AIRCRAFT CABIN PROPAGATION FOR MULTIMEDIA COMMUNICATIONS

Núria Riera Díaz, Matthias Holzbock
German Aerospace Center (DLR), Institute of Communications and Navigation
Wessling-Oberpfaffenhofen, Germany
nuria.riera@dlr.de, Telephone: +49 8153 28 28 48, Telefax: +49 8153 28 28 44

ABSTRACT

In this paper an innovative service concept based on wireless technologies for aircraft cabins is presented. The peculiarities of radio propagation and interference for UMTS, IEEE 802.11b for WLAN and Bluetooth inside a cabin are discussed.

Part of this work is supported by the EU in the framework of the IST WirelessCabin Project (IST-2001-37466).

I. INTRODUCTION

During the lasts years, In-flight Entertainment (IFE) has become one of the hot topics in the communications world. This is mainly due to the fact that aircraft seem to be one of the last remaining islands where personal communications, Internet access, and in general, up-dated information and real-time communication are not available, as pointed out in [1]. Therefore, airlines are increasingly requiring in-flight services to offer similar entertainment or business experience to passengers as their terrestrial counterparts.

To make this possible, broadband communications with high bit rate have to be provided to aircraft. Moreover, as far as global coverage is desired, access through satellite segment is the best approach. Due to the big market and the business opportunity showing up, many investigations and commercial activities are being developed in this direction. For instance, Inmarsat will introduce its service Inmarsat Swift64 to deliver fast e-mail, image transfer, ISDN access and video communications at speeds of up to 64kbit/s, over the Inmarsat Aero H Antenna mounted on the top of the aircraft [2]. Also Connexion™ by Boeing [3] and LiveTV™ have announced broadband services to aircraft; their goal is to provide high-speed data communications services (real-time internet services and television) via a Ku-band link to travellers flying in appropriately equipped aircraft, e.g. aircraft with special terminals installed in the seats.

These announced services have two common characteristics: none of them allows passengers to use their own personal equipment, and the user devices are fixed terminals installed in the cabin seats. That is, voice communication and Internet access are possible always through devices with wired installation in the cabin and of which the ownership has the airline.

Since people are becoming more and more used to their own communications equipment accommodated for their special needs, such as mobile phones and laptops with Internet connection, either through a network interface card or dial-in access through modems, travellers will soon be demanding wireless access to communication services in aircraft. This is the main objective of the WirelessCabin IST Project presented here.

This paper aims at introducing the WirelessCabin project by describing their general objectives. From the wide range of research topics related with it, the paper focuses on describing the considerations that have to be taken into account in terms of (i) propagation inside the aircraft, and (ii) different kinds of interference and electromagnetic compatibility (EMC).

The rest of the paper is organised as follows. In Section II the WirelessCabin motivation and objectives are described and the concept of collectively mobile heterogeneous network is defined, as the core idea behind the project. Section III makes a quick overview and comparison of the three wireless access standards considered, to later analyse co-channel and inter-segment interference. Section IV deals with the cabin propagation issues, the expected problems and the envisaged countermeasures. It also includes an indoor area description. Finally, interference and EMC constraints are discussed in Section V.

II. WIRELESSCABIN PROJECT

A. MOTIVATION

To meet the increasing and ever changing needs of the most demanding passengers a solution in which passengers, both business and economy, could use *their own wireless equipment* must be developed. This approach has many advantages. From the users point of view, their service acceptance will be increased by the following facts: they can be reached under their usual telephone number, they may have available telephone numbers or other data stored in their cell phones or PDAs, their laptops have the software they are used to, the documents they need and with their personalised configuration (starting web site, bookmarks, address book). In addition, since users in an aircraft are passengers, the electronic devices they carry with them is wireless, like laptops with WLAN interface. From the airlines point of view there is a huge saving of the investment that would suppose the installation of terminals (screens, stations, wired telephones), the consequent software licenses (in case of PCs) and the further investment due to hardware updating to offer always last technology to their customers. Currently, one of the major IFE costs is due to film copies and delivery expenses of new movies. This could be reduced if other broadband services were offered to passengers via satellite. Anyway, the wireless access solution is not replacing other kinds of IFE, such as TV on board or provision of Internet access with dedicated installed hardware in the cabin seats. Hence, it should not be seen as an alternative to a wired architecture in aircraft, but as an added service for passengers.

