When transmitting, they typically emit an average power in the range of 100–500 mW, making their power consumption higher than a typical IrDA

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transmitter. Diffuse receivers typically employ silicon PIN detectors including different means to provide some light concentration while maintaining a wide FOV. [1, 2]

There are two different types of traffic we have considered for the link design; personal traffic and broadcast traffic. Personal traffic includes all the individual passenger applications that need to interact with the on-plane server, e.g. e-mail, health monitoring, network gaming and voice over IP. The broadcast traffic includes all the on-board broadcasting of video and music programs.

Compared to broadcast, personal traffic is bidirectional and does not demand a large bandwidth for normal applications. Since only low bandwidth demanding applications are considered (such as e-mail, health monitoring etc) with few users in each cell (a maximum of 12 passengers in economy class), a bandwidth requirement of 0.5-1.0 Mbit/s for the personal interactive traffic is recommended. For the personal interactive communication, CDMA techniques, with their relative immunity to interference, can be used with advantage in this environment.

The broadcast traffic requires a larger bandwidth to carry multiple video and music channels. A digital video broadcast channel includes a video stream, an audio stream and a dedicated stream for teletext and other information. The bandwidth for a video channel depends on the resolution of the video, as well as on the compression rate of the video and audio signals. The typical bandwidth for a digital video broadcast channel is 0.5-1.0 Mbit/s currently. A digital music broadcast channel typically includes a music stream and an optional lyrics information stream. The bandwidth for a music channel depends on the compression algorithm used and the resulting rate. The typical bandwidth for a music channel is about 32 to 64 kbit/s. Thus, for 10 video and 20 music channels with operational margins for future expansion, a 10 Mbit/s net data rate is required for broadcast purposes in each cell. UDP frames will be used for video and audio streaming. In this respect all downlink data (including personal and broadcast) will be transmitted through an Ethernet 2PPM link, while the personal data uplink will be implemented by CDMA.

Multiplexing can be used for the merging of both traffics in one transport scheme and for the management of the total available bandwidth, as shown in Figure 1a.

An alternative candidate scheme uses separate packets for broadcast and personal data with priority management. At the passenger end, a packet splitter, whose structure is much simpler (and cheaper) than that of the de-multiplexer, discriminates between broadcast and personal data. An outline is shown in Figure 1b.

Figure 1a. Network structure when both broadcast and personal traffics are transmitted in one broadcast stream

Figure 1b. Network structure when broadcast and personal traffic is transmitted in different packets

3. Power vs. Bandwidth Limitations

The safety of optical sources, equipment classification requirements and user’s guide as covered by IEC 60825 – Part 1 [3] sets the maximum permissible emission (MPE) and accessible emission limits (AEL) for eye and skin safety at close range to the source. The IEC 60825 – Part 7 document provides the requirements and specific guidance for the safe use of products, within the scope of IEC 60825 – Part 1, emitting infrared optical radiation used exclusively for wireless “free air” data transmission and surveillance. In part 7 of IEC 60825 [4], the safety philosophy and classification requirements of IEC 60825 – Part 1 have been adopted, although it has been taken into account the particularity of the LEDs which are incoherent intermediate sources with typically Lambertian radiation characteristics avoiding the overestimation of the viewing risk in comparison with the one of the coherent point sources with Gaussian radiation characteristics. The IEC 60825 – Parts 1, 7 standards tighten the eye safety classification requirements of free space radiator laser products as they require measurement of the emitted radiation over a circular
aperture of 7 mm diameter (to simulate the collection of an optical instrument of a stationary laser beam) at a distance of 100 mm from the radiating source (Condition 3 for classification according to AEL requirement, IEC 69825 – Part 1). In practice, these standards assuming unintended viewing on a time basis of 100 sec, a minimum viewing accommodation distance of 100 mm, radiation geometry characterized by the Lambertian model, limit the average optical power emitted by the source to a few hundred milliwatts per LED (Figure 1 of IEC 60825 – Part 7).

An estimate of the power requirements compatible with the anticipated bandwidth can be obtained by considering generic LED and PIN devices. The power intercepted by the receiver, \( P_R \), can be written as:

\[
P_R = \frac{P_T (n+1)A \cos^n(\theta) \cos^m(\phi)}{2 \pi d^2}
\]

where \( P_T \) is the source power and \( n \) and \( m \) correspond to a source intensity variation proportional to \( \cos^n(\theta) \) and a (lensed) photodiode response proportional to \( \cos^m(\phi) \). \( A \) is the detector area and \( d \) the source-to-detector distance.

Assuming a detector responsivity of \( \rho \), a background light power of \( P_B \) and a receiver bandwidth of \( B \), the signal to noise ratio is given by [4]

\[
SNR = \left[ \frac{\rho P_T A \cos(\theta) \cos(\phi)}{\pi d^2} \right]^2 \frac{1}{8 \rho \pi d B}
\]

and for a required \( SNR \), the distance \( d \) becomes

\[
d = \sqrt{\rho(n+1)P_T A \cos^n(\theta) \cos^m(\phi)} \frac{1}{4 \pi \sqrt{2 \rho P_B B \cdot SNR}}
\]

In Figure 1, assuming a bandwidth of 1 Mbit/s, the optical link distances that can achieve a \( SNR \) of 15.56 dB corresponding to a \( BER \) of \( 10^{-9} \) (using \( BER = Q\left(\sqrt{SNR}\right) = \frac{1}{2} \text{erfc}\left(\sqrt{\frac{SNR}{2}}\right)\right) \) are plotted against the transmitter power \( (P_T) \) for five different sizes of the receiver area \((A)\). The transmitter and receiver angles are both assumed to be 30 degrees, the photodiode responsivity is 0.5 A/W, and \( P_B \) is 100 \( \mu \)W. A Lambertian response is considered \((m=n=1)\). From Fig. 2, in order to achieve a 3 m range with a transmitter power less than 180 mW, for 30 degrees directionality, detector areas larger than 50 mm\(^2\) are required. It can be seen that using LED powers below 1 W and receiver areas below 100 mm\(^2\), a maximum link distance of about 6 m can be achieved.
Figure 2. Example of a high power LED array (top) and the measured optical power characteristics.

The limitations imposed by multipath reflections within the specific application environment are currently under investigation. Multipath reflections may cause inter-symbol interference and signal fading. In order to evaluate the relevance of this effect, the layout of the cabin (i.e. distance between light sources and walls, seat arrangement) is required. According to [6], multipath becomes a more significant problem for higher data rates (tens of Mbit/s) in the case of diffuse infrared links.

Initial experiments were performed using a 10 Mbit/s NLOS link, with diffuse reflection at the ceiling panel of an aircraft cabin mock-up. Data rates up to 8 Mbit/s have been demonstrated for a single MPEG-2 video transmission using UDP frames, as well as the simultaneous transmission of 3 videos, each at 2 Mbit/s. In Fig. 4 a transmission of a single, high-data rate video at about 8 MBit/s is shown using MPEG2 compression. One computer acted as a server, another as the passenger front end. Both computers were connected to one of the IR terminals - the server to the terminal mounted at the ceiling of a two-aisle A340 cabin mock-up, illuminating the ceiling panels and overhead racks, the passenger frontend to a seat-back mounted terminal illuminating the ceiling panels as well. The terminals were separated by about 4m longitudinal and 1 m in height. An optical blocking device was used to block direct line-of-sight between the terminals, ensuring that only diffusely scattered light is received.

The terminals where connected to the computers using standard 10baseT Ethernet connections. The ethernet protocol was used for the IR transmission as well, using Manchester re-coding and collision avoidance half-duplex connection. The data rate is recorded using the perfmon tool. The recorded data rate, as shown in figure 4, displays typical ripples, which are the same as found in reference set-up measurements using a cabled connection, thus not showing any performance reduction of the diffuse link versus a cabled one.

The experiment was performed within standard cabin illumination with fluorescent lamps, driven at 115V-400Hz, 220V - 50 Hz, and incandescent lamps.

Figure 4. Data rate recording of 8 Mbit/s transmission of a high bandwidth over the NLOS optical link output.

4. Conclusions

A bottom-up investigation and feasibility study for the realization of an intra-cabin communication scheme for passenger aircraft was carried out. Results show that such a scheme can be put into place using currently available components and communication techniques with significant advantages over alternative – wired - solutions.

5. References


[4] IEC 60825-7 publication, 1999