The above mentioned reasons are the motivation for the WirelessCabin project. The wireless access standards chosen are UMTS, IEEE 802.11b for WLAN and Bluetooth, as far as they are considered as the most accepted protocols by travellers in the next few years: UMTS for personal telephony and packet data, Bluetooth and WLAN for IP access. The Bluetooth interface will also be used for transport of UMTS services.

B. OBJECTIVES

The goal of developing a system architecture for wireless access technologies in aircraft cabins can be divided into four technical aspects: protocol development, propagation and interference study, topology and capacity planning and global implementation with a final demonstrator. Furthermore, a market survey will perform passenger and airline interviews and relations between the actors in the value chain will be studied (service, airlines, satellite, content and aircom providers). Accounting and billing strategies among them will be studied to derive a business model for aeronautical services.

The three protocol access methods must be integrated through a service integrator (SI), allowing the separation and transportation of the services over a single (or several) satellite bearers. New protocol concepts have to be developed to support the integrated services with asymmetrical bit rate on satellite up- and down-link and dynamic bandwidth sharing among the services depending on the traffic demand.

Resource management schemes for wireless access points (APs) have to be addressed to enable transmission over satellite links with restricted data rate or asymmetric data rate links. Also the intra- (between beams) and inter-satellite handover have to be studied. It has to be discussed the necessary aircraft and ground infrastructure for the protocol support to AAA, VPN and mobility and develop solutions for QoS support for the traffic streams in the different access segments by using an appropriate priority scheme in the service integrator (SI). The signalling protocols of UMTS with respect to the longer propagation delay over the satellite link must be analysed, and an adaptation layer protocol to combat these delay effects must be defined. There will be also an analysis for the use of Bluetooth as air interface standard to transport UMTS, instead of UTRAN.

Considering the propagation aspects, an indoor cabin channel for the UMTS, WLAN and Bluetooth frequency bands will be proposed based on the statistics derived from measurements performed in an A340 and in an A380 mock-up. The different types of interference (see Section IV) will be analysed and countermeasures will be developed. Also EMC analysis to achieve further certification will be considered. After these studies a coverage and topology planning will be done and optimal topology network configurations for different aircraft types and frequency re-use will be recommended, determining cell sizes depending on expected traffic.

Finally an SI prototype will be developed and with the use of available commercial aircraft antenna, an in-flight demo in a commercial long-haul aircraft will be performed accessing the backbone terrestrial networks through a GEO satellite link. For more details about the WirelessCabin project, refer to [4].

C. COLLECTIVELY MOBILE HETEROGENEOUS NETWORK

The concept of having several users, which are collectively on the move forming a group with different access standards into this group, is called Collectively Mobile Heterogeneous Network (CMHN). In such a scenario [5] one can find two types of mobility and two types of heterogeneity: the mobile group itself and the user mobility inside the group from one side, and heterogeneous access segments and heterogeneous user access standards from the other side. The aircraft cabin represents a CMHN (see Fig. 1) supporting three types of wireless (user mobility) access standards (heterogeneous user access) inside an aircraft (the mobile group) using one or more satellite access segments. The CMHN may cross coverage areas and then inter-/intra- satellite handover will be required. The communication infrastructure to support the cabin CMHN is depicted in Fig 2. The architecture consists of (i) several wireless access segments in the aircraft cabin which can coexist with the standard wired IP LAN, (ii) a satellite segment for interconnection of the cabin with the terrestrial telecom networks, and (iii) an aircom service provider segment supporting the integrated cabin services.

III. TECHNICAL OVERVIEW

In this section the UMTS, IEE 802.11b WLAN and Bluetooth technologies are described, and their relevant parameters are compared.

A. UMTS

The Universal Mobile Telecommunication System (UMTS) [6] is the third generation mobile communications system being developed within the IMT-2000 framework. UMTS will build on and extend the capability of today’s mobile technologies (like digital cellular and cordless) by providing increased capacity, data capability and a far greater range of services.

In January 1998, ETSI reached an agreement concerning the radio access technique to be used for UMTS. This air interface, named UTRAN (UMTS Terrestrial Radio Access) is applicable in the two existent duplexing schemes for UMTS: UMTS–FDD and UMTS–TDD. UMTS–FDD relies on wideband–CDMA (W–CDMA) access technique, while UMTS–TDD uses the TD-CDMA access technique, a combination of CDMA and TDMA technologies.

B. Bluetooth

Bluetooth [7] operates in the unlicensed 2.4–GHz ISM (industrial, scientific and medical) band and uses a frequency–hopping spread spectrum (FHSS) technique to minimise interference. A Bluetooth unit has a nominal range of approximately 10 meters (in the *Class 3* defined in the standard, but which can be enlarged by amplifying the transmit power in *Class 2* and *Class 1* up to 100 m.). Two or more Bluetooth units sharing the same channel form a piconet. Each piconet consists of a master unit and up to seven active slave units. Furthermore, two or more piconets can be interconnected to form a scatternet. To be a part of more than one piconet a unit called inter–piconet unit (gateway) is required.

C. IEEE 802.11b

Wireless local area networking (WLAN) radio technology provides superior bandwidth compared to any cellular technology. The IEEE 802.11b standard offers a maximum throughput of 11 Mbps (typical 6.5 Mbps) working in the same 2.4-GHz ISM band as Bluetooth by the use of direct sequence spread spectrum (DSSS). WLANs were originally intended to allow local area network (LAN) connections where premises wiring systems were inadequate to support conventional wired LANs, but they were later identified with mobility.

A WLAN cell is formed by an AP and an undefined number of users in a range from approximately 20 to more than 300 m. (100 m. in indoor environments) that access the AP through network adapters (NAs), which are available as a PC card that is installed in a mobile computer.

Table 1 summarises the main parameters of each standard, where only Class 3 of the Bluetooth standard has been considered, as long as the Bluetooth version 1.0 specification focuses primarily on the 10-meter ranger standard radio. Notice that the coverage range in the UMTS case is capacity dependent and it can vary from 200 m. up to 1.4 Km., a phenomena known as “cell breathing”.

IV. CABIN PROPAGATION

Indoor radio propagation is subject to multipath, increased shadowing (propagation path is rarely direct) and excess losses. General indoor channel models like the ones of the Joint Technical Committee on PCS (JTC) [8] and planning studies to cover indoor areas, are mainly done for office environment, so they may not be applied in the particular scenario of an aircraft cabin due to its special characteristics. While in an office environment one of the highest limitations besides multipath is the attenuation of walls, this problem disappears in a cabin, where there is a single cavity. Otherwise its higher obstacles density increases dramatically the path losses. The elongated structure of a cabin causes smaller losses than expected in other type of room shapes, because the cabin cavity acts in a similar was as a waveguide does; anyway the power addition of local signal paths can lead to fading of the signal in particular points and small movements of the receiver can have a substantial effect on reception. So the cell size is hard to determine.

Hence, to face the difficulties of designing a wireless network in an aircraft where up to now there is no valid channel model available, the WirelessCabin project plans to do a measurement campaign in an A340-600 and in an A380 mock-up.

A wide variety of operational scenarios have to be planned for this campaign due to the big amount of critical parameters that may vary the received power in a single location. These parameters are discussed in the following lines. To start, different user terminals for a same access segment have to be taken into account, because of the different antenna patterns of each one. Moreover, their shapes modify the near field and therefore they determine the interference exposed to nearby users (remember the small distance between passengers in an aircraft). Not only the link budget between AP and different seats has to be calculated, but also several positions within a same seat, due to the very different shadowing conditions: under the seat (simulating a device in a handbag), on the seat (device in a pocket), at ear's height of a seated passenger (user speaking on a telephone), on the backseat-table, and in the stowage bins. Of course, different AP locations have to be checked to determine the optimal one in terms of best coverage and minimum interference into avionics systems. Some foreseen possibilities are: (i) on the walls over the windows, where the best direct path can be achieved for the nearest users (good option if only coverage in a reduced number of rows is desires, like for instance in first class); (ii) under the seats (to increase the losses and reduce in this way the undesired interference); (iii) on the roof along the corridor; or (iv) on the roof over the seats. The above mentioned variables in the scenario description have to be considered for the three access methods.

As said in Section III, both Bluetooth and 802.11b, work in the 2.4 GHz band. 2.4 GHz is a good frequency for absorption by water, so one will note a difference propagation range as people move around and depending on the amount of people. Therefore, the effect of the passenger density has to be considered as well. In the worst case propagation condition the effect of a trolley (moving or not) should be examined due to its metallic structure, which may increase the multipath effects.

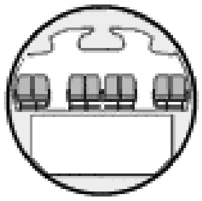

Fig. 3 A340 cross-section

All the data recorded from the narrow- and wide-band measurements will be analysed and a channel model will be derived for the frequency bands given in Table 1. It is expected that this channel model (for a fixed position of the APs) will be valid for a large number of aircraft models, not only for the ones used during the campaign, as far as all the Airbus aircraft of the families A300/A310 and A330/ A340 have the same cross-section with a maximum cabin width of 5.28 m., see Figure 3 with a business class configuration. It will be interesting to extend the results to the cross-section of the aircraft family A320 (formed by A318, A319, A320 and A321), which have the same shape but a smaller diameter with a maximum cabin width of 3.70 m. What really geometrically changes from one model to another is the length, which is about 61 m. in the case of the A340-600 cabin. If a model for a shorter range is found, results might be easily extended in a scalable way. Seat layout on each aircraft model changes from one airline to other, as well as the material of the indoor objects. Tests done up to now show that the complex interior of a cabin with its systems, metallic boxes, wiring, different cabin layouts is very likely to have more influence than varying their material. The relative permeability (ε) of materials inside cabin is in the range between 2 and 5, but all the dielectric materials can be considered having $\varepsilon = 3$.

It is important to point out that measurements of the power received outside the cabin will be also performed in order to determine the interference caused outside.

V. INTERFERENCE

Once the above described measurements finish, four types of interferences within the CMHN have to be studied: the co-channel interference among the terminals of the same wireless access segment, the inter-segment interference between terminals of different wireless networks, the cumulative interference of all simultaneous active terminals with the aircraft avionics equipment and the interference of the CMHN into terrestrial networks.

From the co-channel interference analysis the re-use distance and the re-use frequency factor for in-cabin topology planning will be derived. For this reason it is important to consider different AP locations during the measurements.

It is not expected to have major problems due to interference from UMTS towards WLAN and Bluetooth, thanks to the different working frequency. On the other hand, particular interest has to be paid in the interference between Bluetooth and WLAN. Due to the market acceptance of Bluetooth and WLAN, there is a special interest of designers and portable data devices manufacturers to improve the coexistence of the two standards. There are many studies showing the robustness and the reliability of Bluetooth in presence of WLAN and vice versa [9] [10].

A description of the electromagnetic behaviour of conventional aircraft equipment is necessary to analyse the interference and the EMC of the new wireless network with the avionics systems. The allowed radiated field levels are regulated and must be respected if certification is desired. So far, GSM telephony is prohibited in commercial aircraft due to the uncertain certification situation and the expected high interference levels of the TDMA technology. With the advent of spread spectrum systems such as UMTS and WLAN, and low power pico-cell access such as Bluetooth™, this situation is likely to change. With small business jets such as Bombadier LearJets, Gulfstream, etc., individual equipment certification is already established.

Concerning the interference level outside the cabin an important legal regulatory aspect must be considered: there must be no radiated power in the UMTS band, because it is necessary a license in each country to operate in it. Moreover, the incoming interference from the terrestrial networks has to be taken into account because multiple registrations of subscribers while on ground or near can occur. So, it is possible that the CMHN have to be switched-off while aircraft are on ground at airports, and during landing and take-off. As a countermeasure to reduce the outgoing radiation, the nominal transmitted power of the APs inside the aircraft could be changed or their location moved away from the windows. To study this effect a model of an aircraft as an array antenna in space where the windows are the array elements will be developed and simulations will determine the optimal APs locations in terms of minimum outgoing radiation.

REFERENCES

[1] Kun-De Lin, Jin-Fu Chang, “Communications and entertainment onboard a high-speed public transport System”, IEEE Wireless Communications, vol. 9, no. 1, pp. 84-89, Feb. 2002

[2] Inmarsat, www.inmarsat.com/swift64

[3] Connexion™ by Boeing, www.connexionbyboeing.com

[4] A. Jahn, M. Holzbock, N. Riera Díaz, M. Werner: “Passenger Multimedia Service Concept Via Future Satellite Systems”, to be published in Proceedings DGLR-Workshop, Stuttgart, Germany, Sept. 2002.

[5] M. Holzbock, A. Jahn: “Land-mobile Demonstration of Multimedia IP Services in Multi-Segment Access Networks”,

Proceedings 20th International Communications Satellite Systems Conference, 2002, Montreal AIAA-2002-1921, on CD-ROM.

[6] ETSI TR 125 922 V3.5.0 (2001-03) Universal Mobile Telecommunications System, http://www.3gpp.org/3G_Specs/3G_Specs.htm.

[7] Specifications of the Bluetooth System - Core vol.1 v1.1, www.bluetooth.com

[8] JTC Technical Report on RF Channel Characterization and Deployment Modeling, Air Interface Standards, September 1994.

[9] Jaap C. Haartsen, Stefan Zürbes: “Bluetooth voice and data performance in 802.11 DS WLAN environment” Bluetooth SIG White paper.

[10] Jyrik Oraskari “Bluetooth versus WLAN IEEE 802.11x” 37266J Project in the Helsinki University of Technology.

ACKNOWLEDGMENT

The background of this work is the IST project IST-2001-37466 WirelessCabin (Development and Demonstrator of Wireless Access for Multimedia Services in Aircraft Cabins), sponsored by the European Union. The effort of the projects partner is gratefully acknowledged. The consortium consists of German Aerospace Center (DLR), Airbus, Ericsson, ESYS, Inmarsat, KID-Systeme, Siemens Austria, TriaGnoSys, University of Bradford. This paper, however, does not implicitly represent the opinion of the project partners.

	Bit rates		**Bw. (MHz)**	**Band (GHz)**	**Coverage range (m.)**	**Duplexing scheme**	**Tx. P. (dBm)**	**Modu-lation**
	Max	typ						
UMTS	2 Mbps	144 Kbps	5,10,20	FDD: 1.92-1.90 (ul) 2.11-2.17 (dl) TDD: 1.90-1.92 2.01-2.025	Depends on capacity	FDD/TDD	20	QPSK (dl) BPSK (ul
Bluetooth	1 Mbps	728 Kbps	1	2.4-2.4835	10	TDD	0	GFSK
IEEE 802.11b	11 Mbps	6,5 Mbps	26	2.4-2.4835	20-100	TDD	20	Depends on bit rate

Table. 1: General Parameters Comparison

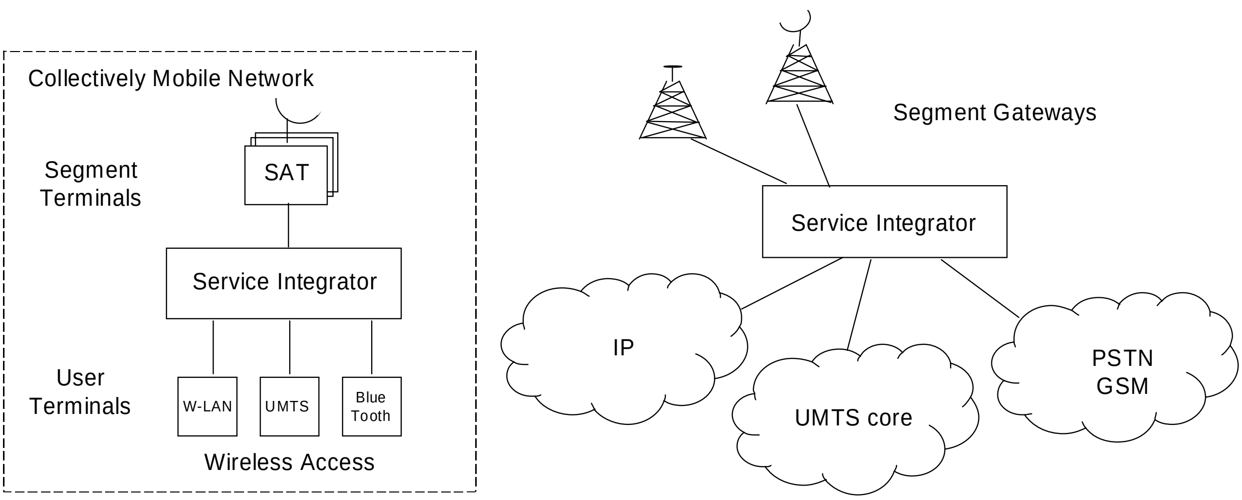

Fig. 1 CMHN System Architecture

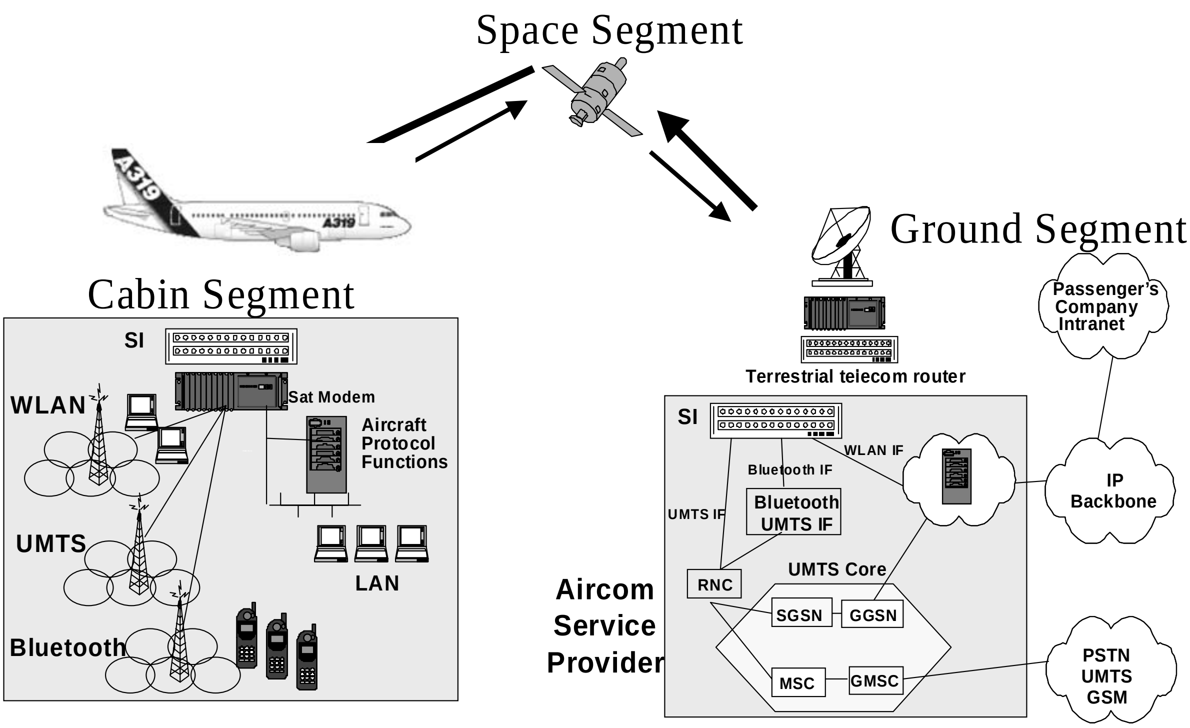

Fig. 2: Cabin CMHN Network Architecture